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Worker and Community Health Impacts Related to Mining Operations Internationally

A Rapid Review of the Literature

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International Institute for Environment and Development

World Business Council for Sustainable Development

Worker and Community Health Impacts Related to Mining Operations Internationally

A Rapid Review of the Literature

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…..The city fathers named
a city park after him
and some even wanted to put up a statue
of Martinez but others said
that was going too far for just an Indian
even if he was the one who started that area
into a boom.
Well, later on,
when some folks began to complain
about chemical poisons flowing into the streams
from the processing mills, carwrecks on highway 53,
lack of housing in Grants,
cave-ins in Section 33,
non-union support,
high cost of living,
and uranium radiation causing cancer,
they - the Chamber of Commerce - pointed out
that it was Martinez
that Navajo Indian from over by Bluewater
who discovered uranium,
it says so in this here brochure,
he found that green stone over by Haystack
out behind his hogan;
it was that Indian who started that boom"

Simon Ortiz *It was that Indian* from Woven Stone (1992) Tucson: University of Arizona Press.

Preface and Acknowledgements

The work on which this report is based was developed through meetings between environmental health specialists of the London School of Hygiene & Tropical Medicine (LSHTM) and team members of the Mining, Minerals and Sustainable Development (MMSD) project in the International Institute of Environment and Development (IIED). MMSD needed to improve its understanding of the key worker and community health issues related to mining operations internationally. Two members of staff of the LSHTM were asked to undertake a rapid (four week) literature review and produce a summary of the key mining-related health issues. LSHTM also agreed to co-host, (with MMSD), an informal expert meeting related to worker and community health issues in mining and minerals development.

The authors of this review have no conflicts of interest in this area of investigation, and are both environmental epidemiology and public health specialists.

The rapid review took place between August – September of 2001. The workshop was held in the London School of Hygiene & Tropical Medicine on 10th September 2001. Details of the workshop are available on the website of the MMSD project of IIED (www.iied.org/mmsd). This work has been made possible by the support of the World Business Council for Sustainable Development. Terms of reference for the desk study are found at the Annex.

Comments on this review can be made to Carolyn Stephens, or Mike Ahern at the London School of Hygiene & Tropical Medicine.

Contents

List of acronyms

AIDS	Acquired immune deficiency syndrome
BMI	Body Mass Index
CI	Confidence interval
CV/VC	Closing Volume/Vital Capacity
Hg	Mercury
HIV	Human Immunodeficency Virus
mg/dl	Milligrammes per decilitre
mg/g	Milligrammes per gramme
mg/kg/day	Milligrammes per kilogramme per day
MMSD	Mining, Minerals and Sustainable Development Project
NGO	Non-Governmental Organisation
OR	Odds Ratio
OSHA	Occupational Health and Safety Administration
Pb	Lead
PbB	Blood lead
PM_{10}	Particulate matter (diameter less than 10 micrometers)
ppm	Parts per million
PTB	Pulmonary tuberculosis
RR	Relative Risk
SD	Standard Deviation
SIR	Standardised Incidence Ratio
SMR	Standardised Mortality Ratio
SSM	Small-Scale Mining
TB	Tuberculosis
UNIDO	United Nations Industrial Development Organisation
UK	United Kingdom
USA	United States of America
US-FDA	United States – Food and Drugs Administration
WHO	World Health Organisation
WTO	World Trade Organisation

