Coal workers' pneumoconiosis
prevalence disparity between Australia and the United States

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Abstract Although rates of pneumoconiosis in coal miners have declined substantially in the United States since the passage of the Federal Coal Mine Health and Safety Act of 1969, new cases continue to occur, including cases of rapidly progressive disease. In contrast, Australia's underground coal mining industry has reported few new cases of pneumoconiosis for more than 20 years. Mortality from coal workers' pneumoconiosis in official health statistics and the prevalence of pneumoconiosis among miners screened in X-ray surveillance programs are also lower in Australia. The U.S. National Institute for Occupational Safety and Health (NIOSH) was requested by both industry and labor stakeholders to examine this issue, with the ultimate aim of reducing the rate of pneumoconiosis among U.S. coal miners. A number of factors, including coal dust exposure, silica exposure and coal rank were examined as potential contributors to the above noted differences. Comparison of coal rank data from each country did not illuminate the issue. Air sample data from the coal mining industries in both countries show that coal dust levels in Australian mines are somewhat higher than those reported in similar U.S. mines; however, quartz exposure for Australian miners is lower than for many U.S. miners. If quartz is contributing to the greater number of cases of pneumoconiosis in the United States, more effective dust control measures, as well as an independent exposure standard for respirable quartz in coal mining, should be implemented to reduce this potentially disabling condition.

Introduction

Australia has an active underground coal mining industry in two states — New South Wales and Queensland — but has maintained a low rate of pneumoconiosis for more than 20 years. By comparison to the United States, mortality from coal workers' pneumoconiosis (CWP) in official health statistics and the prevalence of pneumoconiosis among miners screened in X-ray surveillance programs are also lower in Australia. Clouding the difference in disease rates between the two countries is the fact that the occupational exposure standard for the respirable fraction of coal mine dust (RCMD) in the above two Australian states is higher than the regulatory exposure standard in the United States.

The U.S. National Institute for Occupational Safety and Health (NIOSH) was requested by stakeholders from both U.S. industry and labor to investigate the disparity in pneumoconiosis rates between Australia and the United States.

Pneumoconiosis is a disease of the lung parenchyma caused by deposition of dust particles and the reaction of lung tissue to the dust. The inhaled dust particles responsible for the disease must be small enough to pass through the upper airways and into the lung, with these particles generally smaller than 10 μm (10^{-5} m) aerodynamic equivalent diameter. Dust of this size is considered to be within the respirable dust fraction.

Coal miners are susceptible to two types of pneumoconiosis, CWP and silicosis. The two conditions are difficult to distinguish on chest X-rays (Laney et al., 2009), but they show different tissue patterns on pathologic diagnosis and may have different clinical presentations as well. The likelihood of CWP development is directly related to the magnitude and duration of exposure to coal mine dust, as well as to the quartz content of the respirable dust and to the rank of the coal. Coal rank represents a measure of the geologic maturity of the

Figure 1

Mortality from coal workers pneumoconiosis, United States and Australia, by year.

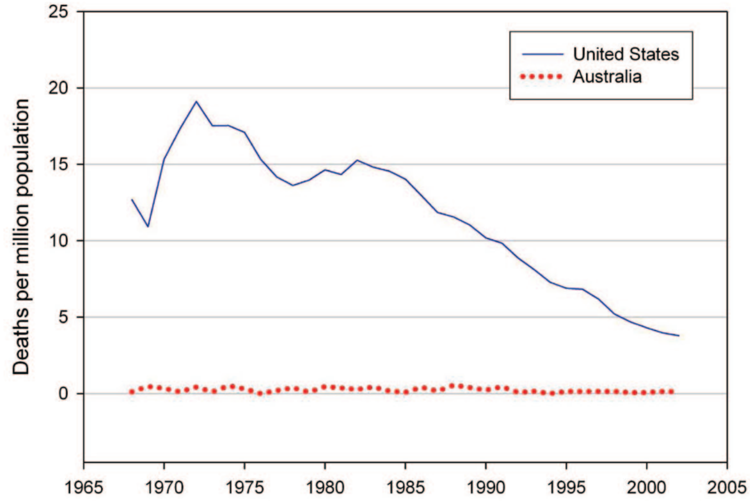
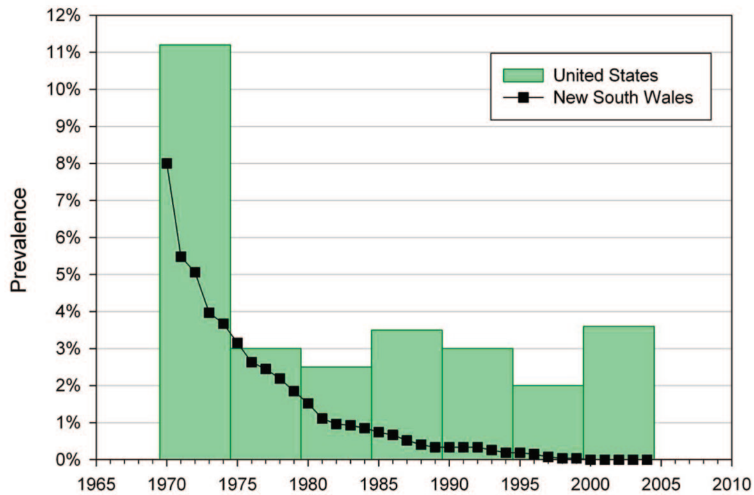


