Coal Dust Exposures in the Longwall Mines of New South Wales: a Respitory Health Risk Assessment Using Joint Coal Board Exposure Data from 1985-1999

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Abstract

This paper presents an analysis of personal respirable coal dust measurements recorded by the Joint Coal Board in the underground longwall mines of New South Wales from 1985 to 1999. 11,829 measurements from 33 mines were analysed and the results given for each occupation, for seven occupational groups, for individual de-identified mines and for each year of study. The mean respirable coal dust concentration for all jobs was 1.51mg/m^3 (SD 1.08mg/m^3). Only 6.9% of the measurements exceeded the Australian exposure standard of 3mg/m^3. Published exposure-response relationships were used to predict the prevalence of progressive massive fibrosis and the mean loss of FEV_1, after a working lifetime (40 years) of exposure to the mean observed concentration of 1.5mg/m^3. Prevalences of 1.3 and 2.9% were predicted, based on data from the United Kingdom and the United States respectively. The mean loss of FEV_1 was estimated to be 73.7ml.

Introduction

Longwall mining was first introduced to New South Wales in 1962 [1]. Currently, there are 34 longwall mines in Australia and 23 of them are in New South Wales [2]. Figure 1 illustrates the amount of coal produced by longwall, bord and pillar and open-cut methods in New South Wales for the period 1970/1971-1999/2000. Longwall production has increased substantially from 2.2Mt (4% of total coal production) in 1980-81, to 24.5Mt (25% of total production) in 1990-91, to 43.5Mt (33% of total production) in 1999-2000.

In 1996/1997, New South Wales longwall production accounted for approximately 4.8% of world coal extracted by longwalls [3,4].

The major coal deposits of New South Wales range from bituminous coking and thermal coals to sub-bituminous thermal coals [4]. The coal is classified as medium to high rank.

The Joint Coal Board in New South Wales has undertaken personal gravimetric samples of respirable coal dust in coal mines since 1984 [5]. Before 1984 the particle counting method was used [5]. Samples are collected by Joint Coal Board Officers at least every 6 months at longwall faces, during a production shift. Samples are taken from the breathing zone of at least five operators including at least one shearer operator, two roof support operators, a deputy, and one other person selected by the mine manager [5]. SIMPEDS cyclones are used, which sample the respirable fraction of dust according to the UK Medical Research Council curve. The samples are analysed at the Joint Coal Board laboratory [5].

The Joint Coal Board also undertakes chest x-rays, on average every 3 years for current underground miners, and every 5 years for current surface miners [6]. The entire workforce is sampled. The prevalence of coal worker's pneumoconiosis in miners has declined substantially in recent decades, from 16.0% in 1948 to consistently less than 0.5% during the period 1990 - 2000 [6-9]. All of the current cases are below International Labour Office (ILO) profusion category 2 [7].

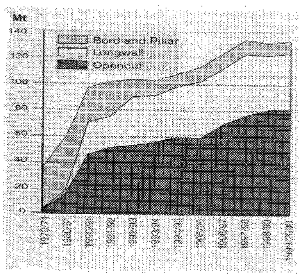

Figure 1: New South Wales coal production from 1970 to 2000 (Courtesy of the New South Wales Department of Minerals Resources).

In this paper we present an analysis of the Joint Coal Board's longwall exposure data, for the years 1985 to 1999. The aims of the analysis are:

1. To determine recent compliance with the national exposure standard
2. To estimate the future prevalence of coal worker's pneumoconiosis and progressive massive fibrosis and the mean loss of FEV_1 due to chronic obstructive pulmonary disease, in lifetime miners (40 years exposure), using published exposure-response relationships.

Method

We analysed the Joint Coal Board database of personal respirable coal dust concentrations, for the period 1985-1999. There were several identifiers in the database, including mine code, date and job. We constructed seven occupational groups from 28 of the 41 jobs listed in Table 1, that we thought were likely to stratify the longwall operation by exposure. The occupational groups and their constituent job identifiers are presented in Table 2. A brief description of each constituent job is also given in Table 2.

