Safety and Health in Mining: Part 1

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Safety and health in mining is a position paper summarising key occupational safety and health risks in mining and their prevention. The paper is a joint effort by the members of the Scientific Committee on Mining Occupational Safety and Health (SC MinOSH) of the International Commission on Occupational Health (ICOH). The position paper will be published in three parts, in Occupational Health Southern Africa. The abbreviations and references used will be listed for each of the three parts. References are numbered consecutively across the three parts. The paper will also be published in its entirety on the ICOH website, as an output of SC MinOSH.

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PART 1

1. OBJECTIVES AND SCOPE

This paper provides a summary of the occupational safety and health risks related to mining, seen from the perspective of the Scientific Committee on Mining Occupational Safety and Health (SC MinOSH) of the International Commission on Occupational Health (ICOH). The main occupational safety and health concerns in mining are highlighted by professionals engaged in occupational health issues in the sector, either in terms of research or from a practical angle, or a combination of both aspects. The paper is intended to provide a broad overview of the topic, in a simple format that can be read and understood by anyone interested in the subject. The listed references are for further reading.

The paper starts with an overall description of mining activities and definitions of formal and informal mining. The main section deals with key occupational risks and diseases. For many of these risks and diseases, much of the information is related to formal mining, as details about the informal mining sector are not recorded in national registers and the sector is not regulated. Generally, however, it is estimated that the working conditions and adverse impacts in informal mining are far worse than those in the formal mining sector due to an absence of facilities or culture for safety and health concerns, and little or no control and support by authorities. The final section considers issues of special importance for informal mining: women workers and child labour, and the impact of mining on the health of communities.

2. MINING

Extraction of minerals has been in existence since prehistoric time, in many parts of the world. Today, mining exists in most countries. Modern mining processes involve prospecting for ore, analysis of the sustainable profit potential of a proposed mine, extraction of the desired materials, preparation (including crushing, grinding, concentration and washing) of the extracted material and, finally, reclamation and rehabilitation of the land after the mine is closed. Mining techniques can be divided into two common excavation types: surface mining and underground mining.[1]

Commodities recovered by mining include metals, coal, oil shale, gemstones, limestone, dimension stone, rock salt, potash, gravel, and clay. Mining, in a wider sense, includes extraction of any non-renewable resource such as petroleum, natural gas, or even water.

In this paper, mining is referred to as either formal or informal mining. Formal mining belongs to the formal economy, where taxes are paid, registers are kept and the authorities exert control and provide support. Informal mining belongs to the informal economy, where there may be no employer, taxes are not paid, registers are not kept and contact with authorities is rare. In some countries informal mining is considered illegal but in most countries it is accepted, and in some countries it contributes greatly to exports. Sometimes, the terms artisanal and small-scale mining are used; artisanal mining being informal, while small-scale mining may be either formal or informal.

In recent decades, industrial development has accelerated in many countries, including China and India, and this has had impacts all over the world. Rising demands for minerals have resulted in booming mining activities. Mining companies have increased employment and have had excellent financial performances. The number of people involved in informal mining has increased. That which is regarded as industrial development in some countries, however, may only result in the increase of primary production in other countries, because the product is exported and not used for manufacturing in the country of origin.

2.1 Mining in the formal economy

Mining companies can be classified by their size and financial capabilities. Major companies are considered to have adjusted annual mining-related revenue of more than US$500 million, with the financial capability to develop a major stand-alone mine. Intermediate companies have at least US$50 million in annual revenue but less than US$500 million. Junior companies rely on equity financing as their principal means of funding exploration. Junior companies are mainly pure exploration companies, but may also produce minimally, and have a revenue not exceeding US$50 million.[2]

The four major mineral mining commodities that provide the most revenue in the formal economy are coal, copper, iron ore and gold.[3] Even though the debate on global warming is ongoing, coal fires the furnaces in many industries and contributes about 27% of the world's total energy supply.[4]

Mining in the formal economy has about nine million employees, worldwide.[5,6] The major mining companies are mostly multinational and have tens or hundreds of thousands of employees. Their headquarters are in London, Melbourne, Beijing, Moscow, Toronto, Rio de Janeiro and Johannesburg, and they have operations in many different countries across five continents. The mining giants all have well-developed websites, so information about their sizes, ambitions and activities is easily accessible. They are committed to environmental sustainability, social responsibility, and the protection of the health and wellbeing of their employees. Most of them adhere to 'safety first', and some mention 'zero accidents' or 'zero harm' as an objective. However, there are also reports from other sources, such as Wikipedia and Human Rights Watch, about controversies due to removal of local populations from their land, or toxic waste from mining processes that causes contamination of soil, groundwater and surface water. Periodically, there are media reports about catastrophic accidents in mining, or other events with negative outcomes and far-reaching consequences.