Figure 2

Prevalence of pneumoconiosis, ILO category 1/0 or greater among U.S underground coal miners and New South Wales coal industry employees, by year.



coal, with coals of differing ranks having differing physical and chemical characteristics. CWP may progress in severity from nonsymptomatic simple CWP to complicated CWP, which is also called progressive massive fibrosis (PMF), a debilitating condition. The presence of simple CWP increases the risk of developing PMF (NIOSH, 1995). Coal miners are also susceptible to silicosis, due to inhalation of respirable quartz from cutting or drilling rock, and silicosis may also progress to PMF. In miners found to have simple CWP, removal from or substantial reduction to exposure can prevent progression to PMF. Silicosis, however, may progress to PMF even after cessation of exposure.

This investigation is subject to limitations, including little comparable exposure and surveillance data. These limitations are due in part to differing regulatory and surveillance schemes under which the data is generated and collected. As a result, this investigation adopted the ecological approach, and is presented as a hypothesis-generating work, rather than as a definitive resolution of the question.

Background

At the beginning of the 20th century, pneumoconiosis prevalence and mortality among coal miners were very high in the United States and Australia. Following implementation of legislative standards for coal dust exposure in the United States, prevalence dropped substantially. Nevertheless, new cases have continued to occur in the United States over the last 20 years, while reported CWP mortality rates in Australia are close to zero, supported by disease surveillance data from New South Wales. Further compounding the problem, the U.S. cases have sometimes resulted in rapid progression and death from PMF in young miners with apparently low levels of coal dust exposure (CDC, 2006; CDC, 2007). CWP mortality rates for the United States and Australia are shown in Fig. 1.[1]

The prevalence of pneumoconiosis among coal miners in the United States and New South Wales from 1970 through 2006 is presented in Fig. 2.[2] As shown, U.S. CWP prevalence among underground coal miners was 3.6% during 2000-2004 (NIOSH, 2008). For New South Wales, the rates shown in Fig. 2 represent both surface and underground miners (Coal Services, 2008).

Pneumoconiosis rates have been near zero for the past decade, which represents a substantial reduction from earlier years (Glick et al., 1972; Griffits, 1990). The prevalence of pneumoconiosis reported in New South Wales has been lower than that reported among underground miners in the United States since the early 1980s.

To give further context to the data in Fig. 2, in the United States, underground coal miners have been screened since 1970 in an X-ray surveillance program mandated under the Federal Coal Mine Health and Safety Act of 1969. In this program, called the Coal Workers' X-ray Surveillance Pro-

[1] Rates of CWP mortality for the U.S. population over age 15 for the years 1968-1999 were obtained from the 2002 edition of the *Work-Related Lung Disease Surveillance Report* (NIOSH, 2003). Rates of CWP mortality for the Australian population over age 15 for the same years were calculated from data in the *General Record of Incidence of Mortality* database (AIHW, 2005). Rates for both the United States and Australia include the International Classification of Disease (ICD) code appropriate to the year of death: ICD-8 code 515.1 (Anthracosilicosis) for the years 1968-1978, ICD-9 code 500 (Coal Workers' Pneumoconiosis) for the years 1979-1998, and ICD-10 code J-60 (Coal Workers' Pneumoconiosis) for deaths 1999 forward (ILO, 2002). The rates presented have not been adjusted for age or gender.

[2] The authors were unable to obtain prevalence data from the Queensland surveillance program.

Table 1

Mean dust concentrations with standard deviation, adjusted to the MSHA sampling convention for all jurisdictions. U.S. occupation description is stated first, followed by the corresponding Australian job title. Missing data are unavailable.