Attfield and Seixas have published predictions of the prevalence of coal workers pneumoconiosis and progressive massive fibrosis after 40 years of exposure to various concentrations of respirable coal dust [10]. Their predictions were based on data from the National Study of Coal Worker's Pneumoconiosis in the United States and data from the National Coal Board's Pneumoconiosis Field Research in the United Kingdom. Their predictions based on the data from the United Kingdom drew on previous works by Hurley and Maclaren, and Attfield [11,12]. A graph of the exposure-response relationships they derived from the United Kingdom and United States data for high rank coal is shown in Figure 2. We linearly interpolated the United Kingdom prevalences at a concentration of 1.5mg/m^3 from the prevalences given for concentrations of 1.0mg/m^3 and 2.0mg/m^3. We used this graph to make predictions of the prevalence of pneumoconiosis and progressive massive fibrosis after 40 years of exposure to coal dust in the longwalls of New South Wales, using the average measured respirable coal dust concentration.

Soutar and Hurley have estimated the average loss of FEV_1, attributable to cumulative coal dust exposure, to be 0.76ml per ghm^{-3} [13]. In a review of coal mining and chronic obstructive pulmonary disease, Coggon and Newman Taylor concluded that this figure was a reasonable best estimate [14]. If one working year is assumed to be 1600 hours, then 0.76ml per ghm^{-3} is equivalent to 1.22ml per mg/m^3-yr. We used this figure to predict the average loss of FEV_1 after 40 years of exposure to coal dust in the longwalls of New South Wales, using the average measured respirable coal dust concentration.

Table 1. Respirable coal dust exposures for each of the 41 occupations.

JOB	n (total)	n (valid)	%	Mean	s.d.
Apprentice Fitter	3	3	0.03	0.73	0.40
Boot End Man	72	72	0.61	0.72	0.41
Check Inspector	1	1	0.01	0.30	-
Chock Transporter	13	13	0.11	0.74	0.24
Chockman	3158	3143	26.57	1.61	1.10
Chockman M/G	501	500	4.23	1.38	1.06
Chockman+M/G Man	71	70	0.59	1.65	1.15
Chockman T/G	18	17	0.14	2.48	1.94
Crusher Attendant	1	1	0.01	1.72	-
Deputy	2202	2189	18.51	1.29	0.86
Driller	2	2	0.02	0.90	0.14
Eimco Driver	1	1	0.01	1.03	-
Electrician	205	201	1.70	1.16	0.81
Electrician+Chockman	3	3	0.03	0.91	0.41
Face Operator	17	17	0.14	0.75	0.68
Fitter	777	769	6.50	1.16	0.86
Fitter+Chockman	24	24	0.20	1.12	0.74
General U/G	5	5	0.04	0.68	0.15
Machine Man	1	1	0.01	0.60	-
M/G Boot	7	7	0.06	1.24	0.86
M/G Dropover	24	24	0.20	0.51	0.26
Maingate Man	353	352	2.98	1.57	1.45
M/G Man+Shearer Op	48	47	0.40	1.01	0.73
M/G Operator	97	95	0.80	0.61	0.39
Materials Driver	1	1	0.01	0.30	-
Mule Driver	7	7	0.06	0.74	0.17
Outbye Man	3	3	0.03	0.38	0.03
Pantechnicon	173	173	1.46	1.06	0.91
Push Operator	22	22	0.19	2.88	1.77
Shearer Operator	2141	2131	18.02	1.81	1.23
Shearer Op 1st	165	165	1.39	1.73	1.04
Shearer Op 2nd	151	150	1.27	1.45	0.94
Shearer Op M/G	673	673	5.69	1.49	1.01
Shearer Op T/G	657	655	5.54	1.73	1.14
Shearer Op MG+TG	25	25	0.21	1.54	0.78
Shearer Op + Chockman	91	91	0.77	1.64	0.91
Shiftman	1	1	0.01	1.90	-
Support Op	171	171	1.45	1.38	0.88
Timberman	1	1	0.01	1.50	-
Undermanager	1	1	0.01	1.40	-
Wagner Fork Lift	2	2	0.02	0.86	0.79
Sum	**11889**	**11829**	**100**		

M/G: Maingate, T/G: Tailgate, U/G: Underground, Op: Operator.