The development of the mining industry is in progress everywhere, to achieve higher efficiency, increased productivity, and also better working conditions. The main tools are mechanisation, computerisation and automation, work organisation and globalisation (involving exportation and importation of technology, production and work; outsourcing; off-shoring; migration; etc.). With ongoing technological development, employment in the mining sector is likely to decrease over time.[6]

The major mining companies are resourceful and well organised, and many of the mining processes are highly mechanised and automated, with a strong focus on innovative methods and continuous improvement. Besides the positive outcomes of improved efficiency and productivity, this development may also dramatically change working conditions. Heavy manual work will decrease and certain types of accidents and occupational diseases will be reduced, but other types of accidents and diseases may increase in risk and prevalence, including noise-induced hearing loss (NIHL) and musculoskeletal disorders. New extraction approaches aiming at lean mining are being developed and may have impacts on occupational safety and health.[7] Risks will increase as mining operations reach greater depths. Organisational and generational changes, continued expansion of mining operations, and economic pressures, will complicate the situation. With increased automation and reduced involvement of workers, there is a growing need for remote surveillance. Person-vehicle collision avoidance systems, communication procedures and devices, headgear, etc., remain important topics for research and development.[6,8]

> "The mining industry is cyclical by nature. Minerals are in high demand when nations are experiencing economic prosperity and growth; the same minerals are in low demand during economic downturns."

A miner being trained at a surface facility on an underground longwall shearer cutting machine, with powered roof supports in the background, at a coal mine in Shandong Province, China

Photo: Dave Feickert

An informal worker exits a pit intended for mining gold in the Ashanti Region in Ghana

Photo: Edith Essie Clarke

2.2 Mining in the informal economy

In 2003, the International Labour Organization (ILO) estimated that there were 13 million people working worldwide in artisanal and small-scale mining, and an estimated 100 million depended on it for their livelihoods. Women represented up to 50% of the small-scale mining workforce, and a large number of children worked in this sector.[9] According to the International Institute for Environment and Development (IIED),[10] the numbers have increased dramatically during the last 10 years, and the IIED estimates the number of artisanal and small-scale miners to be between 20 and 30 million.

Artisanal and small-scale mining activities extract a wide range of minerals in large quantities, ranging from gold, diamonds and other precious stones, to zinc, coal, bauxite, tin, tantalum and tungsten. Artisanal and small-scale mines operate in over 80 countries and are the dominant livelihood in some of these countries. Overall, artisanal and small-scale mining contribute 15 to 20% of the global minerals and metals.[10] Gold is likely to be the mineral providing most revenues in informal mining.

In low-income countries, the informal economy is populated by marginalised and vulnerable workers. It is characterised by poor legal and policy frameworks, especially with regard to the protection of the health and safety of workers. Hazards faced by formal workers are multiplied several-fold for informal workers, often with non-existent controls, limited access to protective equipment or basic occupational health services, and the use of unregulated materials. While national governments and international agencies are crucial for positive policy changes to include the working poor, in most countries it is local government that controls places of informal work and provision of vital work-related infrastructure – such as sanitary facilities in or near markets, drains, storage, lighting, and protection against the elements. In addition, work in the informal sector has characteristics that, in turn, impact further on health: job insecurity, migrant work, increasing numbers of women workers, and child labour.[11,12]

The challenge for government at all levels, policy makers, health and safety professionals, worker organisations, community organisations, and other agencies, is to develop strategies that are inclusive, appropriate and feasible, with the ultimate objective of protecting informal workers and their dependants.

2.3 Economic importance

The economic importance of mining cannot be overestimated. Mining is a necessary prerequisite for much industrial production; extraction and mining are followed by production of metals and metal products, and manufacturing of machines and other equipment. It is difficult to imagine industrial production where metals are not involved in one way or another: 'If it is not grown, it has to be mined'. In 2014, the International Council on Mining and Metals (ICMM) published a report on how mining and metals contribute to each of 214 national economies.[13]

Even if the mining sector is not one of the most important sectors in relation to the number of employees, it employs many millions of workers worldwide. To the already mentioned nine million employees in formal mining, and the 20 to 30 million engaged in informal mining, should be added several million sub-contracted workers and suppliers of goods, transportation and other types of support services. Hundreds of millions depend directly on mining for their livelihood.

The mining industry is cyclical by nature. Minerals are in high demand when nations are experiencing economic prosperity and growth; the same minerals are in low demand during economic downturns.

