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IN-DEPTH REVIEWS

Occupational health hazards in mining: an overview

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Abstract This review article outlines the physical, chemical, biological, ergonomic and psychosocial occupational health hazards of mining and associated metallurgical processes. Mining remains an important industrial sector in many parts of the world and although substantial progress has been made in the control of occupational health hazards, there remains room for further risk reduction. This applies particularly to traumatic injury hazards, ergonomic hazards and noise. Vigilance is also required to ensure exposures to coal dust and crystalline silica remain effectively controlled.

Key words Asbestos; coal; ergonomic; heat; metallurgy; miliaria rubra; mining; noise; safety; silica.

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Introduction

Mining is an ancient occupation, long recognized as being arduous and liable to injury and disease [1,2].

The lifecycle of mining consists of exploration, mine development, mine operation, decommissioning and land rehabilitation.

Mining is a multi-disciplinary industry, drawing on several professions and trades. To ensure precision in clinical and epidemiological work, it is important to enquire about the details of tasks, as the term 'miner' is relatively non-specific.

Mining is traditionally classified as metalliferous or coal, and as surface or underground. Metalliferous mining can also be classified according to the commodity being mined.

Some degree of minerals processing is usually undertaken at mine sites. For metalliferous mining, many of the occupational health hazards relate to these metallurgical processes and for this reason I will include comments on metallurgical hazards.

The In-depth Reviews in this issue are intended to cover the topics that remain most important in mining today. These are: noise induced hearing loss, ergonomics, respiratory disease and system safety/risk management.

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Physical hazards

Traumatic injury remains a significant problem and ranges from the trivial to the fatal [3,4]. Common causes of fatal injury include rock fall, fires, explosions, mobile equipment accidents, falls from height, entrapment and electrocution. Less common but recognized causes of fatal injury include flooding of underground workings, wet-fill release from collapsed bulkheads and air blast from block caving failure. The systematic application of risk management techniques has contributed to a substantial decline in injury frequency rates in developed nations. Further improvement, however, is required to reach rates tolerable to the broader community. The review by Joy in this issue (pp. 311–315) covers system safety and risk management in mining.

Noise is almost ubiquitous in mining. It is generated by drilling, blasting, cutting, materials handling, ventilation, crushing, conveying and ore processing. Controlling noise has proven difficult in mining and noise-induced hearing loss remains common [5,6]. The review by McBride in this issue (pp. 290–296) gives a detailed account of noise and noise-induced hearing loss in mining.

Heat and humidity are encountered in tropical locations and in deep underground mines, where the virgin rock temperatures and air temperatures increase with depth, due principally to the geothermal gradient and auto-compression of the air column [7]. Fatal heat stroke has been a significant problem in the South African deep underground gold mines and heat exhaustion remains a contemporary problem in deep underground mining [7–13]. Miliaria rubra, colloquially also known as 'mucker's mange' is problematic in deep underground mines [14].

Whole body vibration is commonly experienced whilst operating mobile equipment, such as load–haul–dump units, trucks, scrapers and diggers. This can cause or exacerbate pre-existing spinal disorders. Poorly maintained roads and vehicles contribute to the problem.

Hand–arm vibration syndrome is also encountered with the use of vibrating tools such as air leg rock drills [15–19].

Radon daughter exposure in underground mining has increased the risk of lung cancer, but is now generally controlled by mine ventilation [20–27].

Solar ultraviolet exposures in surface mining operations are likely to contribute to the occurrence of squamous cell and basal cell carcinomas, although this is an inference drawn from studies of outdoor workers in other industries [28–30]. Occupations involving substantial outdoor work appear not to be associated with an increased risk of melanoma [28,31–35].

Infra-red exposures in pyrometallurgical processes contribute to heat stress and may induce cataracts.

Electromagnetic fields are encountered in electrolytic smelting and refining processes.

Barometric pressure is elevated in deep underground mines and reduced at high altitude mines in South America. Chronic intermittent hypoxia at altitude has been reported to induce physiological adaptations and symptoms of benign acute mountain sickness (AMS) in mine workers [36]. High altitude pulmonary oedema (HAPO) and high altitude cerebral oedema (HACO) were not seen. Increased barometric pressures in deep mines increase air temperatures, increase convective heat exchange and reduce sweat evaporation rates [37].