Executive Summary

1. This review was undertaken for the Mining Minerals and Sustainable Development Project (MMSD) of the International Institute of Environment and Development. The work was made possible by the World Business Council for Sustainable Development. Our task was to review available scientific literature on worker and community health impacts related to mining internationally and to produce a brief summary. The principal aim of the work was to guide the MMSD team in its understanding of the issues of mining and health.
2. The review was based on literature available through PUBMED, an international database of peer-reviewed scientific journals related to health, occupation and environment. PUBMED was searched using relevant keywords: the launch word was *mining*, and link words were *occupational health; health; community health*; *employment and mining.* We retrieved and downloaded 996 peer-reviewed scientific articles with abstracts related to occupational and community health in the mining sector published between 1965 and 2001.
3. We read all abstracts and selected illustrative and high quality papers to review further and report. We did not select papers only on the basis of methodological excellence, but according to criteria of geographic spread, under-researched themes and under-researched stages of the mining cycle. We finally reported on over 330 papers.
4. The literature included 41 scientific reviews covering specific minerals, policies or manufacturing processes for mined products. Reviews were of epidemiological and toxicological literature on lead; iron oxides; asbestos (tremolite and chrysolite); coal; uranium; nickel and talc.
5. Reviews also cover mining and health by long and short-term health impacts, particularly for workers. Reviews look specifically at injuries; respiratory impacts; and cancers. There were no overview "mining and health" reviews. The literature does not contain comprehensive reviews of the "life cycle" of any one mining process or mineral/metal.
6. There were more studies of occupational health in the mining sector than community health studies. The bulk of the literature discusses health and safety *in* the mines and at the stage of extraction of mineral and metals. A few studies deal with processing stages of minerals, particularly in studies of gold mining.
7. The bulk of the studies refer to large-scale mining and only a limited number (approximately 1/5) of studies were of mining outside of Europe and North America. The bulk of the studies also deal with formal mineworkers. There are few studies looking at the informal small-scale mine sector.
8. Mining remains one of the most hazardous occupations in the world, both in terms of short term injuries and fatalities, but also due to long term impacts such as cancers and respiratory conditions such as silicosis, asbestosis and pneumoconiosis.
9. By sector, mining of asbestos, coal, uranium and gold are most studied. Other minerals and metals studied include copper, zinc, quartz, and sand. Coal, asbestos and uranium

are hazardous products to mine – and some health impacts are specific to these products.

10. Asbestos mining is now the subject of a call for an international ban on the basis of its health impacts at all stages of the mining and mineral use of this substance. The majority of studies focus on asbestos as a hazardous mined product and safety issues relate to exposure through breathing in asbestos particles in and around the mines. The most severe occupational exposure is that with the greatest contact with the asbestos particles in respirable form. Along with coal and other silicate dusts, the dangers of asbestos mining relate largely to damage to respiratory function and lungs. Impacts include asbestosis and lung cancers. Long term health impacts of asbestos mining and use will continue to be seen for up to 100 years from now.

11. Over 250 studies discuss coal mining and its risks to occupational health and safety. There have been changes in health impacts over time "from explosions to black lung". Fatalities, due to explosions, have been replaced by the chronic diseases due to coal (and other silicates) dust inhalation during mineral extraction. Pneumoconiosis and Silicosis are the most severe outcomes related to coal dust exposure by mine workers. Studies show that up to 12% of coal miners develop these fatal diseases.

12. Uranium mining merits over 50 studies, many of them largescale cohort studies. Health impacts of uranium mining are longterm – sometimes over 20 years after end of work. Most studies find relative risks of lung cancer between 2 and 5 times higher in uranium workers who have been exposed to higer levels of radon, or to longer periods of low exposure. Some studies put these risks at levels much higher.

13. Studies report that small-scale mines are more hazardous than large scale mines in terms of risks of accidents or injuries. But small-scale mines also tend to be surface mines or smaller scale operations employing younger less experienced workers and sometimes children.

14. Studies of mining and health by type of mine process are divided into deep and open cast mine. Deep mines produce severe problems for workers in terms of their risks of high blood pressure; heat exhaustion; myocardial infarction and nervous system disorders. Studies of surface mining focus on coal, granite and rock mining and health risks related to dust inhalation. In all levels of mining health risks occur with dust exposure.

15. Respiratory impacts are the most studied and problematic of health impacts for workers. Injuries have declined in importance but continue to be an important safety issue in mines. Long-term impacts include cancers, mental health impacts and some evidence of impacts on genetic integrity of workers.

16. Community health impacts of the mining and minerals sector are less well defined than those faced by workers. There are problems not only in defining 'community', but also in conducting the kinds of epidemiological studies that might provide evidence of links between mining activities and health outcomes.

17. Compared to the number of studies on occupational exposures, the number of articles that focused on non-occupationally exposed populations was limited. Existing studies provide indications of the health problems faced by communities. The range of articles

was broad, in terms of the different types of minerals studied; the range of countries covered; and the type of mining sector (large-scale and small-scale) included.