3. KEY OCCUPATIONAL RISKS AND DISEASES

Mining remains one of the most hazardous employment sectors, despite the considerable efforts in many countries to implement and maintain occupational safety and health. The toll of death, injury and disease remains high amongst the world's mine workers. Much preventive work, in terms of health and safety, is still required. Over and above accidents, many of the adverse health effects associated with mining and the extractive industries are caused by the inhalation of airborne pollutants which are not controlled at source. Furthermore, mining may include heavy work, exposure to toxic chemicals, noise, vibration, heat and cold stress, work at high altitude, shift work, etc.[6,14,15]

Self-employed miners in the smallest underground mines typically work in unsupported tunnels, drilling and removing rock with hand tools and carrying the ore to the surface in sacks. The most common accidents are trips or falls, being hit by machinery or a moving object, and cave-ins or rock falls. The biggest health risks are exposure to dust (silica dust causes silicosis, particularly in gold miners), mercury and other chemicals; the effects of noise and vibration, poor ventilation (heat, humidity, lack of oxygen) and overexertion; inadequate work space; and the incorrect use of equipment which may not be fit for purpose.[16] Other commonplace health issues include poor sanitation and lack of clean water, malaria, typhoid, dysentery, malnutrition, substance abuse, tuberculosis (TB), and sexually-transmitted infections (STIs), including the Human Immunodeficiency Virus (HIV) that can lead to Acquired Immunodeficiency Syndrome (AIDS). These can reach epidemic proportions when make-shift camps arise, for instance in 'gold rush' mining.[17]

3.1 Accidents

Every year, thousands of miners die in accidents and many more are injured, especially in the processes of coal and hard rock mining.[18] Since the end of the 19th century there have been many mining accidents with hundreds of fatalities.[19]

3.1.1 Risk and prevalence

Mining accidents may be caused by gas or dust explosions, gas intoxications, improper use of explosives, electrical faults, fires, collapse of mine structures, rock falls from roofs and side walls, flooding, workers stumbling/slipping/falling, malfunctioning or improperly used mining equipment, or risks related to transport (including rail equipment and trackless machinery). Fatigue, as a consequence of long working hours, may constitute an accident risk, not least in transport work.

In many countries, the rates of accidents, including fatal accidents, have been reduced in the last few decades. Most deaths in mining nowadays occur in rural parts of low-income countries, especially China.

Among China's many millions of mine workers, the number of yearly fatalities in mining has fallen steadily from 6 995 in 2002 to 1 384 in 2012.[20] The same trend can be found in the USA[21] and South Africa; in the latter, TB causes more deaths in mine workers than mine accidents.[22] Sweden, with about 6 000 mine workers, has had, on average, one fatality per year in the last decade.[23] The decreasing number of fatalities in formal mining is accompanied by decreasing fatality and accident rates, due partly to improved safety measures. However, mining is still ranked high amongst the formal economy sectors for leading fatality rates in many countries. Where reliable national statistics exist, mining is the sector with the highest, or among the two to three highest, rates of fatal occupational accidents.

Illnesses and injuries in the informal mining sector (artisanal, illegal and/or small-scale mining) are not represented in national records. Generally, it is estimated that the working conditions in informal mining are worse than those in the formal mining sector. Most occupational hazards in informal mining are a consequence of poor physical conditions, such as ground failure and shaft collapses, although machinery accidents, poor lighting and ventilation, electrocution and explosive misuse, are also pervasive issues.[17] Women, men and children who work in artisanal small-scale mining face additional illness, injury and stress from dust and noise pollution, extreme exertion from highly labour-intensive jobs, and stress caused by economic and other pressures.[24] Although accidents are under-reported in artisanal small-scale mining, the ILO states that the number of non-fatal accidents in artisanal small-scale mining is still six to seven times greater than in formal, large-scale operations.[17]

3.1.2 Prevention

The prevention of accidents in mining should be based upon relevant national legislation and a resourceful supervision and control of the implementation of this legislation. The ILO *Safety and Health in Mines Convention No. 176*[25] supports the development of such legislation. It states the preventive and protective measures that should be undertaken by the employer to assess the risk, and address it in the following order of priority: eliminate or reduce the risk; control the risk at source; minimise the risk by means that include the design of safe work systems; and, in so far as the risk remains, provide for the use of personal protective equipment.

By 2017 (February 1), 31 countries had ratified this Convention, among them Brazil, Germany, Morocco, Peru, Poland, Russian Federation, South Africa, Spain, Sweden, Turkey, Ukraine, the USA and Zambia. Among important mining countries that have not yet ratified this Convention are Australia, Canada, Chile, China, India, Indonesia and Japan.

In the mining enterprise, systematic risk assessments should be performed periodically. Based upon these assessments, short-term and long-term action plans should be established and implemented. Actions should be taken, and the results of the actions should be evaluated and followed-up.[26]

When it comes to technical and organisational measures to improve mine safety and prevent mining accidents, there are several guidelines and codes of practice. Reference is given to the ILO,[27] the National Institute for Occupational Safety and Health (NIOSH, USA),[28] and Safe Work Australia.[29] The ICMM has a number of guidelines, i.e. critical controls which guide companies on best practices.[30] The Chamber of Mines in South Africa has established a learning hub to address risks, including risks related to falls of ground, and transport and machinery.[31] Preventive measures in informal mining are described in some ILO publications[15,32] and the World Bank Program, "Communities, Artisanal and Small-Scale Mining" (CASM).[12]

The table lists officially reported mining accidents, based upon information in Wikipedia.[1,19] Of the listed 22 disasters, 18 concern coal mining.