Chemical hazards

Crystalline silica has long been a serious hazard in mining, with the risk of silicosis at its worst during dry drilling late in the nineteenth century [38]. Silicosis has been subject to considerable investigation [39–46]. Axial water-fed rock drills, wet techniques, ventilation, enclosed cabins and respiratory protection have largely controlled silicosis in developed nations. However, silicosis remains a problem in developing nations and silico-tuberculosis is important in Africa, where the high prevalence of HIV infection among miners increases the risk. Prolonged exposure to crystalline silica can also cause chronic obstructive pulmonary disease [47,48]. There is some evidence for accelerated silicosis in rheumatoid arthritis and of renal disease following prolonged silica exposure [49,50]. There is also now good evidence that prolonged exposure to crystalline silica increases the risk of lung cancer [51].

Coal dust has also been a serious hazard in mining, causing coal workers' pneumoconiosis or 'black lung' and chronic obstructive pulmonary disease [52–69]. The risks have now been largely controlled in developed nations by dust suppression, ventilation and respiratory protection [70,71]. Vigilance is, however, required to maintain effective control.

Although largely historic in the developed world, the mining and milling of asbestos has caused a legacy of asbestos-related diseases, which continue to occur today.

The review by Ross and Murray in this issue (pp. 304–310) gives a detailed account of respiratory diseases in mining.

Diesel particulate exposures occur in underground mines because of diesel powered mobile equipment, used primarily for drilling and haulage. Diesel particulate is an IARC Group 2A probable human carcinogen and several epidemiological studies from other industries suggest there is an excess risk of lung cancer [72–83]. Control measures include the use of low sulphur diesel fuel, engine maintenance and mine ventilation [84].

Arsenic is sometimes a contaminant of metal ores and has been commercially extracted during copper smelting with an accompanying risk of lung cancer [85–88].

Exposures to nickel compounds in some nickel refineries have been reported to increase the risk of lung cancer and nasal sinus cancer [89–92]. However, these risks have declined substantially with improving hygiene.

Several other metal ores, including those of lead, cadmium, manganese, platinum and cobalt, present health hazards [93–97]. The risks are usually greatest during metallurgical processing, when air concentrations exceed those experienced during mining of the ore. Appropriate control measures are required.

Exposures to coal tar pitch volatiles in Soderberg aluminium smelters have been reported to increase the risk of lung cancer and bladder cancer [98–102]. Occupational asthma has also been a problem in the pot rooms of aluminum smelters [103–105].

Coal dust and methane gas explosions in underground coal mines remain a serious risk requiring comprehensive monitoring and management [106]. Some underground coal mines also have problems with carbon dioxide and hydrogen sulphide gas.

Cyanide is used as a solvent for metals such as copper and gold in hydrometallurgical processes. Exposure to hydrogen cyanide gas can occur during cyanide solution preparation. Skin splashes with cyanide solutions are hazardous, although the risk is minimized by the use of low concentration solutions. Cyanide solutions are usually alkalinized to reduce the risk of hydrogen cyanide gas being evolved on contact with water.

Xanthates are reagents commonly used in hydrometallurgical processes. They evolve carbon disulphide gas on combustion or on mixing with water. Suspected acute carbon disulphide toxicity has been reported during xanthate reagent preparation at a gold mine [107].

Mercury is still used in some gold mining operations, especially in developing nations, to extract gold through the formation of mercury–gold amalgams [108–112]. Toxicity can result from inhalation of mercury vapour during preparation of amalgam, retorting or smelting [108].

Hydrofluoric acid is used in the analysis of core samples taken during exploration drilling.

Smelting of sulphide ores produces sulphur dioxide gas, which can cause acute bronchospasm.

Irritant dermal exposures are common in mining and often result in dermatitis [3].

Biological hazards

The risk of tropical diseases such as malaria and dengue fever is substantial at some remote mining locations.

Leptospirosis and ankylostomiasis were common in mines, but eradication of rats and improved sanitation has controlled these hazards effectively in the developed world [113].

Cooling towers are commonly found on mine sites. Regular microbiological analysis of the water is necessary to detect *Legionella* contamination or high concentrations of other heterotrophic microorganisms [114].

Ergonomic hazards

Although mining has become increasingly mechanized, there is still a substantial amount of manual handling. Cumulative trauma disorders continue to constitute the largest category of occupational disease in mining and often result in prolonged disability [3]. Overhead work is common underground, during ground support and during the suspension of pipes and electrical cables. This can cause or exacerbate shoulder disorders. Broken ground is often encountered and can cause ankle and knee injuries.

Most mines operate 24 h per day, 7 days per week, so shiftwork is very common. There has generally been a trend towards 12 h shifts in recent years.

Fatigue in relation to shiftwork has been subject to considerable investigation in the industry [115]. Sleep deficits, which might be expected in hot locations, have been shown to cause impairments of cognitive and motor performance among drivers from other industries [116].