Occupation	United States 1995-2000		New South Wales 1985-1999		Queensland 1999-2001		Queensland 1995-2000	
	N	mg/m³ (sd)	N	mg/m³ (sd)	N	mg/m³ (sd)	N	mg/m³ (sd)
Jack setter-longwall/ chock operator	3,305	1.28 (0.80)	3,831	1.94§ (1.25)	-	2.86	205	2.52§ (2.21)
Longwall operator/ shearer operator	6,560	1.40 (0.83)	3,799	2.12§ (1.33)	-	2.63	187	2.37§ (1.20)
Headgate operator/ maingate operator	1,584	0.80 (0.67)	447	1.67§ (1.55)	-	1.83	54	1.94§ (1.96)
Return-side face worker/ face operator	8,156	1.55 (0.97)	247	2.05§ (1.33)	-	2.44	-	-

Significantly different values are indicated in Table 1 by the superscript §.

gram (CWXSP). The cost of X-rays is borne by employers, but the overall program is managed by NIOSH, which sets standards for obtaining the films and for their interpretation.[3] By contrast, in New South Wales, all medical surveillance is performed by Coal Services Pty Limited, an organization composed of labor and industry representatives. Data on pneumoconiosis prevalence are published in annual reports; however, no published information is available on the methods used to conduct the screening, nor on how the prevalence rates are generated.

To further expand on the above differences, participation in pneumoconiosis screening programs in both the United States and New South Wales is voluntary. Initial participation in the CWXSP was estimated at 90%, but it has dropped over time. In fact, during the period from 2000 to 2004, the participation rate was estimated at 48% (NIOSH, 2008). No published data are available on current participation rates among New South Wales miners; however, participation has been estimated at about 40% of all eligible industry employees (Delaney, 2008).

Approach to this study

In this study, two factors were postulated that might contribute to different disease rates in Australia and the United States: (1) dust exposure limits and dust-control-related issues and (2) physicochemical properties of coals (coal rank). These factors were compared as far as practicable between the two nations to identify any significant differences. The methods applied were a review of the relevant literature, published data on coal dust exposure and coal rank data; consultations with members of industry, labor and academia; and visits to operating underground coal mines in Australia to observe operating practices and dust control methods.

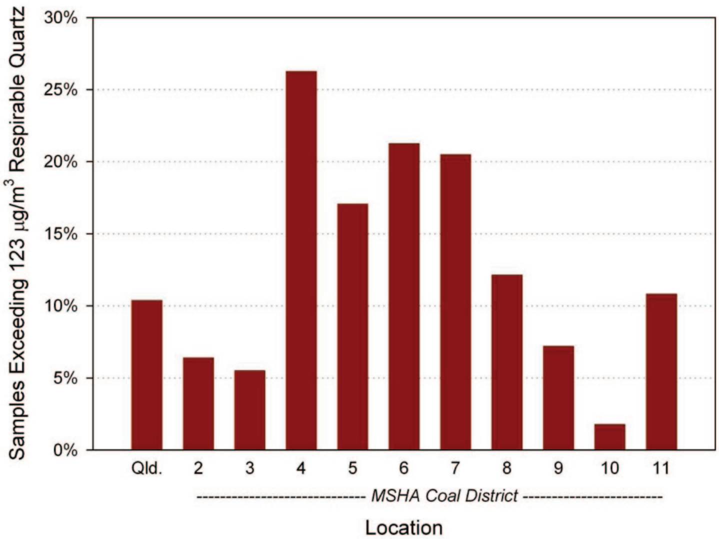
Comparison of dust exposure limits. The current regulatory standards for respirable coal mine dust (RCMD) in the three jurisdictions studied are substantially different. In the United States, the exposure level enforced by Mine Safety and Health Administration (MSHA) (excluding Part 90 miners with diagnosed CWP) is 2.0 mg/m^3, (*Federal Register*, 1970). In New South Wales, the standard is 2.5 mg/m^3 and in Queensland, the standard is 3.0 mg/m^3. The Australian standards are based on AS-2985, an International Standards Organization (ISO)-compliant sampling method (Standards Australia, 2004), which differs from the MSHA method, primarily in the sampler flow rate value (1.7 L/min in the AS-2985 method and 2.0 L/min in the MSHA method). Using the conversion factor (1.23) (Page and Volkwein, 2009) to account for the effect of the different sampling flow rates, the standards for the two Australian jurisdictions may be adjusted to allow comparison to the MSHA sampling convention. Thus, the adjusted exposure standards are 3.1 mg/m^3 for New South Wales and 3.7 mg/m^3 for Queensland. The Queensland limit is reduced for shifts longer than eight hours, so that the cumulative exposure does not exceed 24 mg·hr/m^3 ISO mass basis over the extended shift duration.