18. The debate on the impact of the mining and minerals sector on both worker and community health is polarised. On the one hand the industry tends to highlight the alleged benefits of the sector, whilst on the other, community groups and NGOs suggest that the sector is detrimental to health and sustainable development.

19. In the peer-reviewed literature some studies suggest that the sector has adverse effects on community health. Other studies are less conclusive. Only one study discussed the positive impacts of mining companies on community health.

20. There were relatively few studies of policy initiatives. Health and safety improvements in mines have been developed over a long period of negotiation and struggle. Laws have come after union and management activities. Governments have supported organised labour in the improvements.

21. Scientific understanding of long-term impacts has grown. Workers have been able to use scientific evidence for improved "hazard visibility" and for shifts in health and safety legislation. However, much of the small-scale mining sector falls outside formal legislative protection or scientific analysis.

22. Companies have provided a range of community initiatives including vaccination programmes and health services. These have mixed results. Companies have rarely addressed the community claims for damage made against them internationally. Communities have worked with scientists to understand some of the impacts associated with living near to mines. Unions have rarely played an explicit role in support for community claims.

23. There is a need for more openness and transparency within the mining sector, particularly in countries of Latin America, Asia and Africa. There is a further need for in-depth long-term evaluation of the impacts of mining of health on workers and communities.

24. There is evidence of long-term impacts of mining on health of workers and communities. This implies that the sector's activities currently undermine the human objectives of sustainable development, which are to protect the health of current and future generations.

25. There is still a long way to go before mining becomes a healthy work or a healthy development activity to take place in a community. There is also a long way to go before the industry, the workers and the community agree over the real health impacts of the sector and the real responsibility of each of the actors in the sector.

1 Introduction

This section reports the methods of the review and the overall themes and trends within the literature.

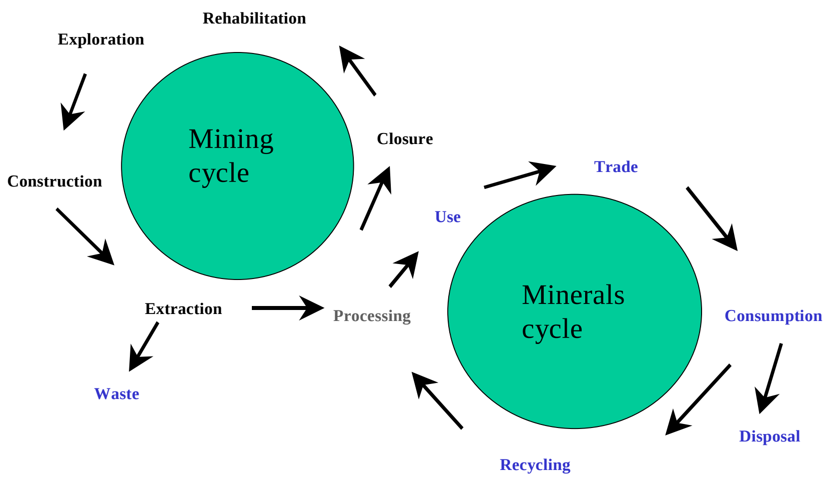
1.1 Methods of Review

This review was based principally on a desk analysis of literature available through PUBMED, an international database of peer-reviewed scientific journals related to health, occupation and environment. PubMed, a service of the National Library of Medicine, provides access to over 11 million MEDLINE citations back to the mid-1960's and additional life science journals. PubMed includes links to many sites providing full text articles and other related resources.

PubMed was searched using a series of keywords relevant to this desk study: the launch word was *mining*, and link words were *occupational health; health; community health*. We added to this *employment and mining.* Through this search method we retrieved and downloaded 996 peer-reviewed scientific articles with abstracts related to occupational and community health in the mining sector published between 1965 and 2001. We searched this database via abstracts for further keywords to extract the following themes:

- Historical studies on mining and health
- Mining and health by mineral type
- Mining and health by type of mining process
- Mining and health: occupational exposures and impacts
- Mining and community health impacts
- Mining and health policy