The remote control of mobile equipment in underground mining has been introduced to reduce the risk of fatal injuries from rock falls. This has required attention to cognitive ergonomic issues, many of which are similar to those found in metallurgical plant control rooms. Proximity safety devices have also been developed [117].

The review by McPhee in this issue (pp. 297–303) gives a detailed account of ergonomic issues in mining.

Psychosocial hazards

Drug and alcohol abuse has been a difficult issue to deal with in mining, but policies and procedures are now in place in most large mining operations. Debate continues about how to measure psychophysical impairment. Nevertheless, mining operations commonly require the measurement of urinary drug metabolites and breath or blood alcohol on pre-employment and following accidents.

Remote locations are common in mining. Massive ore-bodies, such as those at Mount Isa in Queensland, Australia that have been mined for 80 years, justify the establishment of a city. Contemporary finds, however, tend to be smaller and do not justify establishment of permanent townships. As a result, there has been a trend towards 'fly-in-fly-out' operations, with mine employees separated from their families and communities during work periods.

Expatriate placements are also common in mining and the associated psychosocial hazards have been reviewed recently [118].

Unfortunately, fatal and severe traumatic injuries continue to occur in mining and often have a profound impact on morale. Post-traumatic stress disorders sometimes develop in witnesses, colleagues and managers. Registered managers often feel personally responsible for such injuries, even in the absence of negligence, and face the ordeal of government inquiries and legal proceedings.

Useful resources

The South African Safety in Mines Research Advisory Committee (SIMRAC) has recently published a book entitled *Handbook of Occupational Health Practice in the South African Mining Industry* [119]. This is the most recent comprehensive book on the subject. *The Mining Industry* is a useful state of the art review, although it is concerned primarily with respiratory conditions [120]. Much of the material in *Medicine in the Mining Industries* is now dated, but it remains a very useful reference [121]. The *SME Mining Engineering Handbook* and *Australasian*

Mining and Metallurgy are useful references for details of mining and metallurgical processes [122,123].

The medical literature on mining is readily accessible using Medline. Unfortunately, most of the technical documents written within the mining industry have tended to be presented at conferences rather than published in peer-reviewed journals. These papers are more difficult to access, but frequently contain detailed information related to exposures and control methods.

There are several useful websites, most of which are accessible through the mining and minerals section of the Steelynx website [124]. The Mines Safety and Health Administration and SIMRAC websites are particularly useful [125,126].

Contemporary and emerging issues

Many of the contemporary and emerging issues are common to the practice of occupational medicine in all industries. Risk management and sustainability have become central to the way companies operate and occupational health needs to be integrated into these systems. Multinationals are developing global corporate occupational health and hygiene standards, which require core components compatible with local legislative requirements. Effective health surveillance and biological monitoring require sophisticated information technology systems that are only now being adequately developed. We are faced with the paradox of increasing intolerance of occupational and environmental health risks at a time when they are declining rapidly. This emphasizes the need for more effective risk communication. The provision of medical services at remote locations is problematic, with difficulty attracting and retaining appropriately trained staff. Few have the desired mix of occupational health and emergency medicine skills and maintaining these skills at remote locations is difficult. There is a tendency to outsource non-core functions, including occupational medicine. Epidemiological studies are needed to understand the relationship between genetic markers and the risks of diseases.