The United States and Queensland sample portal-to-portal, meaning that the sampling starts when the miner enters the portal of the mine, including travel time to and from the working face, and continues until the miner exits the mine portal. However, in New South Wales, samples are not collected during this travel time, but only during the miner's underground work period, denoted crib-room-to-crib-room — that is, from underground areas within the mine. The difference between the crib-room-to-crib-room and portal-to-portal methods in New South Wales and Queensland, respectively, has been estimated to increase the measured concentration of New South Wales samples by approximately 10% (Cliff and Kizil, 2002). All three jurisdictions collect dust on the most highly exposed occupations, but the particular occupations included differ, and similar job titles in the United States and Australia may not include identical

[3] The current surveillance program is titled the Enhanced Coal Workers' X-Ray Surveillance Program (ECWXSP).

Figure 3

Proportion of respirable dust samples exceeding 123 µg/m³ quartz in Queensland and U.S. MSHA bituminous coal districts, 1995 through 2000.

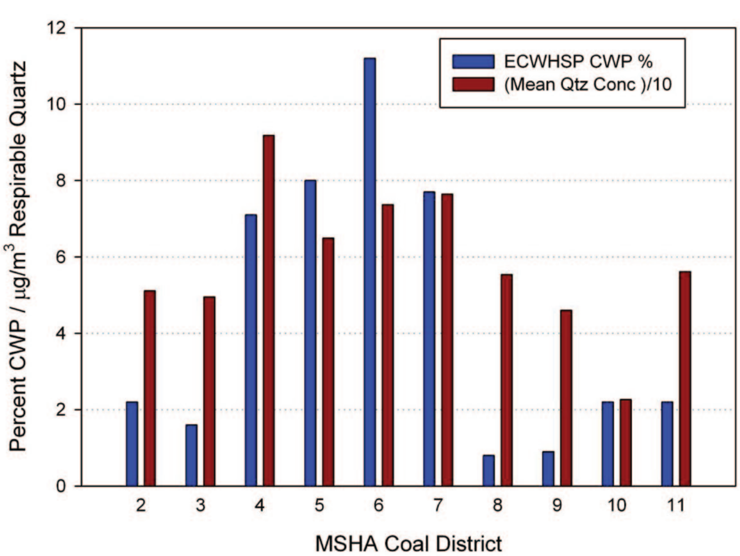


job responsibilities.

Further differences relate specifically to quartz exposure. New South Wales and Queensland regulate exposure to quartz separately from respirable coal dust, with specific exposure limits (New South Wales: 120 µg/m³; Queensland: 100 µg/m³ — both ISO mass basis). In the United States, MSHA regulates exposure to quartz through reduction of the permitted RCMD concentration, according to the relationship 10 divided by the percentage of quartz found in the sample (*Federal Register*, 1994). This method is intended to limit quartz exposures at or below 100 µg/m³. Finally, while New South Wales and Queensland assess compliance via individual sample results, MSHA uses an average of multiple samples to assess compliance with the standard.

Figure 4

ECWXSP pneumoconiosis prevalence rates and mean respirable quartz concentrations by MSHA coal district.



Comparison of coal rank. In the literature, one factor that has been associated with CWP is coal rank (Bennett et al., 1979; Attfield and Seixas, 1995), which is a measure of the geologic maturation of the coal. The risk of incidence and progression of CWP increases with coal rank, although the exact properties of higher-rank coal that are responsible for the increased hazard to the lungs are not known.

Study results

Dust exposure limit data. Among the three jurisdictions, directly comparable dust exposure data are limited. Table 1 shows a comparison between dust levels for several longwall occupations in the three jurisdictions.

The U.S. Longwall Operator description includes headgate- and tailgate-side longwall shearer operators. The data for the United States are from the MSHA Standardized Information System (MSIS) database (MSHA, 2010). New South Wales data and Queensland 1999-2001 data are from Cliff and Kizil, 2002. Queensland 1995-2000 data are from Ham et al., 2001.

Where the available data included sample number (N), mean and standard deviation information, the dust concentration means for the United States and the two Australian states were tested for equivalence using the SAS® TTEST procedure. Associated testing of variance showed unequal variances for all groups; therefore, the t-test results incorporating the Satterthwaite approximation were used. Where the t-test could be applied, the U.S. mean dust concentrations were all significantly less than the related Australian means at $p < 0.01$.

Among the three jurisdictions, data regarding exposure to respirable quartz are even more limited. The Queensland respirable quartz exposure limit is 100 µg/m³ measured according to AS-2985; this equates to 123 µg/m³ on an MSHA basis. Quartz exposure samples from Queensland were compared to MSHA inspector samples for the same set of occupations during the same time period. No respirable quartz exposure data for New South Wales were available.

