

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.

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.

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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 hydro-metallurgical 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.

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