References

1. Agricola G. *De Re Metallica. Translated from the First Latin Edition of 1556 by Herbert Clark Hoover and Lou Henry Hoover*. New York: Dover, 1950.
2. Ramazzini B. *De Morbis Artificum. The Latin Text of 1713 Revised, with Translation and Notes by Wilmer Cave Wright*. Chicago, IL: University of Chicago Press, 1940.
3. NIOSH. *Injuries, Illnesses, and Hazardous Exposures in the Mining Industry, 1986–1995: A Surveillance Report*. Washington DC: NIOSH, 2000.
4. The Minerals Council of Australia. *Safety and Health Performance Report of the Australian Minerals Industry 2001–2002*. Dickson, ACT: The Minerals Council of Australia, 2002.
5. Hessel PA, Sluis-Cremer GK. Hearing loss in white South African goldminers. *S African Med J* 1987;**71:**364–367.
6. Frank T, Bise CJ, Michael K. A hearing conservation program for coal miners. *Occup Health Safety* 2003;**72:**106–110.
7. Donoghue AM, Sinclair MJ, Bates GP. Heat exhaustion in a deep underground metalliferous mine. *Occup Environ Med* 2000; **57:**165–174.
8. Wyndham CH. A survey of the causal factors in heat stroke and of their prevention in the gold mining industry. *J S African Inst Mining Metall* 1965;**66:**125–155.
9. Donoghue AM, Bates GP. The risk of heat exhaustion at a deep underground metalliferous mine in relation to body mass index and predicted VO_2 max. *Occup Med* 2000;**50:**259–263.
10. Donoghue AM, Bates GP. The risk of heat exhaustion at a deep underground metalliferous mine in relation to surface temperatures. *Occup Med* 2000;**50:**334–336.
11. Donoghue AM. Type A lactic acidosis in occupational heat exhaustion. *Occup Med* 2003;**53:**139–142.
12. Donoghue AM. Heat illness in the US mining industry. *Am J Ind Med* 2004;**45:**351–356.
13. Shearer S. Dehydration and serum electrolyte changes in South African gold miners with heat disorders. *Am J Ind Med* 1990;**17:**225–239.
14. Donoghue AM, Sinclair MJ. Miliaria rubra of the lower limbs in underground miners. *Occup Med* 2000;**50:**430–433.
15. Dasgupta AK, Harrison J. Effects of vibration on the hand–arm system of miners in India. *Occup Med* 1996;**46:**71–78.
16. Narini PP, Novak CB, Mackinnon SE, Coulson-Roos C. Occupational exposure to hand vibration in Northern Ontario gold miners. *J Hand Surg* 1993;**18A:**1051–1058.
17. Bovenzi M, Franzinelli A, Strambi F. Prevalence of vibration-induced white finger and assessment of vibration exposure among travertine workers in Italy. *Int Arch Occup Environ Health* 1988;**61:**25–34.
18. Brubaker RL, Mackenzie CJG, Hutton SG. Vibration-induced white finger among selected underground rock drillers in British Columbia. *Scand J Work Environ Health* 1986;**12:**296–300.
19. Chatterjee DS, Petrie A, Taylor W. Prevalence of vibration-induced white finger in fluorspar mines in Weardale. *Br J Ind Med* 1978;**35:**208–218.
20. Roscoe RJ, Steenland K, Halperin WE, Beaumont JJ, Waxweiler RJ. Lung cancer mortality among non-smoking uranium miners exposed to radon daughters. *J Am Med Assoc* 1989;**262:**629–633.
21. Tirmarche M, Raphalen A, Allin F, Chameaud J, Bredon P. Mortality of a cohort of French uranium miners exposed to relatively low radon concentrations. *Br J Cancer* 1993;**67:**1090–1097.
22. Howe GR, Nair RC, Newcombe HB, Miller AB, Abbatt JD. Lung cancer mortality (1950–80) in relation to radon daughter exposure in a cohort of workers at the Eldorado Beaverlodge uranium mine. *J Natl Cancer Inst* 1986;**77:**357–362.