Table 2. The seven occupational groups constructed from the database and their constituent occupations.

Job Category	'Job Identifier' in JCB Database	Job Description
Deputy	Deputy	Manages and supervises a coal producing longwall face operation and all employees working therein. Monitors the condition of mechanical belt splices, and looks for rips in the belt.
Shearer Operator	Shearer Operator	Operates M/G and T/G shearer drums.
	Shearer Operator M/G Shearer Op 1st	Operates shearer from M/G to mid-face and from mid-face to T/G.
	Shearer Operator T/G Shearer Op 2nd	Operates the shearer from T/G to mid-face and from mid-face to the T/G.
	Shearer Op MG+TG	M/G and T/G shearer operators switch jobs during the shift.
Chockman	Chockman Support Operator	Advances chocks from M/G to T/G and from T/G to M/G.
	Chockman M/G	Advances chocks from M/G to mid-face and from mid-face to M/G.
	Chockman T/G	Advances chocks from T/G to mid-face and from mid-face to T/G.
Maingate Man	M/G Operator Main Gate Man	Monitors the control panel if the panel is at M/G. Examines M/G area for hazardous conditions. Watches for blockages at the transfer point and if necessary stops the AFC to clear coal build up. Operates the first few M/G chocks. Ensures the whole operation runs smoothly.
Face Operator	Face Operator	Advances the chocks from M/G to T/G and from T/G to M/G. Also operates the shearer from M/G to T/G and from T/G to M/G.
	Chockman + M/G Man	Workers switch jobs during a shift.
	Shearer Op + Chockman	Workers switch jobs during a shift.
	M/G Man + Shearer Op	Workers switch jobs during a shift.
	Push Operator	Pushes the AFC forward as the longwall is retreated.
Boot End Men	Boot End Man M/G Boot M/G Dropover Crusher Attendant Pantechnicon	Monitors coal transfer through crusher, BSL and boot end onto conveyor belt. A pantechnicon operator is in charge of a pantechnicon. The pantechnicon is a train of sleds carrying auxiliary equipment, and monitoring and communication equipment.
Tradesmen	Fitter Apprentice Fitter	Performs general maintenance of the mechanical equipment and other related tasks.
	Fitter + Chockman	Workers switch jobs during a shift.
	Electrician	Sets all the transformers for the longwall face and performs general maintenance of the electrical equipment and other related tasks.
	Electrician + Chockman	Workers switch jobs during a shift.

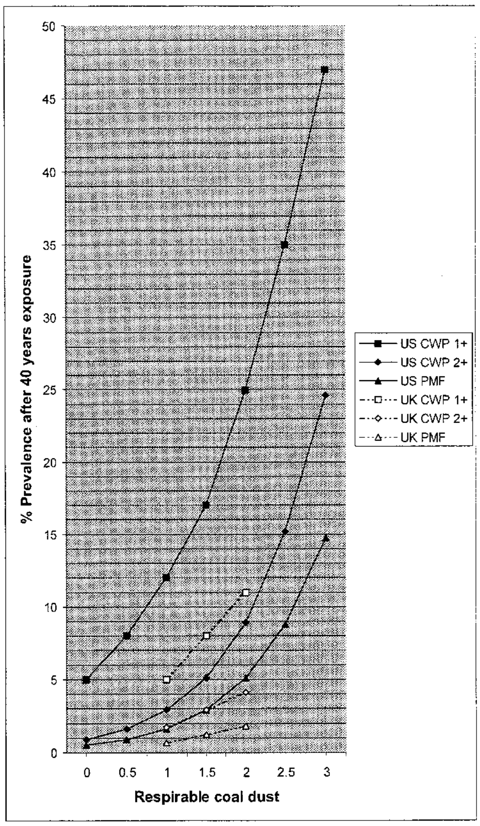

Figure 2. Exposure-response relationships for high rank coal. From the data of Attfield and Seixas [10]. Respirable coal dust (mg/m^3).