Mining Disasters: 150 years… 22 events… > 300 fatalities per event

1866: Gas explosions in the coal mine Oaks Colliery in Yorkshire, England, claimed 383 lives	**1892**: A fire in St. Mary Mine (silver and iron mining) in Příbram, now Czech Republic, then Austria-Hungary, caused 319 deaths
1899: Sumitomo Besshi Copper Mine, landslide and flow disaster, Niihama, Japan, 512 died	**1906:** The Courrières Mine disaster in France; a total of 1 099 workers died due to a coal dust explosion
1906: Takashima Coal Mine explosion in Nagasaki, Japan, 307 fatalities	**1907:** Hokoku Coal Mine accident in Itoda, Fukuoka, Japan, 365 fatalities
1907: Coal mining explosion in Monongah, West Virginia, USA; official death toll was 362 but, due to inadequate record keeping, the true death toll could have been around 500	**1910:** The Hulton Colliery explosion in Lancashire, England, claimed the lives of 344 miners
1913: The Senghenydd Colliery disaster in Glamorgan, Wales, 439 deaths caused by a gas explosion	**1914:** New Yubari Coal Mine accident, Hokkaido, Japan, 423 fatalities
1914: Hojo Coal Mine explosion in Miyata, Fukuoka, Japan, 687 fatalities	**1918:** Onoura Coal Mine accident in Miyata, Fukuoka, Japan, 376 fatalities
1942: The Benxihu (Honkeiko) Colliery disaster in China; methane and coal dust explosion, followed by closure of ventilation system and carbon monoxide poisoning, killing 1 549 miners	**1945**: During a fire in El Teniente Copper Mine in Chile, 355 workers died by inhaling carbon monoxide
1960: Coalbrook Coal Mine disaster, South Africa, 437 died due to cascading pillar failure	**1960:** Laobaidong Colliery coal dust explosion, Datong, China, 682 died
1963: Mitsui Miike Coal Mine disaster, Ōmuta, Fukuoka, Japan, 458 died	**1965:** Dhanbad Coal Mine disaster in Jharkhand, India, killing over 300 miners
1972: Wankie Coal Mine disaster in Wankie, then Rhodesia, now Zimbabwe, 426 fatalities	**1975:** Chasnala mining disaster in Jharkhand, India, 372 miners died and another 130 contract workers are claimed to have died when a roof of coal caved in and water flooded into the mine; the miners were trapped under a mountain of debris and drowned when the water surged into the mine
1993: The Nambija Mine disaster was a landslide which occurred in a remote gold mining settlement in Ecuador; a part of the mountain above the countless mines gave way and buried about 300 people; a definite number of fatalities is not known, as there are no records	**2014:** In Soma, Turkey, an explosion at a coal mine caused an underground fire, 301 miners died

3.2 Silicosis and coal workers' pneumoconiosis

Exposure to respirable crystalline silica and respirable coal mine dust causes a spectrum of lung diseases. Inhalation of respirable crystalline silica causes silicosis, chronic obstructive pulmonary disease (COPD) and lung cancer, and is associated with increased risk for TB, chronic renal failure and several autoimmune diseases. Respirable coal mine dust is a complex mixture of materials, causing coal workers' pneumoconiosis (CWP), silicosis and COPD.[33,34] This section focuses on two lung diseases caused exclusively by these agents: silicosis and CWP.

Pneumoconiosis is a general term referring to a group of fibrotic interstitial lung diseases caused by the inhalation of mineral dust. These are serious diseases with no curative treatment, because fibrosis of the lung is irreversible. CWP is caused by the accumulation of coal mine dust in the lung, and the subsequent tissue reaction. CWP associated with only small radiographic opacities is called 'simple CWP'. CWP associated with large opacities (>10 mm) is known as progressive massive fibrosis. Anthracosis is the asymptomatic accumulation of carbon without a tissue reaction.[35]

Silicosis is a fibro-nodular lung disease caused by exposure to crystalline silica (silicon dioxide). The disease is irreversible and incurable, but it is preventable. Its radiographic appearance is similar to CWP and the two conditions cannot be distinguished by radiographic appearance alone. Quartz is the most common form of crystalline silica and is found in granite, slate and sandstone. Granite and slate often contain 30 to 40% silica. Sandstone is composed almost exclusively of silica.