Figure 1 The minerals system and health



We reviewed all abstracts by these thematic headings and selected studies to review, report and to illustrate key themes of mining and health. We excluded studies that were tangential to the themes of the review. Our working definition of "mining" focused principally on the mining cycle (exploration; construction; extraction; closure; rehabilitation) although where studies dealt with important complex health links with the metal/mineral cycle (processing; use; trade; consumption; disposal; recycling) we reported these also. Figure 1, (drawn from MMSD 2000) shows these cycles. The stages marked in black are those covered by this review, and those in blue are not covered or are referred to only in the context of key community studies. In the community study section we cover a small number of studies dealing with processing. Our working definition of "health" was broad and included concepts of safety, and of well-being, thus we included, where possible, studies that discussed indirect health impacts. It should be noted however, that the majority of studies reviewed dealt with a narrow conception of both mining and health.

Most sections of the report summarise the key themes emerging from a number of studies, where we use specific studies these were selected on the basis of the following criteria:

- Study Design
- Original findings
- Specific reviews (meta-analyses) of certain minerals, health outcomes, or policy themes
- Studies reporting on under-investigated themes or regions

We attempted to be systematic within the above framework, but due to time availability this was not an exhaustive literature review, covering extensively both peer-reviewed studies and unpublished "gray" literature. We also were unable to cover all stages of the minerals and mining cycle, or all minerals/metals. However, to supplement our understanding, we also undertook a web-search, again using the keywords we identified for the PubMed search.

1.2 Peer-reviewed literature themes and trends

There were 768 peer-reviewed articles in our first search using "mining and health". By adding more searches, principally using "employment and mining" we increased our database to 923 mining and health related articles. We added to these mineral specific searches and web-searches. The scientific search included many more occupational studies than community studies, and we supplemented the community studies particularly with web-based searches of unpublished or institutional reports. We ended with a total of 996 references. Of these 359 are cited in this desk study.

The peer-reviewed articles included 41 scientific reviews covering specific minerals, policies or manufacturing processes for mined products. These include reviews of epidemiological and toxicological literature on lead (Hodous and Layne 1993)(Cikrt and Bencko 1982); iron oxides (Stokinger 1984); asbestos (tremolite and chrysolite) (Churg 1988; Short and Petsonk 1993; Gibbs 1994; Lippmann 1994); coal (Corn, Breysse et al. 1985; Attfield 1992; Weeks 1993) uranium (Hornung 2001) nickel (Morgan and Usher 1994) and talc (Hildick-Smith 1976).

Reviews also cover the issues of mining and health by long and short term health impact: injuries (Stokinger 1984; Howell, Brown et al. 1990; Hodous and Layne 1993; Short and Petsonk 1993); respiratory impacts (Short and Petsonk 1993) and cancers (Morgan and Usher 1994; Hornung 2001) are covered specifically. There were no overview "mining and health" reviews. Nor does the literature contain comprehensive reviews of the "life cycle" of any one mining process or mineral/metal.

Looked at individually, specific studies in the reviewed papers clustered around themes and regions. Table 1 organises the literature by mineral/metal and region.

Mineral	**Number of Studies**	**Region and comments**
Arsenic	10	UK, East Germany, Brazil, U.S, Russia. Mostly historical studies
Asbestos	79	International, but focused on U.S, Canada and Brazil. Mix of occupational and community studies and debates over chrysolite and tremolite asbestos.
Coal	325	International but with a focus on UK and U.S. Predominantly occupational studies
Copper	16	Mostly U.S – focused on smelting, and extraction processes
Gold	51	Nicaragua, South Africa, U.S, Venezuela, Philippines, Tanzania, Ecuador, Brazil, Colombia. Focused on occupational and community exposures in extraction and processing (particularly mercury exposures).
Lead	54	South Africa, Poland. U.S. Linked to other mineral and metal extraction and to processing.
Mercury	17	Brazil, U.S, Venezuela, China, Philippines. Most studies look at mercury related to Gold mining
Sand and Gravel (silicas)	48	U.S. Canada. Australia. Studies focus on silica, but also sand as part of gold mining, and more generally
Uranium	60	International, but focus on Canada, U.S, and Eastern Europe. Studies cover acute and chronic risks occupationally, and community indirect exposures
Zinc	8	Scattered studies Brazil, Poland. Links to other metals (lead particularly)

Only one study was found related to precious metals (diamond mining) within the PubMed review, although several covered the hazards of diamond cutting (Coutu-Wakulczyk, Brammer et al. 1997) and any literature on the mining of precious gems is drawn largely from web searches.