Statistical Analysis

The number, mean, and standard deviation of respirable coal dust exposures were calculated for each occupation. The number, mean, 95% confidence interval for the mean, standard deviation, minimum and maximum values were determined for the respirable coal dust exposures of each of the occupational groups. A box and whisker plot of coal dust exposure for each of the seven occupational groups was made. The significance of differences in mean coal dust concentrations between the seven occupational groups was determined using the Kruskal Wallis test. Six comparisons between occupational groups were then made, two groups at a time, using the Mann-Whitney U test. To prevent error inflation due to multiple comparisons, a downward adjustment of the alpha level from 0.05 to 0.008 was made. A box and whisker plot of coal dust exposure for each of the mines was made. Another box and whisker plot of coal dust exposure for each year of the study period was made. The box and whisker plots do not contain outlier or extreme values because of the large coal dust exposure scale that would be needed. SPSS 10.1 for Windows was used for all statistical analyses following importation of the data from Microsoft Excel spreadsheets.

Results

In total 11,829 valid measurements from 33 mines were analysed. The seven occupational groups we derived from 28 of the 41 jobs, comprise 11,790 (99.7%) of the measurements.

The respirable coal dust exposures (number, mean, standard deviation) for each of the 41 occupations are listed in Table 1. The respirable coal dust exposures (number, mean, 95% confidence interval for the mean, standard deviation, minimum, maximum) for each occupational group are listed in Table 3 and the corresponding box and whisker plots are presented in Figure 3. Table 3 also lists the percentage of measurements for each occupational group that exceed 1.0, 1.5, 2.0 and 3.0mg/m^3.

Table 3. Respirable coal dust exposures (mg/m^3) for each occupational group

Occupational Group	N	Mean	95% CI for the Mean	S.D.	Min	Max	% > 1.0	% > 1.5	% > 2.0	% > 3.0
Shearer Operator	3799	1.72	1.68 to 1.76	1.16	0.10	17.00	72.4	46.1	27.8	9.1
Chockman	3831	1.58	1.54 to 1.61	1.09	0.10	13.08	67.0	39.8	22.6	7.6
Face Operator	247	1.57	1.43 to 1.72	1.16	0.20	8.68	58.7	37.2	27.5	10.1
Maingate Man	447	1.36	1.24 to 1.49	1.35	0.07	15.28	48.8	28.0	16.8	8.3
Deputy	2189	1.29	1.25 to 1.32	0.86	0.10	6.97	54.0	27.7	13.6	3.5
Tradesmen	1000	1.15	1.10 to 1.21	0.84	0.10	8.40	45.4	20.8	10.3	3.8
Boot End Men	277	0.93	0.84 to 1.03	0.79	0.10	8.18	32.1	14.4	6.5	1.1
All 41 Jobs	11829	1.51	1.49 to 1.53	1.08	0.07	17.00	62.7	36.8	21.0	6.9

Kruskal Wallis

The Seven Occupational Groups	P < 0.001 sig

Mann Whitney U Results

Shearer Operator - Chockman	P < 0.001 sig
Chockman - Face Operator	P = 0.185 n.s.
Face Operator - Maingate Man	P < 0.001 sig
Maingate Man - Deputy	P = 0.020 n.s.
Deputy - Tradesmen	P < 0.001 sig
Tradesmen - Boot End Men	P < 0.001 sig

There was insufficient data to characterise exposures during longwall installation and recovery.

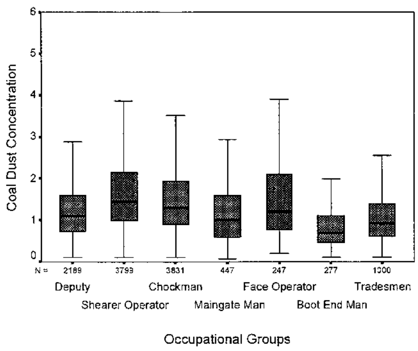

Figure 3. Box and whisker plot of respirable coal dust concentration (mg/m^3) for each occupational group.