3.2.1 Risk and prevalence

The risk of CWP depends on total lung dust burden and coal rank, a term referring to the coal carbon content. Anthracite has a high rank, followed by bituminous and sub-bituminous coal, and lignite. Higher rank is associated with greater CWP risk. Coal mine dust can contain respirable crystalline silica, so coal miners can also develop silicosis. Silica exposure and silicosis are more common in coal mine workers such as roof bolters and others who cut or drill through quartz-containing rock outside coal seams. In recent decades, the following CWP prevalence has been reported: USA 3.2%, UK 0.8%, Turkey 1.6% and China 6%.[36] In earlier years, prevalence of 10 to 20% was common. Data suggest that CWP rates have increased among US underground coal miners since the mid-1990s. Working in small underground coal mines is a risk factor.[37]

Silicosis risk exists in all industries that involve working with stone. Examples include mining, quarrying, tunnelling, stone crushing, foundry work, masonry, and construction, as well as manufacturing of cement, glass and heat-resistant bricks. Sandblasting is especially hazardous. Non-crystalline amorphous silica does not cause silicosis. Silicosis is closely associated with risk for developing active TB.[38] Together, silica dust, silicosis and HIV have a multiplicative effect on the development of TB.[39]

Small-scale mining is increasing and very widespread. This work is poorly paid, seasonal, dangerous and usually unregulated. Two studies from Tanzania examined silicosis risks in small-scale mining, and very high silica dust exposures were found. Air monitoring for crystalline silica demonstrated silica concentrations of 0.2 and 16.9 mg/m^3 associated with surface and underground mining, respectively.[40,41] The prevalence of silicosis in small-scale mining is largely unknown. An Ecuadorian study in gold small-scale miners found a prevalence of silicosis of 11%.[42] The use of preventive measures, such as wetting, reduces both silicosis and TB risks, but may be difficult to implement in small-scale mines.[40,41]

Accurate estimates of silicosis and CWP frequency are often difficult to obtain. Occupational diseases are generally under-represented in statistics because of poor diagnosis and lack of acknowledgement of their relationship to working conditions. Poor record keeping, as well as latency (time delays of 10 to 30 years from initial exposure to clinical manifestation) present further difficulties.

The current permissible exposure limit (PEL) for respirable coal dust is 1.5 mg/m^3 in the USA, and 2 mg/m^3 in Finland and the Netherlands. PELs in Australia, Italy and the UK are 3, 3.3, and 3.8 mg/m^3, respectively.[43] The PEL for respirable crystalline silica in the USA was reduced in 2016 to 0.05 mg/m^3 for general industry, which is regulated by the Occupational Safety and Health Administration (OSHA).[44] USA mining is regulated by the Mine Safety and Health Administration (MSHA) which has indicated that a proposed rule will be published to address miners' exposure to respirable crystalline silica, adapting OSHA's work for the metal and non-metal mining industry.[45] The PELs for crystalline silica range from 0.05 to 0.2 mg/m^3 for 26 member states of the European Union.[46]

3.2.2 Prevention

The primary prevention for silicosis and CWP requires that workers' exposure to silica dust and coal dust be eliminated or reduced. This includes introducing dust control measures, using appropriate technologies in the hierarchy of control, i.e. local exhaust ventilation, process enclosure, wet techniques and elimination or substitution to limit exposure to respirable crystalline silica dust. Primary prevention is important not only in the prevention of silicosis but also in the prevention of TB, since exposure to silica dust and silicosis are both risk factors for developing TB.[47]

The ongoing mechanisation of mining operations may increase dust exposure.

The prevention of silicosis and CWP has been the subject of many national and international initiatives during the last 100 years. However, these diseases have not been eradicated, even in wealthy countries. To address the prevention of silicosis globally, the ILO and World Health Organization (WHO) established the ILO/WHO Global Program for the Elimination of Silicosis in 1997. This was identified as a priority area for action in occupational health, encouraging countries to place it high on their agendas. The objective was to reduce the incidence of silicosis drastically by 2015, and have silicosis as a public health problem eliminated by 2030.[48] Based upon what has been accomplished to date by the mining countries that have adopted the Global Program, it is evident that preventive actions have been non-existent or inadequate.

A quarry site in southern Mozambique. Employees and contractors working in this environment are at risk of exposure to respirable dust that contains silica. The dust control measures that are implemented at this operation are wetting down methods and the wearing of respiratory personal protective equipment Photo: Claudina Nogueira

3.3 Asbestosis

Asbestosis and other asbestos-related diseases are disorders of the lung and pleura caused by the inhalation of asbestos fibres. Asbestos is a set of naturally occurring silicate minerals commonly known, by their colour, as 'blue asbestos', 'brown asbestos' and the most common, 'white asbestos', also known as chrysotile. Asbestos is mined in closed and open mines, amounting to two million tons per year, although asbestos mining is banned in many countries. In mining, the ore is crushed and pure asbestos is obtained by milling. Asbestos-related diseases include non-malignant disorders such as asbestosis (pulmonary fibrosis), diffuse pleural thickening, pleural plaques, pleural effusion, and rounded atelectasis; as well as lung cancer and malignant mesothelioma. The symptoms of asbestosis and other asbestos-related diseases do not manifest until after an appreciable latency, often several decades. Sufferers of asbestos malignancies experience severe shortness of breath that eventually leads to respiratory failure and death.[49-53]