23. Howe GR, Nair RC, Newcombe HB, Miller AB, Burch JD, Abbatt JD. Lung cancer mortality (1950–1980) in relation to radon daughter exposure in a cohort of workers at the Eldorado Port radium uranium mine: possible modification of risk by exposure rate. *J Natl Cancer Inst* 1987;**79:**1255–1260.
24. Lundin FE, Lloyd W, Smith EM, Archer VE, Holaday DA. Mortality of uranium miners in relation to radiation exposure, hard rock mining and cigarette smoking—1950 through September 1967. *Health Phys* 1969;**16:**571–578.
25. Morrison HI, Villeneuve PJ, Lubin JH, Schaubel DE. Radon-progeny exposure and lung cancer risk in a cohort of Newfoundland fluorspar miners. *Radiat Res* 1998; **150:**58–65.
26. Radford EP, St Clair Renard KG. Lung cancer in Swedish iron miners exposed to low doses of radon daughters. *N Engl J Med* 1984;**310:**1485–1494.
27. Yu-tang L, Zhen C. A retrospective lung cancer mortality study of people exposed to insoluble arsenic and radon. *Lung Cancer* 1996;**14(Suppl. 1):**S137–S148.
28. Armstrong BK, Kricker A. The epidemiology of UV induced skin cancer. *J Photochem Photobiol B Biol* 2001;**63:**8–18.
29. Green A, Battistutta D, Hart V, *et al*. Skin cancer in a subtropical Australian population: incidence and lack of association with occupation. *Am J Epidemiol* 1996;**144:**1034–1040.
30. Marks R, Jolley D, Dorevitch AP, *et al*. The incidence of non-melanocytic skin cancers in an Australian population: results of a five-year prospective study. *Med J Aust* 1989;**150:**475–478.
31. Linet MS, Malker HSR, Chow WH, *et al*. Occupational risks for cutaneous melanoma among men in Sweden. *J Occup Environ Med* 1995;**37:**1127–1135.
32. Elwood JM. Melanoma and sun exposure: contrasts between intermittent and chronic exposure. *World J Surg* 1992;**16:**157–165.
33. Holman CDJ, Armstrong BK, Heenan PJ. Relationship of cutaneous malignant melanoma to individual sunlight-exposure habits. *J Natl Cancer Inst* 1986;**76:**403–414.
34. English DR, Heenan PJ, Holman CDJ, *et al*. Melanoma in Western Australia 1975–76 to 1980–81: Trends in demographic and pathological characteristics. *Int J Cancer* 1986;**37:**209–215.
35. Holman CDJ, Mulroney CD, Armstrong BK. Epidemiology of pre-invasive and invasive malignant melanoma in Western Australia. *Int J Cancer* 1980;**25:**317–323.
36. Richalet JP, Donoso MV, Jimenez D, *et al*. Chilean miners commuting from sea level to 4500 m: a prospective study. *High Alt Med Biol* 2002;**3:**159–166.
37. Gagge AP, Gonzalez RR. Mechanisms of heat exchange: biophysics and physiology. In: Fregly M, Blatteis C, eds. *Handbook of Physiology: Section 4, Volume 1. Environmental Physiology*. New York: Oxford University Press, 1996; 45–84.
38. Holman T. Historical relationship of mining, silicosis, and rock removal. *Br J Ind Med* 1947;**4:**1–29.
39. de Klerk NH, Musk AW. Silica, compensated silicosis, and lung cancer in Western Australian goldminers. *Occup Environ Med* 1998;**55:**243–248.
40. Chen S, Hayes RB, Wang J, Liang SR, Blair A. Nonmalignant respiratory disease among hematite mine workers in China. *Scand J Work Environ Health* 1989;**15:**319–322.
41. Hnizdo E, Murray J. Risk of pulmonary tuberculosis relative to silicosis and exposure to silica dust in South African gold miners. *Occup Environ Med* 1998;**55:**496–502.
42. Steenland K, Brown D. Silicosis among gold miners: exposure–response analyses and risk assessment. *Am J Public Health* 1995;**85:**1372–1377.
43. Buchanan D, Miller B, Soutar CA. Quantitative relations between exposure to respirable quartz and risk of silicosis. *Occup Environ Med* 2003;**60:**159–164.
44. Mannetje AT, Steenland K, Attfield M, *et al*. Exposure–response analysis and risk assessment for silica and silicosis mortality in a pooled analysis of six cohorts. *Occup Environ Med* 2002;**59:**723–728.
45. Kreiss K, Zhen B. Risk of silicosis in a Colorado mining community. *Am J Ind Med* 1996;**30:**529–539.
46. Hnizdo E, Sluis-Cremer GK. Risk of silicosis in a cohort of white South African gold miners. *Am J Ind Med* 1993;**24:**447–457.
47. Cowie RL, Mabena SK. Silicosis, chronic airflow limitation, and chronic bronchitis in South African gold miners. *Am Rev Respir Dis* 1991;**143:**80–84.
48. Holman CDJ, Psaila-Savona P, Roberts M, McNulty JC. Determinants of chronic bronchitis and lung dysfunction in Western Australian gold miners. *Br J Ind Med* 1987;**44:**810–818.
49. Sluis-Cremer GK, Hessel PA, Hnizdo E, Churchill AR. Relationship between silicosis and rheumatoid arthritis. *Thorax* 1986;**41:**596–601.
50. Kallenberg CGM. Renal disease—another effect of silica exposure? *Nephrol Dial Transplant* 1995;**10:**1117–1119.
51. Steenland K, Mannetje A, Boffetta P, *et al*. Pooled exposure–response analyses and risk assessment for lung cancer in 10 cohorts of silica-exposed workers: an IARC multicentre study. *Cancer Causes Control* 2001;**12:**773–784.
52. Kuempel ED, Stayner LT, Attfield MD, Buncher CR. Exposure–response analysis of mortality among coal miners in the United States. *Am J Ind Med* 1995;**28:**167–184.
53. Morgan WKC, Burgess DB, Jacobson G, *et al*. The prevalence of coal workers' pneumoconiosis in US coal miners. *Arch Environ Health* 1973;**27:**221–226.
54. Attfield M, Reger R, Glenn R. The incidence and progression of pneumoconiosis over nine years in US coal miners: 1. Principal findings. *Am J Ind Med* 1984;**6:**407–415.
55. Lainhart WS. Roentgenographic evidence of coal workers' pneumoconiosis in three geographic areas in the United States. *J Occup Med* 1969;**11:**399–408.
56. Althouse R, Attfield M, Kellie S. Use of data from X-ray screening program for coal workers to evaluate effectiveness of 2 mg/m^3 coal dust standard. *J Occup Med* 1986;**28:**741–745.
57. Cullen MR, Baloyi RS. Prevalence of pneumoconiosis