Table 4 lists the total number of measurements taken at each mine and the number and percentage of measurements for each mine that exceed 3mg/m^3. Figure 4 presents a box and whisker plot of respirable coal dust exposure for each of the 33 mines. The box and whisker plot represents the exposures for all occupations over the period 1985 to 1999. During this period some of the mines opened, some closed and some changed ownership.

Table 4. The total number of coal dust measurements for each mine and the number and percentage of measurements that exceed 3 mg/m^3

Measurements (Mine Number)	1	2	3	4	5	6	7	8	9	10	11
N	242	363	728	678	36	693	156	974	267	125	83
N > 3 mg/m^3	5	19	64	7	1	13	45	59	3	1	11
% > 3 mg/m^3	2.1	5.2	8.8	1.0	2.8	1.9	28.8	6.1	1.1	0.8	13.3

Measurements (Mine Number)	12	13	14	15	16	17	18	19	20	21	22
N	30	283	10	138	283	366	87	363	485	40	990
N > 3 mg/m^3	0	8	0	15	10	4	2	21	77	0	109
% > 3 mg/m^3	0.0	2.8	0.0	10.9	3.5	1.1	2.3	5.8	15.9	0.0	11.0

Measurements (Mine Number)	23	24	25	26	27	28	29	30	31	32	33
N	687	689	804	154	157	128	288	338	212	205	747
N > 3 mg/m^3	86	11	62	35	19	53	32	20	3	4	19
% > 3 mg/m^3	12.5	1.6	7.7	22.7	12.1	41.4	11.1	5.9	1.4	2.0	2.5

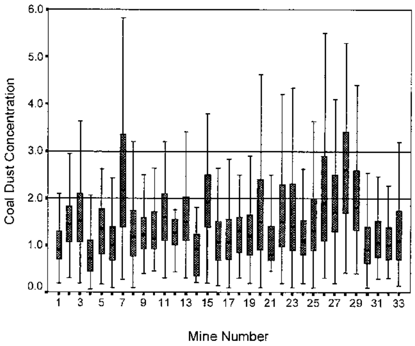

Figure 4. Box and whisker plot of respirable coal dust concentration (mg/m^3) for each of the 33 mines.

Figure 5 presents a box and whisker plot of respirable coal dust exposure for each year from 1985 to 1999. The box and whisker plot represents the exposures for all mines and all occupations.

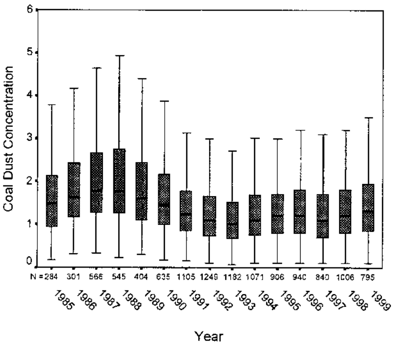

Figure 5. Box and whisker plot of respirable coal dust concentration (mg/m^3) for each year from 1985 to 1999.

The mean respirable coal dust concentration for all longwall jobs was 1.51mg/m^3. Predictions of the prevalence of coal worker's pneumoconiosis and progressive massive fibrosis after 40 years of exposure to 1.5mg/m^3 are given in Table 5. These are based on the predictions derived from the United Kingdom and United States databases by Attfield and Seixas, as described in the methods section.

Table 5. The predicted % prevalence of coal workers pneumoconiosis, after 40 years exposure to 1.5mg/m^3 respirable coal dust. Based on UK and US predictions by Attfield and Seixas.

Category	Predicted % Prevalence (UK)	Predicted % Prevalence (US)
CWP 1+	8	17
CWP 2+	2.9	5.1
PMF	1.3	2.9

The predicted average loss of FEV$_1$ after 40 years of exposure to 1.5mg/m^3 is:

1.22ml per mg/m^3-yr x 1.51mg/m^3 x 40 yr = 73.7ml.