In many cases it is difficult to break studies down by mineral and metal type, since mines can often source a combination of minerals/metals in one location (for e.g a lead-copper-zinc mine (Chiaradia, Gulson et al. 1997)). With multiple metal/mineral exposures, health impacts are often difficult to detect and several studies cover scientific uncertainty in understanding health impacts related to mining particularly in the longer term (Heederik and Miller 1988; Bang, Althouse et al. 1999; Werner and Attfield 2000).

From the perspective of regional focus, the majority of studies were from the "North", including the United States, Australia, Canada and Europe. But themes were interestingly related with several countries sharing a mining and health concern, for example over mercury and gold mining. Table 2 shows studies by country and by themes in mining and health.

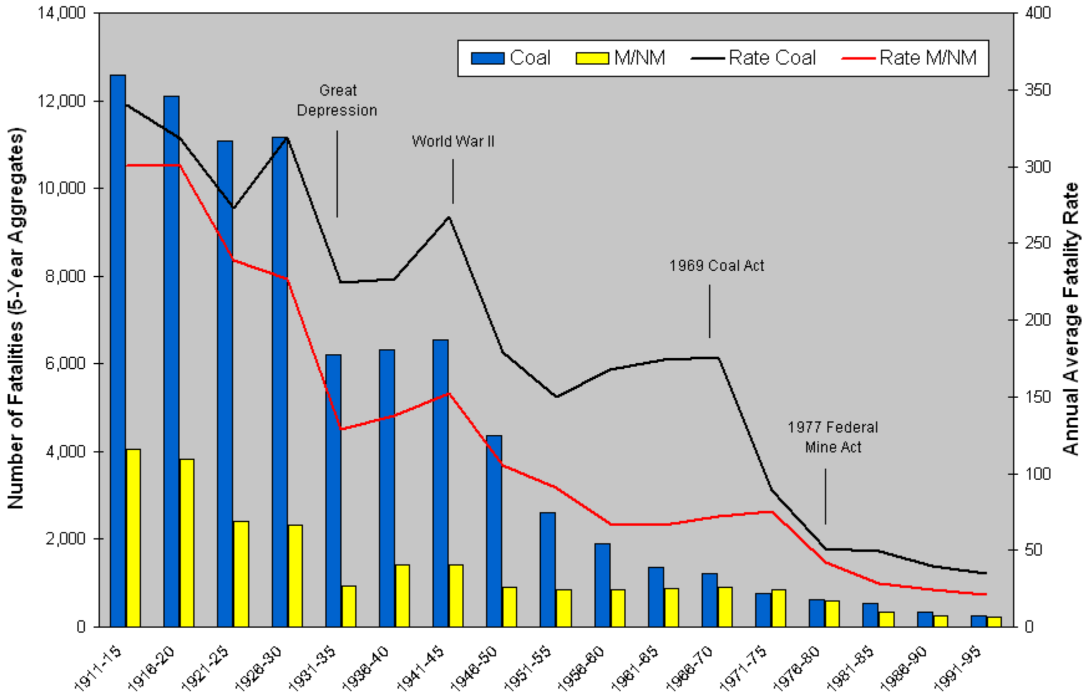
Country	Theme by mining sector
Australia	16 studies covering a range of mining processes and outcomes (inc coal, lead-zinc-copper, iron)
Brazil	8 studies covering gold, asbestos and manganese.
Britain	44 studies largely covering coal mining
Canada	18 studies focused largely on asbestos and some nickel
Germany	23 studies focused on coal and uranium
Italy	6 studies focused on pyrite and marble
Namibia	2 studies on uranium mining
Peru	3 studies, focused on silicon.
Philippines	1 study on mercury in gold mining
Tanzania	2 studies on gold and mercury
United States	148 studies covering coal, mercury, nickel, silica
Zimbabwe	8 studies covering asbestos and the history of labour conditions and health

From the perspective of health impacts, a large number of studies (93) looked at occupational health impacts of mining related to **acute and chronic respiratory disease**. **Neoplasms/cancers** were the second group of outcomes studied (87 studies), again related largely to occupational exposures. An additional 49 studies addressed the problems of **injuries** related largely to occupational exposures in the mining sector. Indirect and long term outcomes to mining related exposures were less rarely studied, but amongst outcomes, **AIDS and sexually transmitted diseases** gain attention, **chronic hypertension**, and **mental health** including **suicides** was discussed. Long-term impacts include studies on uranium (to be reported in the following sections) and impacts on **genetic** health of mineworkers.