In Queensland, 10.4% (103/986) of samples collected by Queensland Mines Department personnel from 1995 to 2000 to measure respirable quartz exposure exceeded the 100 µg/m³ exposure limit (Ham et al., 2001). In the United States, for the same set of miner occupations, 22.1% of MSHA inspector samples collected in the central Appalachian region, which includes southern West Virginia, western Virginia and eastern Kentucky, exceeded 123 µg/m³. This area is included in MSHA coal districts 4, 5, 6 and 7. The fraction of samples exceeding 123 µg/m³ in the western United States (MSHA coal district 9), where coal seams tend to be similar in thickness to those in Australia, was 7.2%, and the fraction for the remaining MSHA coal districts (excluding the anthracite operations of district 1) was 7.4% (Fig. 3).

Table 2

Values for mean fixed carbon content for coals from Australian and U.S. sources.

Percent fixed carbon (proximate analysis)

Source	Mean	N	Std. Dev.
New South Wales	53.90	80	6.31
Queensland	62.48	97	10.53
MSHA District 4	58.87	455	8.73
MSHA District 5	58.04	456	6.01
MSHA District 6	49.76	350	5.15
MSHA District 7	51.37	397	3.91
Colorado	44.75	292	7.41
New Mexico	38.49	175	7.57
Utah	39.03	153	8.41
Wyoming	36.80	549	6.75

Pneumoconiosis prevalence rates from the NIOSH ECWHSP and the mean respirable quartz concentration of MSHA inspector samples from 2000 through 2009 for MSHA coal districts 2 through 11 are illustrated in Fig. 4 (NIOSH, 2010; MSHA, 2010). As shown, districts with the higher silica exposures generally have higher rates of CWP. The correlation (Spearman's rho) between these two variables is 0.68, $p < 0.05$.

Coal rank data. Table 2 presents data on coal rank from various sources in the United States and Australia as measured by fixed carbon content by proximate analysis. Coal data for Australian coals was extracted from a commercial Coal Quality database (Wood Mackenzie, 2008). Data for U.S. coals was extracted from the U.S Geological Survey COALQUAL database (USGS, 1997).

The mean fixed carbon content of coal samples from New South Wales and Queensland were compared to coal samples from the United States using the *t*-test. The mean fixed carbon content of coal samples from Queensland was significantly higher than that of coal samples from all U.S. sources, all $p < 0.001$. Coal samples from New South Wales were significantly higher in fixed carbon content than coals from U.S. sources, except for MSHA districts 4 and 5, all $p < 0.001$. The mean fixed carbon content of coals from MSHA districts 4 and 5 was significantly higher than for coals from New South Wales, $p < 0.001$.

Discussion

The difference in CWP prevalence and mortality between the United States and Australia is significant and of long duration. However, in interpreting this difference, analysis of prevalence data among the United States, New South Wales and Queensland is limited by the lack of directly comparable exposure data at the occupation level and, also, by the lack of information on job tenure from New South Wales and Queensland. The occurrence of CWP is related to cumulative exposure, so information on job tenure is important in interpreting rates — i.e., a low incidence of CWP may simply reflect a population of miners who have not been exposed long enough to develop disease. However, if Australian coal miners do, in fact, have lower job tenures than U.S. miners, note that for the past 20 years, even the lowest tenure group in the United States has a higher rate of CWP than miners in New South Wales, so this potential difference appears unimportant (Table 3).

Of note, longwall mining, with its generally higher dust exposures, began in Queensland in the mid-1980s. Given the latency of CWP, new cases among the cohort of miners who worked on these longwalls may begin to be discovered through an effective surveillance program in the current timeframe.

The coal rank data presented allow this potential factor to be discarded. If coal rank were an important factor, rank in Australia would be expected to be substantially lower than U.S. ranks. Additionally, New South Wales experienced high pneumoconiosis rates in the mid-20th century, and, while mining still occurs in the same coal formations – with similar coal rank – today, disease prevalence is very low.

Another possible explanation for the differences between the two countries is illuminated by examining coal seam thickness. Australian coal mining involves less disturbance of roof or floor rock to produce coal than does mining in the Appalachian regions of the United States, where the coal is found in thin seams. The average coal seam thickness in New South Wales for mines operating in 2004 was 3.2 m (10.5 ft), and in Queensland for mines operating in 2003 it was 4 m (13.2 ft). By comparison, seam heights in U.S. mines range from 1.2 m (4 ft) in MSHA coal district 1.8-2.3 m (6-8.5 ft) in district 9. In the central Appalachian region, where rapidly progressive CWP has been documented, the average seam height is 1.4 m (4.5 ft).