The derivation of this prediction was described in the methods section.

Discussion

Most of the 33-longwall mines comply well with the current Australian exposure standard of 3mg/m^3 [15]. However 16 mines (48.5%) have greater than 5% of measurements in excess of the 3mg/m^3 exposure standard. It is worth noting that 4 mines (12.1%) have had less than 50 measurements taken in total and are therefore probably inadequately characterised.

Inspection of the box and whisker plots of Figure 4 shows that to successfully comply with the 3mg/m^3 exposure standard, longwall mines need to operate at a median exposure of less than 1.5mg/m^3.

Given that most mines comply well with the exposure standard, it seems likely that improved application of existing dust suppression and ventilation technology at the mines with the highest concentrations would enable compliance. A standardised survey of the mines may be of benefit, to determine:

- Which of the known technologies are applied well in the mines with low dust concentrations
- What are the barriers to the use of these successful methods in mines that have high dust concentrations
- What known technologies are not used, that could further reduce exposure, and what are the barriers to their introduction

The box and whisker plots of Figure 5 shows that the industry has been able to prevent substantial increases in exposure during the period 1985-1999 while production has approximately doubled.

There are significant differences in exposure between the occupational groups. As expected, the shearer operators have the highest mean exposure (1.72mg/m^3). They work closest to the shearer where there is exposure to dust as coal is cut from the face and as it falls onto the AFC. They are also exposed to dust from chock movement, spalling of coal, and collapse of the roof in the mined area (formation of goaf) behind the chocks. Chockmen have the next highest mean exposure (1.58mg/m^3). They are exposed to the same sources as the shearer operators, but are usually at a greater distance from the shearer. The face operators consist mostly of people rotating between the jobs of shearer operator and chockman. Their mean exposure (1.57mg/m^3) is similar to that of the chockmen. The maingate men have a significantly lower mean exposure (1.36mg/m^3). This is probably because they are at a greater distance from the above mentioned sources of dust except for when the shearer is at the maingate. They are also usually at the upstream end of the face, in relatively fresh air, when U type ventilation is in use. Maingate men are also exposed to spalling of coal, which may occur even when the shearer has moved away from the maingate. The deputies have a similar mean exposure (1.29mg/m^3) to the maingate men. They supervise the longwall operation and are on the face for only a portion of their shift. Tradesmen have a significantly lower mean exposure (1.15mg/m^3). This is

probably because they are also on the face for only a portion of their shift and because the shearer may not be operating. The boot end men have the lowest mean exposure (0.93mg/m^3). This is probably because they usually work upstream of the face, in relatively fresh air, when U type ventilation is in use.

Of the seven occupational groups, the shearer operators, the chockmen, the face operators and the maingate men all have greater than 5% of measurements in excess of the 3mg/m^3 exposure standard. It seems clear that if improvements are to be made, they should be targeted at reducing exposure along the face and at the maingate.

The predictions based on the exposure-response relationships published by Attfield and Seixas indicate that if recent exposures are maintained, there remains a risk of pneumoconiosis and progressive massive fibrosis for those people spending a working lifetime as longwall coal miners. The risk of the most serious form of pneumoconiosis, progressive massive fibrosis, is for lifetime miners: 1.3% and 2.9%, based on data from the United Kingdom and the United States respectively. Miller and Jacobsen reported survival rates for coal miners with and without pneumoconiosis over a 22-year period [17]. From their summary data it is possible to calculate the attributable risk of death of progressive massive fibrosis. For the pre-retirement age group of 55-64 years, the attributable risks over a 22-year period were about 7.1% for category A, 10.3% for category B, and 23.1% for category C progressive massive fibrosis. For younger age groups the attributable risks are higher because of the lower mortality rates from other causes. If one assumes from the predictions that approximately 2% of lifetime longwall miners will develop progressive massive fibrosis at retirement, then one might further predict from the attributable risks listed above that about 10% of this group will die from their disease. In other words approximately 0.2% or 1 in 500 lifetime longwall miners may die of progressive massive fibrosis in their retirement. Given that most miners will probably work for substantially less than 40 years the overall risk will be much less than this. By way of comparison the recent fatal injury rate for the Australian mining industry is such that approximately 2 in 500 to 6 in 500 workers may die from occupational trauma in a 40-year career [18].