among coal and heavy metal miners in Zimbabwe. *Am J Ind Med* 1990;**17:**677–682.

58. Attfield MD, Morring K. An investigation into the relationship between coal workers' pneumoconiosis and dust exposure in U.S. coal miners. *Am Ind Hyg Assoc J* 1992;**53:**486–492.
59. Love RG, Miller BG, Groat SK, *et al.* Respiratory health effects of opencast coalmining: a cross sectional study of current workers. *Occup Environ Med* 1997;**54:**416–423.
60. Amandus HE, Petersen MR, Richards TB. Health status of anthracite surface coal miners. *Arch Environ Health* 1989;**44:**75–81.
61. Amandus HE, Hanke W, Kullman G, Reger RB. A re-evaluation of radiological evidence from a study of U.S. strip coal miners. *Arch Environ Health* 1984;**39:**346–351.
62. Attfield MD, Seixas NS. 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* 1995;**27:**137–151.
63. Hurley JF, Maclaren WM. *Dust Related Risks of Radiological Changes in Coalminers over a 40-year Working Life: Report on Work Commissioned by NIOSH*, Report TM/87/09. Edinburgh: Institute of Occupational Medicine, 1987.
64. Attfield MD. British data on coal miners pneumoconiosis and relevance to US conditions. *Am J Public Health* 1992;**82:**978–983.
65. Soutar CA, Hurley JF. Relation between dust exposure and lung function in miners and ex-miners. *Br J Ind Med* 1986;**43:**307–320.
66. Coggon D, Newman Taylor A. Coal mining and chronic obstructive pulmonary disease: a review of the evidence. *Occup Environ Med* 1998;**53:**398–407.
67. Miller BG, Jacobsen M. Dust exposure, pneumoconiosis, and mortality of coalminers. *Br J Ind Med* 1985;**42:**723–733.
68. Goodwin S, Attfield M. Temporal trends in coal workers pneumoconiosis prevalence. *J Occup Environ Med* 1998;**40:**1065–1071.
69. Hurley JF, Alexander WP, Hazeldine DJ, Jacobsen M, Maclaren WM. Exposure to respirable coalmine dust and incidence of progressive massive fibrosis. *Br J Ind Med* 1987;**44:**661–672.
70. Kizil GV, Donoghue AM. Coal dust exposures in the longwall mines of New South Wales, Australia: a respiratory risk assessment. *Occup Med* 2002;**52:**137–149.
71. Li H, Wang ML, Seixas N, Ducatman A, Petsonk EL. Respiratory protection: associated factors and effectiveness of respirator use among underground coal miners. *Am J Ind Med* 2002;**42:**55–62.
72. Borgia P, Forastiere F, Rapiti E, *et al.* Mortality among taxi drivers in Rome: a cohort study. *Am J Ind Med* 1994;**25:**507–517.
73. Gustavsson P, Plato N, Lidstrom EB, Hogstedt C. Lung cancer and exposure to diesel exhaust among bus garage workers. *Scand J Work Environ Health* 1990;**16:**348–354.
74. Boffetta P, Dosemeci M, Gridley G, Bath H, Moradi T, Silverman D. Occupational exposure to diesel engine emissions and risk of cancer in Swedish men and women. *Cancer Causes Control* 2001;**12:**365–374.
75. Hansen ES. A follow-up study on the mortality of truck drivers. *Am J Ind Med* 1993;**23:**811–821.