3.3.1 Risk and prevalence

Asbestos mining started on a large scale at the end of the 19th century when manufacturers and builders used asbestos because of its desirable physical properties, viz. sound absorption; tensile strength; resistance to fire, heat, electrical and chemical damage; and affordability. Currently, about 125 million people in the world are exposed to asbestos in their workplaces.[49] Occupational exposure to asbestos fibres occurs when mining or milling asbestos, or when producing and handling materials containing asbestos, such as cement building materials (90% of asbestos used in building is chrysotile), isolation materials and friction products.[49-52]

Non-occupational exposures have been shown to occur among family members of asbestos workers and those living in asbestos-contaminated environments, due to nearby mining or industrial activities involving asbestos. In some areas of the world, the soil contains amphibole asbestos (blue, brown and some other non-commercial forms), causing a high incidence of mesothelioma among the inhabitants of these areas. Asbestosis due to non-occupational exposure has been shown in several studies. A study among wives and sons of asbestos-exposed shipyard workers found a prevalence of asbestosis of 11 and 8% respectively, and another reported a prevalence of 35% among household contacts of asbestos insulation workers. These studies are described in the 2014 WHO report[49] and Braun and Kisting's paper.[50]

Because exposures in small-scale and informal mining and industries are higher than in regulated mines and industries, asbestosis and asbestos-related diseases are more frequent among workers in these workplaces.[50] The real numbers are not known as this sector is most often outside public control and employs temporary workforces. In South Africa and India, many small-scale or informal mining industries have produced and sold the asbestos to the big mining companies, thereby enabling the latter to avoid direct responsibility towards the miners for the dangerous working environments in the mines.[49,50,52]

In 2004, asbestos-related lung cancer, mesothelioma and asbestosis from occupational exposures resulted in 107 000 deaths annually and 1 523 000 Disability Adjusted Life Years (DALYs – a measure of overall disease burden, expressed as the number of years lost due to ill-health, disability or early death).[49] For asbestosis, the global burden estimate for the year 2000 was 7 000 deaths and 380 000 DALYs, and nearly 400 additional deaths were attributed to non-occupational exposures to asbestos.[49] Numerous studies have investigated occupational exposure to asbestos and the associated health outcomes, across sectors and geographical locations, as reported by the WHO.[49] Two examples are an Italian cohort of miners where 21 out of 590 deaths were reported to be due to asbestosis, and a cohort study among miners and millers from Canada where 108 out of 8 009 were attributed to pneumoconiosis (discussed in the 2014 WHO report).[49] Studies on miners in India showed an asbestosis prevalence diagnosed by radiography among 3% of miners and 21% of mill workers, and an overall prevalence of clinical asbestosis among millers of 12%.[52]

Reliable records of pneumoconiosis are sparse because asbestosis is inadequately recorded as a cause of death on death certificates, and mortality studies are not sufficient for detecting clinical morbidity. There are few studies on miners due to a lack of data as miners are often migrant workers and escape diagnosis when moving back home. It may be that some mining companies do not perform regular health checks, to avoid paying compensation for occupational diseases. Studies from the USA among asbestos textile workers have shown standardised mortality ratios (SMRs – a ratio or percentage quantifying the increase or decrease in mortality of a study cohort, with respect to the general population) from 3 to 5 for pneumoconiosis, and a SMR of 233 for asbestosis. In China, one study showed a SMR of 100 for asbestosis among textile workers, and another found that one third of textile and friction product workers were diagnosed with asbestosis during the period 1958 to1980 (discussed in the 2014 WHO report).[49]

3.3.2 Prevention

Asbestos must be substituted with known alternatives to avoid the serious health consequences. The international organisations, WHO, ILO, and ICOH, have made declarations aiming at a total ban on the production and use of asbestos.[54] By 2014, widespread and large-scale use of asbestos was banned in more than 50 countries worldwide.[49,55] A notable exception is the USA, where some uses of asbestos continue, for example asbestos cement is used in construction. Other countries, such as China, Russia, India, Brazil and Indonesia, have continued mining and/or widespread use of asbestos, and have actually increased its use during recent decades. In most low-income countries, no decrease in asbestos use has been seen.[49,56]

While working on a total ban, the exposure of workers to asbestos fibres should be minimised through methods for reducing dust exposure. A particular problem exists for small-scale mines and industries and the informal sector, where fewer resources exist for implementing preventive measures, and where control of the working environment by the relevant authorities is non-existent or insufficient.