The predicted average loss of FEV$_1$ of 73.7ml over 40 years of exposure to the mean observed concentration of 1.5mg/m^3 seems tolerable. This equates to only 6% of the average FEV$_1$ of a short elderly Caucasian male (1180ml for an 80-year-old of 145cm height) [19]. Even allowing for individual variation and the effects of smoking, it seems unlikely that the loss attributable to coal dust exposure at 1.5mg/m^3 would be of clinical significance.

It is important to note that the current practice of wearing particulate respirators at the coalface will probably reduce the risk of respiratory diseases to below the estimates we have derived.

Predictions of the prevalence of coal worker's pneumoconiosis after 40 years exposure to the mean observed concentration of 1.5mg/m^3 (Table 5), greatly exceed the observed prevalence of less than 0.5% ILO 1+, for all coal miners in New South Wales. In addition the observed prevalence is substantially less than that found in the fourth round of the United States National Study of Coal Worker's Pneumoconiosis (3.9% ILO 1+), undertaken 13-16 years after the introduction of the 2mg/m^3 standard [16]. There are several possible explanations for these differences:

- The mean duration of work as a coal miner in New South Wales is likely to be substantially less than 40 years, and may be less than that which prevailed in the United States during the National Study of Coal Worker's Pneumoconiosis survey.
- The sampling period in New South Wales is cribroom to cribroom whereas in the United States it is portal to portal. Measurements under the same dust conditions in the United States are therefore systematically lower.
- There may be a survivor bias, whereby miners with more severe pneumoconiosis have left the industry and are not therefore included in chest x-ray surveillance.
- Bord and pillar mining and surface mining may give rise to lower exposures, thereby diluting the risk.
- Exposure may have increased substantially within a period less than the latent period for coal worker's pneumoconiosis. However inspection of Figure 5 suggests this is unlikely, as there has been no substantial increase in exposure over the period 1985-1999.
- Secondary prevention may be more consistently applied and at a lower category of pneumoconiosis. However the predictions by Attfield and Seixas based on the United States data assumed removal of workers of category ILO 1+ to exposures less than 1 mg/m^3. It is unlikely that secondary prevention in New South Wales is more conservative than this.
- The rank of coal may be lower than that of the high rank predictions of Attfield and Seixas. Higher rates of pneumoconiosis are associated with exposure to higher ranks of coal [20-23].
- The crystalline silica content of coal in New South Wales may be lower.
- The exposure-response relationship in New South Wales may be different to that in the United States and the United Kingdom. Before being able to comment further on this, a comprehensive study of the respiratory health of miners and ex-miners would be required.
- Coal miners in New South Wales may have used respiratory protection more frequently during the study period 1985-1999, than did miners in the United States and the United Kingdom during the earlier study periods, which resulted in the exposure-response predictions published by Attfield and Seixas.

Our analysis has some limitations. We have not included estimates of variability in the predictions of prevalence and loss of FEV$_1$ after 40 years exposure. This is partly an intentional simplicity, but also there is limited variability data in the published exposure-response relationships. We have not attempted to estimate the future incidence of coal worker's pneumoconiosis in New South Wales. This would require data on numbers of workers, their age and work duration. Instead we have used existing exposure-response relationships to predict the prevalence of coal worker's pneumoconiosis in lifetime miners (40 years exposure) as a means of risk assessment. Finally, two components of the longwall process have not been studied:

1. Longwall changeout (installation and recovery) could not be characterised because of a lack of data. We suggest more data should be collected during this part of the process in future, especially given that ventilation is likely to be poor.
2. Longwall development was not clearly distinguished from bord and pillar development in the database because these processes are regarded as being essentially the same [9]. We hope to analyse development data in the near future.

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