Table 3

CWP prevalence for U.S. miners with 0-4 years' tenure, and miners in New South Wales.

	CWP prevalence % > 1/0	
Surveillance period*	**United States**	**New South Wales**
1990-1994	0.8	< 0.5
1995-1999	0.6	
2000-2004	1.2	
2005-2009	0.5	

* Surveillance periods apply to the United States. New South Wales prevalence is reported annually by Coal Services Pty Ltd.

Although the impact of the above geologic difference may not be immediately apparent, it may result in higher exposure to respirable quartz among U.S. miners. To evaluate this argument, a selection of 63 mines in the central Appalachian region (MSHA coal districts 4, 5, 6 and 7), was examined to evaluate how much rock was actually being cut. The amount of rock cut was assessed using notes made by MSHA inspectors as part of their normal activities. For 16 mines in district 4, an average of 26% of the total material height extracted was rock (46 of 175 cm); in district 5 (20 mines), 25% (43 of 173 cm) was rock; in district 6 (13 mines), 19% (28 of 147 cm) was rock; and in district 7 (14 mines), 31% (53 of 173 cm) was rock (Pollock et al., 2009).[4] Australian coal mines, with substantially thicker seams, would be able to economically extract coal without disturbing roof or floor rock at anywhere near these quantities, with a coincident reduction of respirable quartz generated.

A final potential explanation for the differences between the two countries relates to the sampling methods employed. The regulatory systems in New South Wales and Queensland evaluate compliance by comparing each dust sample individually to the applicable dust standard, described as a "single-sample" method. In the United States, MSHA evaluates compliance by averaging multiple samples collected on one occupation over successive (up to five) shifts or days. MSHA has reported that multiple sample averaging methods are not protective for all miners (*Federal Register*, 1998). In fact, MSHA has attempted to adopt a single-sample approach to compliance assessment on three occasions — in 1991, 1998 and 2000. The first two attempts involved changes to sampling policy, but these were reversed subsequent to legal challenges. Following extended public comment, a revised proposed rule was published in 2003, and that rulemaking activity remains ongoing. The authors note that the proposed rule to lower miners' exposure to respirable coal mine dust published on Oct. 19, 2010 (FR 75 64412) includes a provision to adopt a single-sample, full-shift approach for exposure determination.

Conclusions

Objective exposure data directly applicable to conditions in both countries is limited; however, analysis of available data and the commonality of mining technologies in Australia and the United States offers directions for further research on this important issue.

As evidenced by data from the last 20 years, the rate of pneumoconiosis in underground coal miners in New South Wales is lower than rates in U.S. miners. Based on the available information, exposure to respirable coal mine dust is higher in Australian underground coal mines than in the United States; however, Australian miners appear to be exposed to lower respirable quartz dust. Differences in coal rank do not explain the difference in CWP prevalence.

A potential explanation for this apparent paradox involves two factors. The first is that the thicker coal seams in Australia permit mines to cut much less rock than in U.S. mines, particularly compared to the central Appalachian area, where coal seams are thin. This leads to the possibility of Australian miners having lower quartz exposures than U.S. miners who work in thinner seam deposits. This argument is bolstered by the association between the rapid development and progression of simple CWP in U.S. underground coal miners exposed to relatively low overall RCMD concentrations but to RCMD with elevated quartz content.

The second factor to explain the paradox may be the procedure used in the United States to measure exposure to RCMD and quartz in coal mines. MSHA's own analysis of its sampling data has shown that using the average of several samples to assess compliance can obscure individual samples that are substantially above the exposure limit. Further, this assessment method is not protective of all miners on all work shifts, and, as recommended in the1995 NIOSH Criteria Document, should be revised to enhance protection of miners' health. Finally, regarding the argument that quartz exposure may be responsible for some of the elevated pneumoconiosis prevalence in the United States compared to Australia, it should also be recognized that it is not the only factor contributing to the higher U.S. disease rates. This is demonstrated by the observed pneumoconiosis rates in MSHA coal districts with the low sample quartz content (see Fig. 4, district 10), which still exceed rates in New South Wales.