3.4 Cancer

Globally, occupational carcinogens are an important cause of death and disability. Industries and occupations with large numbers of cancer deaths and registrations include construction, metal working, mining, land transport, roofing, road repair and construction, printing, farming, machine manufacturing, transport equipment, non-ferrous metals and metal products, and chemicals. Numerous studies have shown associations between lung cancer and various exposures during mining activities.[57-59]

Occupationally-induced cancer usually occurs decades after the start of the exposure that caused the cancer.[60] The long latency of some cancers means that the numbers of deaths due to past high exposures will continue to be substantial into the future.

3.4.1 Risk and prevalence

Lung cancer and mesothelioma are the cancers most likely to be caused from exposure to asbestos in the mining sector. Mesothelioma is a cancer of the inside lining of the chest wall which is uniquely and very specifically associated with exposure to asbestos. The association of asbestos exposure with asbestosis and lung cancer is strong.[57] Because asbestos is mined or used in industry in a few high-income countries and in many low-income countries, cases of lung disease related to asbestos exposure will continue to occur well into the future. This is due mainly to the long latency period (20 to 40 years) that exists between first exposure to asbestos fibres and the onset of cancer.[61] Despite many years of clinical research, there is no effective therapy for malignant mesothelioma.[62] Untreated, the median survival time is nine months; chemotherapy, radiotherapy and surgery have not shown consistent improvement in survival.

Silicosis and lung cancer are the main silica-related diseases in mining workforces. There is a link between silica dust, silicosis and lung cancer, even though this relationship is not as strong as for asbestos.[57] Workers in underground mines are particularly at risk, since the silica component in the rock is usually high. There is good evidence that prolonged exposure to crystalline silica increases the risk of lung cancer.[57-59] However, it is debatable if silica exposure, in the absence of silicosis, carries an increased risk for lung cancer.[58,59] Additional factors, such as smoking and exposure to other carcinogens in the workplace, may increase the risk for lung cancer.

Synthetic mineral fibres are classified by the International Agency for Research on Cancer (IARC) as being possible human carcinogens, hence exposure to synthetic mineral fibres may predispose to the development of lung cancer.[63] Certain chemical compounds which are common in smelting, refining and reduction environments are also known to be carcinogenic. Nickel has been reported to increase the risk of lung and nasal sinus cancer, and exposures to coal tar pitch volatiles in aluminium smelters have been reported to increase the risk of bladder and kidney cancer.[64,65]

Underground exposure to radon gas and diesel engine exhaust fumes are other likely causes of lung cancer. Radon daughter exposure in underground mining has increased the risk of lung cancer, but can now be controlled by appropriate mine ventilation.[66] Exposure to ionising radiation in mining activities involving radioactive ores, such as uranium and thorium, has been shown to increase the risk of developing lung cancer.[67]

Exposure to diesel exhaust fumes (consisting of diesel particulate matter, carbon monoxide, carbon dioxide, oxides of nitrogen and polycyclic aromatic hydrocarbons) occurs mainly in underground mines because of the use of diesel powered mobile equipment for drilling and haulage, in confined spaces where there is limited dilution of emissions via natural ventilation. Diesel emission levels are dependent on the fuel quality (the best quality fuel contains low sulphur levels), and also on the type of engine used and the effectiveness of exhaust filter systems deployed. Diesel particulate matter (DPM) has been classified as a Group 1 Carcinogen by IARC and there is an international awareness and need for improved DPM risk management. Several epidemiological studies from other industries indicate that there is an excess risk of lung and bladder cancer from exposure to DPM.[68-70]

In surface mining operations, ultraviolet radiation from the sun is likely to increase the risk of developing skin cancer (squamous cell and basal cell carcinomas), and is potentially an important skin cancer risk factor. Some studies have indicated an increase in the risk of developing melanoma, while others have shown that occupations involving considerable outdoor work appear not to be associated with an increased risk of melanoma.[71,72]

Various studies in the USA, China and Spain have provided evidence of increased risk of certain cancers (e.g. cancers of the respiratory, digestive and haematologic systems, and the thyroid) in the proximity of different types of mining facilities, due to both occupational and environmental exposures.[73-75]

The human health impacts associated with exposure to toxicants in artisanal mining populations in low-income countries are well recognised.[77] Metalloids such as arsenic, a known carcinogen, and heavy metals such as lead, mercury and cadmium, are well-researched, naturally-occurring pollutants of which environmental levels continue to increase in artisanal mining communities.[76,77]