76. Soll-Johanning H, Bach E, Olsen JH, Tuchsen F. Cancer incidence in urban bus drivers and tramway employees: a retrospective cohort study. *Occup Environ Med* 1998;**55:**594–598.
77. Guberan E, Usel M, Raymond L, Bolay J, Fioretta G, Puissant J. Increased risk for lung cancer and for cancer of the gastrointestinal tract among Geneva professional drivers. *Br J Ind Med* 1992;**49:**337–344.
78. Garshick E, Schenker MB, Munoz A, *et al.* A retrospective cohort study of lung cancer and diesel exhaust exposure in railroad workers. *Am Rev Respir Dis* 1988;**137:**820–825.
79. Jarvholm B, Silverman D. Lung cancer in heavy equipment operators and truck drivers with diesel exhaust exposure in the construction industry. *Occup Environ Med* 2003;**60:**516–520.
80. Larkin EK, Smith TJ, Stayner L, Rosner B, Speizer FE, Garshick E. Diesel exhaust exposure and lung cancer: adjustment for the effect of smoking in a retrospective cohort study. *Am J Ind Med* 2000;**38:**399–409.
81. Hayes RB, Thomas T, Silverman DT, *et al.* Lung cancer in motor exhaust-related occupations. *Am J Ind Med* 1989;**16:**685–695.
82. Hohlfeld IB, Mohner M, Ahrens W, *et al.* Lung cancer risk in male workers occupationally exposed to diesel motor emissions in Germany. *Am J Ind Med* 1999;**36:**405–414.
83. Lipsett M, Campleman S. Occupational exposure to diesel exhaust and lung cancer: a meta-analysis. *Am J Public Health* 1999;**89:**1009–1017.
84. Davies B. 2002 William P Yant Award Lecture: Diesel particulate control strategies at some Australian underground coal mines. *AIHA J* 2002;**63:**554–558.
85. Enterline PE, Day R, Marsh GM. Cancers related to exposure to arsenic at a copper smelter. *Occup Environ Med* 1995;**52:**28–32.
86. Enterline PE, Marsh GM, Esmen NA, Henderson VL, Callahan CM, Paik M. Some effects of cigarette smoking, arsenic, and SO_2 on mortality among US copper smelter workers. *J Occup Med* 1987;**29:**831–838.
87. Lee-Feldstein A. Cumulative exposure to arsenic and its relationship to respiratory cancer among copper smelter employees. *J Occup Med* 1986;**28:**296–302.
88. Wall S. Survival and mortality pattern among Swedish smelter workers. *Int J Epidemiol* 1980;**9:**73–87.
89. Andersen A, Berge SR, Engeland A, Norseth T. Exposure to nickel compounds and smoking in relation to incidence of lung and nasal cancer among nickel refinery workers. *Occup Environ Med* 1996;**53:**708–713.
90. Doll R, Morgan LG, Speizer FE. Cancers of the lung and nasal sinuses in nickel workers. *Br J Cancer* 1970;**24:**623–632.
91. Enterline PE, Marsh GM. Mortality among workers in a nickel refinery and alloy manufacturing plant in West Virginia. *J Natl Cancer Inst* 1982;**68:**925–933.
92. Doll R, Andersen A, Cooper WC, *et al.* Report of the International Committee on Nickel Carcinogenesis in Man. *Scand J Work Environ Health* 1990;**16:**1–82.
93. Roels H, Lauwerys R, Konings J, *et al.* Renal function and