Other factors that could impact the differing CWP prevalences involve physical and operational characteristics of underground coal mines in Australia and the United States. Mines in Australia on average are larger, in terms of employment, than mines in the United States. This difference follows from the larger proportion of longwall mines in Australia compared to the United States, particularly in the Appalachian region. In 2006, the average Australian underground coal mine employed more than 200 miners (Australian Coal Association, 2008). In the United States, underground coal mines, excluding anthracite mines, employed an average of 40 employees in MSHA district 6, to 277 in MSHA district 11 (MSHA, 2008). Larger mines may have higher levels of financial resources for installation of dust controls, and for maintenance of dust controls and production equipment. The effect of mine size was examined, and mines with fewer than 50 employees were found to have higher rates of CWP (Laney and Attfield, 2010).

Operational differences were observed to exist between the two nations. An example is the U.S. practice of roof bolters working downwind of the continuous miner, potentially exposing them to high dust concentrations. This practice is rare in Australia. Another aspect is the use of respiratory protection, which appears higher in Australian mines. These observations at this time have not been systematically examined, but could have some effect on dust exposure. A difficulty with comparing current practices is rooted in the latency of CWP. The differing practices would have had to have been established decades ago to be reflected in today's CWP rates.

Based on this analysis, it seems possible that some of the cases identified as CWP in the United States — particularly those in the central Appalachian region — may be due to

[4] It should be noted that these mines are not representative of all mines in the districts, having been selected based on high measured RCMD concentrations, and the inspector's notes described conditions encountered on particular days. However, this information demonstrates that Appalachian mines sometimes cut a significant amount of rock.

quartz exposure. If this is the case, emphasis should be placed on quantifying quartz exposure in U.S. coal miners and on reducing that exposure where necessary. The authors reiterate the sampling methodology recommendations for respirable coal mine dust and quartz found in the 1995 NIOSH Criteria Document — the establishment of an independent exposure standard for respirable quartz in coal mining — and recommend a targeted program to assess the exposure of coal miners to quartz in thin seam underground mines.

Finally, CWP is not the only disease caused by exposure to coal dust. Considerable morbidity from other respiratory diseases such as chronic obstructive pulmonary disease (COPD) can result, negatively affecting the health of coal miners, which makes prevention even more important. Forecasted increases in production and the expected long-term duration of coal utilization worldwide make enhanced preventive measures urgent.

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Disclosure

The findings and conclusions in this report are those of the authors and do not necessarily represent the views of the National Institute for Occupational Safety and Health.

References

AIHW, 2005, *GRIM* (*General Record of Incidence of Mortality*) 2005, Australian Institute of Health and Welfare (AIHW), Canberra.

Attfield, M.D. and Seixas, N.S., 1995, "Prevalence of pneumoconiosis and its relationship to dust exposure in a cohort of U.S. bituminous coal miners and ex-miners," *Am J Ind Med*, Vol. 27, pp. 137–151.

Australian Coal Association; The Australian Coal Industry > Selected Statistics; http://www.australiancoal.com.au/industrystats.htm#employment, cited 03/04/2008.

Bennett, J.G., Dick, J.A., Kaplan, Y.S., Shand, P.A., Shennan, D.H., Thomas, D.J. and Washington, J.S., 1979, "The relationship between coal rank and the prevalence of pneumoconiosis," *Brit J Ind Med,* Vol. 36, pp. 206-210.

CDC, 2006, "Advanced cases of coal workers' pneumoconiosis—two counties, Virginia, 2006," *Morbidity and Mortality Weekly Report 2006*, Vol. 55, Centers for Disease Control and Prevention, pp. 909-913.

CDC, 2007, "Advanced pneumoconiosis among working underground coal miners—eastern Kentucky and southwest Virginia, 2006," *Morbidity and Mortality Weekly Report* 2007, Vol. 56, Centers for Disease Control and Prevention, pp. 652-655.

Cliff, D., and Kizil, G.V., 2002, "An estimation of the exposure of Queensland underground coal longwall workers to respirable dust," presented at Queensland Mining Industry Health and Safety Conference, August 4-7, 2002, Townsville, Queensland, Australia.

Coal Services Pty Limited, 2008, Annual Report 2006-2007.

Delaney B., 2008, Coal Services Pty Limited, personal communication, February 4, 2008.

Federal Register, 1970, 30 CFR Part 74, "Coal mine dust personal sampling units," Vol. 35, March 11, 1970, p. 4326.

Federal Register, 1994, 30 CFR Part 70, "Respirable dust standard when quartz is present," Vol. 59, Mine Safety and Health Administration, February 18, 1994, p. 8327.

Federal Register, 1998, "Mine shift atmospheric conditions; respirable dust sample," Vol. 63, MSHA, Feb 3, 1998, pp. 5664-5687.

Glick, M., Outhred, K.G., and McKenzie, H.I., 1972, "Pneumoconiosis and respiratory disorders of coal mine workers of New South Wales, Australia," *Ann N Y Acad Sci*, Vol. 200, pp. 316-334.