Gibb and O'Leary identified a number of studies reporting on health assessments, kidney dysfunction, neurological disorders and symptoms, and immunotoxicity/autoimmune dysfunction in individuals living in or near artisanal mining communities. These studies, conducted in 19 different countries in South America, Asia, and Africa, measured hair and urine concentrations of mercury well above WHO health guidance values in artisanal mining communities. The authors concluded that artisanal mining workers and their families are exposed to mercury vapour. Workers, workers' families, and residents of nearby and downstream communities are known to consume fish heavily contaminated with methylmercury. The latter form of mercury, which is widely used in gold extraction processes, vaporises and eventually settles in soil and the sediment of lakes, rivers, bays, and oceans, and is transformed by anaerobic organisms into methylmercury.[77]

With regard to carcinogenicity, IARC's overall evaluation is that methylmercury compounds are possibly carcinogenic to humans (Group 2B), while metallic mercury and inorganic mercury compounds are not classifiable as to their carcinogenicity to humans (Group 3), as there is insufficient evidence of carcinogenicity in humans.[78] One study investigated the mortality from cancer among a large cohort of workers in mercury mines and mills in Spain, Slovenia, Italy and the Ukraine. Exposure to inorganic mercury in mines and mills did not appear to be strongly associated with cancer risk, with the possible exception of liver cancer; and the observed increase in lung cancer may have been explained by co-exposure to crystalline silica and radon.[79] In contrast to mercury, long-term exposure to arsenic, which is widely used in artisanal mining, is known to cause various types of cancer: skin, kidney, prostate, bladder, and lung.[80,81]

3.4.2 Prevention

Occupational cancers are largely preventable, and the estimated burden of occupational carcinogens can be abated by improving working conditions as many examples from different countries have shown. The recent Global Burden of Disease analysis, using 2015 data, found an estimated 489 000 deaths globally due to occupational carcinogens in IARC Group 1A Definite Human Carcinogens.[82] Quantitative risk assessment is an important tool in the prevention of occupational cancer because different carcinogens produce variable levels of risk, and there are disparities in the risks incurred by people exposed under different circumstances. There may also be threshold effects or interactions with other factors, environmental or genetic, that produce no risk for some exposed workers and high risk for others.

Regulatory procedures and other aspects of cancer prevention depend on the correct listing of carcinogens, such as the IARC Monograph Program which has been in existence since the early 1970s and evaluates human carcinogenicity based on the synthesis of epidemiologic and animal studies, and other evidence.[83] Furthermore, the relatively low burden of occupational cancer in high-income countries is the successful result of strict regulations on recognised carcinogens. Although many exposures to substances that are hazardous to health are regulated, potential exposure can and does occur through accidents, breaches in regulation, unrecognised hazards, or lack of appropriate control measures. Exposures to environmental and occupational carcinogens can be reduced or eliminated, hence the cancers that result from these carcinogens can be prevented through policies promoting healthy working and living environments.[84]

Strong regulatory control, worker education, medical surveillance and constant attention to safe occupational practices are required to minimise workplace exposure to carcinogens. In addition, tobacco smoking is known to greatly exacerbate the risk of many occupational carcinogens. A prime example is found in workers exposed to asbestos, where smokers have a lung cancer risk many times greater than that of non-smokers who are exposed to asbestos.[85]

In summary, there are three health actions that are specifically applied to prevent occupational cancers: health protection, health promotion and health services. Health protection encompasses activities directed at reducing exposure to the specific occupational carcinogen. Redesigning a specific job to eliminate exposure is an example of health protection, as are the high levels of the hierarchy of control in occupational hygiene, such as elimination or substitution of the hazardous substance, or engineering controls to reduce exposure at source. Health promotion implies an organised programme to help workers develop and improve behaviours conducive to good health. The third pillar for intervention (and the least satisfactory in terms of prevention of occupational cancer) is the provision of personal health services as some cancers, if detected early, are more easily treatable. It is through health protection, health promotion and health services that the cancer-causing triad of agent, environment and host can be disrupted to prevent occupational cancer.[60]

ABBREVIATIONS USED IN PART 1

AIDS	Acquired Immunodeficiency Syndrome
CASM	Communities, artisanal and small-scale mining
COPD	Chronic obstructive pulmonary disease
CWP	Coal workers' pneumoconiosis
DALYs	Disability Adjusted Life Years
DPM	Diesel particulate matter
HIV	Human Immunodeficiency Virus
IARC	International Agency for Research on Cancer
ICMM	International Council on Mining and Metals
ICOH	International Commission on Occupational Health
IIED	International Institute for Environment and Development
ILO	International Labour Organization/International Labour Office
MSHA	Mine Safety and Health Administration, USA
NIHL	Noise-induced hearing loss
NIOSH	National Institute for Occupational Safety and Health, USA
OSHA	Occupational Safety and Health Administration, USA
PELs	Permissible Exposure Limit(s)
SC MinOSH	Scientific Committee on Mining Occupational Safety and Health
SMRs	Standardised mortality ratios
STIs	Sexually transmitted infections
TB	Tuberculosis
US/USA	United States/United States of America
US$	United States Dollars
WHO	World Health Organization

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