hyperfiltration capacity in lead smelter workers with high bone lead. *Occup Environ Med* 1994;**51:**505–512.
94. Chalkley SR, Richmond J, Barltrop D. Measurement of vitamin D_3 metabolites in smelter workers exposed to lead and cadmium. *Occup Environ Med* 1998;**55:**446–452.
95. Myers JE, teWaterNaude J, Fourie M, *et al.* Nervous system effects of occupational manganese exposure on South African manganese mineworkers. *Neurotoxicology* 2003;**24:**649–656.
96. Schierl R, Fries HG, van de Weyer C, Fruhmann G. Urinary excretion of platinum from platinum industry workers. *Occup Environ Med* 1998;**55:**138–140.
97. Linna A, Oksa P, Palmroos P, Roto P, Laippala P, Uitti J. Respiratory health of cobalt production workers. *Am J Ind Med* 2003;**44:**124–132.
98. Romundstad P, Haldorsen T, Andersen A. Cancer incidence and cause specific mortality among workers in two Norwegian aluminum reduction plants. *Am J Ind Med* 2000;**37:**175–183.
99. Romundstad P, Andersen A, Haldorsen T. Cancer incidence among workers in six Norwegian aluminum plants. *Scand J Work Environ Health* 2000;**26:**461–469.
100. Ronneberg A, Haldorsen T, Romundstad P, Andersen A. Occupational exposure and cancer incidence among workers from an aluminum smelter in western Norway. *Scand J Work Environ Health* 1999;**25:**207–214.
101. Tremblay C, Armstrong B, Theriault G, Brodeur J. Estimation of risk of developing bladder cancer among workers exposed to coal tar pitch volatiles in the primary aluminum industry. *Am J Ind Med* 1995;**27:**335–348.
102. Armstrong B, Tremblay C, Baris D, Theriault G. Lung cancer mortality and polynuclear aromatic hydrocarbons: a case-cohort study of aluminum production workers in Arvida, Quebec, Canada. *Am J Epidemiol* 1994;**139:**250–262.
103. Sorgdrager B, de Loof AJA, de Monchy JGR, Pal TM, Dubois AE, Rijcken B. Occurrence of occupational asthma in aluminum potroom workers in relation to preventive measures. *Int Arch Occup Environ Health* 1998;**71:**53–59.
104. Kongerud J, Boe J, Soyseth V, Naalsund A, Magnus P. Aluminium potroom asthma: the Norwegian experience. *Eur Respir J* 1994;**7:**165–172.
105. O'Donnell TV, Welford B, Coleman ED. Potroom asthma: New Zealand experience and follow-up. *Am J Ind Med* 1989;**15:**43–49.
106. Hopkins A. *Managing Major Hazards: The Lessons of the Moura Mine Disaster*. St Leonards: Allen & Unwin, 1999.
107. Donoghue AM. Carbon disulphide absorption during xanthate reagent mixing in a mine concentrator. *Occup Med* 1998;**48:**469–470.
108. Donoghue AM. Mercury toxicity due to the smelting of placer gold recovered by mercury amalgam. *Occup Med* 1998;**48:**413–415.
109. Bose-O'Reilly S, Drasch G, Beinhoff C, *et al.* The Mt Diwata study on the Phillipines 2000—treatment of mercury intoxicated inhabitants of a gold mining area with DMPS (2,3-dimercapto-1-propane-sulfonic acid, Dimaval). *Sci Total Environ* 2003;**307:**71–82.
110. Malm O. Gold mining as a source of mercury exposure in the Brazilian Amazon. *Environ Res* 1998;**77:**73–78.
111. de Kom JF, van der Voet GB, de Wolff FA. Mercury exposure of Maroon workers in the small scale gold mining in Suriname. *Environ Res* 1998;**77:**91–97.
112. Aks SE, Erickson T, Branches FJ, *et al.* Fractional mercury levels in Brazilian gold refiners and miners. *J Toxicol Clin Toxicol* 1995;**33:**1–10.
113. Jorgensen H. Hygiene in mines. In: Rogan JM, ed. *Medicine in the Mining Industries*. London: William Heinemann Medical, 1972; 333–343.
114. Australian Standard AS 5059-2003. *Power Station Cooling Tower Water Systems—Management of Legionnaire's Disease Health Risk*. Sydney: Standards Australia International, 2003.
115. Baker A, Heiler K, Ferguson SA. The impact of roster changes on absenteeism and incident frequency in an Australian coal mine. *Occup Environ Med* 2003;**60:**43–49.
116. Williamson AM, Feyer AM. Moderate sleep deprivation produces impairments in cognitive and motor performance equivalent to legally prescribed levels of alcohol intoxication. *Occup Environ Med* 2000;**57:**649–655.
117. Schiffbauer WH. A workplace safety device for operators of remote-controlled continuous mining machines. *Am J Ind Med* 1999;**Suppl. 1:**69–71.
118. Jones S. Medical aspects of expatriate health: health threats. *Occup Med* 2000;**50:**572–578.
119. Guild R, Ehrlich RI, Johnston JR, Ross MH, eds. *Handbook of Occupational Health Practice in the South African Mining Industry*. Johannesburg: The Safety in Mines Research Advisory Committee, 2001.
120. Banks DE, ed. *Occupational Medicine State of the Art Reviews: The Mining Industry*. Philadelphia, PA: Hanley & Belfus, 1993.
121. Rogan JM, ed. *Medicine in the Mining Industries*. London: William Heinemann Medical, 1972.
122. Hartman HL, Britton SG, Gentry DW, *et al.*, eds. *SME Mining Engineering Handbook*, 2nd edn. Littleton: Society for Mining, Metallurgy, and Exploration, 1992.
123. Woodcock JT, Hamilton JK, eds. *Australasian Mining and Metallurgy*, 2nd edn. Melbourne: Australasian Institute of Mining and Metallurgy, 1993.
124. Steelynx website, cited 20 January 2004. Available at http://www.steelynx.net/
125. US Department of Labor Mine Safety and Health Administration website, cited 20 January 2004. Available at http://www.msha.gov/
126. Safety in Mines Research Advisory Committee website, cited 20 January 2004. Available at http://www.simrac.co.za/