Griffits, R., 1990, "An historical review of airborne coal dust levels and the prevalence of occupational lung disease in New South Wales coal mines 1948–1988," *Proceedings of the VIIth International Pneumoconioses Conference Part II*, DHHS (NIOSH) Publication No. 90-108 Part II, http://www.cdc.gov/niosh/901082pd.html, cited July 30, 2010.

Ham, B., Spencer, N. and Domrow, N., 2001, "Analysis of respirable coal dust monitoring programs in Australia," *Best Practices in Workplace Surveillance: Identification and Tracking of Workplace Injury, Illness Exposures, and Hazards*, The NORA Surveillance Research Methods Team and DSHEFS Workshop, November 7-9, 2001, Cincinnati, OH, http://www.cdc.gov/niosh/sbw/posters/pdfs/ham21.pdf, cited Aug. 27, 2008.

ILO, 2002, International Labour Organization (ILO), *Guidelines for the Use of the ILO International Classification of Radiographs of Pneumoconioses*, revised edition 2000 (Occupational Safety and Health Series, No. 22), International Labour Organization, Geneva, Switzerland.

Laney, A.S., Petsonk, E.L. and Attfield, M.D., 2009, "Pneumoconiosis among underground bituminous coal miners in the United States: is silicosis becoming more frequent?" *Occup. Environ. Med*, http://elib.cdc.gov:2157/content/early/2009/09/22/oem.2009.047126.full.pdf, cited Apr 16, 2010.

Laney, A.S., and Attfield, M.D., 2010, "Coal workers' pneumoconiosis and progressive massive fibrosis are increasingly more prevalent among workers in small underground coal mines in the United States," *Occup. Environ. Med.*, Vol. 67, pp. 428-431.

Mine Safety and Health Administration, 2008, "All Coal Mining Data, Table 01. Number of Coal Operations in the United States, by Primary Activity, 1978-2006," *Mining Industry Accident, Injuries, Employment, and Production Statistics*, http://www.msha.gov/STATS/PART50/WQ/1978/wq78cl01.asp, cited 03/03/2008.

MSHA, 2010, *Program Evaluation and Information Resources*, MSHA Standardized Information System, Mine Safety and Health Administration, US Department of Labor, Arlington, Virginia, accessed October, 2010.

NIOSH, 1995, *Criteria for a recommended standard, Occupational exposure to respirable coal mine dust*, Publication No. 95-106, National Institute for Occupational Safety and Health, US Department of Health and Human Services.

NIOSH, 2003, *Work-related lung disease surveillance report 2002*, Publication No. 2003-111, National Institute for Occupational Safety and Health, US Department of Health and Human Services.

NIOSH, 2008, "NIOSH/DRDS/CWHSP celebrates the 35th anniversary of the Federal Coal Mine Health and Safety Act," National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention, http://www.cdc.gov/niosh/topics/surveillance/ORDS/CoalMineHealthSafetyAct35Years.html, cited February 29, 2008.

NIOSH, 2010, "Enhanced Coal Workers' Health Surveillance Program (ECWHSP)," Survey Summaries by MSHA Coal District," Occupational Respiratory Disease Surveillance, National Institute for Occupational Safety and Health, http://www.cdc.gov/niosh/topics/surveillance/ORDS/ecwhsp.html, cited May 6, 2010.

Page, S.J., and Volkwein, J.C., 2009, "A revised conversion factor relating respirable dust concentrations measured by 10 mm Dorr-Oliver nylon cyclones operated at 1.7 and 2.0 L min-1," *J. Environ. Monit.*, Vol. 11, pp. 684–689.

Pollock, D.E., Potts, J.D. and Joy, G.J., 2009, "Investigation into dust exposures and mining practices in mines in the southern Appalachian region," *Mining Engineering*, February, Vol. 62, No. 2, pp. 44-49.

Standards Australia International, 2004, *Australian Standard, Workplace atmospheres—method for sampling and gravimetric determination of respirable dust*, AS-2985, Sydney, New South Wales, Australia.

USGS, U.S. Geological Survey Open-File Report 97-134; U.S. Geological Survey Coal Quality (COALQUAL) Database: Version 2.0; Bragg, L.J., Oman, J.K, Tewalt, S.J., Oman, C.J., Rega, N.H., Washington, P.M., and Finkleman, R.B.; http://energy.er.usgs.gov/products/databases/CoalQual/index.htm; accessed 11/18/2011.

Wood Mackenzie, 2008, Coal Quality Database, Sydney, New South Wales, (proprietary content).