The majority of studies focused on negative health impacts related to both worker and community health. This said, several studies discussed improvement in health and safety over time (1973; Zwi, Fonn et al. 1988; 1993b; 1999c), particularly related to worker safety.

2 Worker Health And Safety Issues

Mining remains one of the most difficult, dirty and hazardous occupations- causing more fatalities than other occupations even in the United States or in Europe (2001). However, several historical studies report improved health for mineworkers since the 15th century. There is no doubt that, internationally, conditions have improved from times of bonded or slave mine labour. Things have changed too from times when miners were working and living without hygiene or safety in all parts of the sector – conditions that authors from North and South describe in their historical studies (Koba 1968; 1969; Hurwitz 1972; Phimister 1976; Coetzee 1979; Shy 1979; Brozek 1984; Kapronczay 1986; Bale 1988; Enderle and Friedrich 1995; 1999c; Fowler 2000). Things in the long term have changed too from the days of pit canaries. Information has improved and to an extent, disempowered workers have gone through a phase of empowerment in some regions.



Number of fatalities (five-year aggregates) and annual average fatality rates in the mining industry by commodity and year, 1911-1995. Annual average fatality rates are calculated per 100,000 workers and plotted by five-year periods. M/NM includes Metal, Nonmetal, Stone, Sand and Gravel.

This has had knock-on effects on miner health, in part through improved use of epidemiological information by workers to improve safety and reduce exposures to occupational hazards (Kerr 1990; Derickson 1991; Mulcahy 1999). Figure 2 shows improvements in mining health and safety in the United States between 1911 and 1995 (Source http://www.cdc.gov/niosh/mining/default.htm). Today, mining labour and health conditions are changing once again, as the mining sector experiences the impacts of so-called "globalisation" with its effects on labour stability and employment, and knock-on effects on mental health of miners and ex miners (Wasserman 1999) .

In terms of scientific evidence, despite studies showing long term historical improvements, particularly in the middle of the last century, the bulk of the literature focuses on the continued burden of largely preventable health impacts that mine workers sustain not just in their working life but beyond into their old age. Studies testify that mining continues to be a primarily male dominated profession, needing to employ principally able-bodied individuals to undertake arduous risky work. Health and safety risks differ according to where the mines are, what products are being mined; who is involved and what processes are used. In different countries women and children may be involved in mining (Smidt, Mohamad et al. 1974; Cocco, Carta et al. 1994; Harari, Forastiere et al. 1997; Wasserman 1999), and depending on what product is mined, and mining conditions, risks change.

Section 2 summarises international literature related to mining worker health and safety. Section 2.1 first covers health and safety risks from the perspective of different characteristics of the mining process. We start by looking at risks by mineral type, selecting important minerals and metals in relation to their health consequences. The section then summarises literature according to different size of mines (e.g. in small-scale and large-scale mining); and different nature of mines (e.g. open cast and underground mines).

Section 2.2 looks at the literature from the perspective of direct and indirect health impacts, identifying the key health impacts for the sector as a whole, rather than by subsector. In a sense this obviously covers some of the same ground, but it draws out the key health issues looking at: respiratory impacts; injuries; cancers; mental health and intergenerational impacts.

2.1 Health and safety risks related to different type of minerals

It is not easy to separate out health and safety issues related to specific minerals, except in certain major cases (such as asbestos or coal). In many cases, the types of materials mined and their associated health effects are complex and interrelated. For example, studies focusing on the silicates attempt to distinguish fibrous silicates such as asbestos, asbestiform fibrous minerals such as wollastonite and fuller's earth, and non-fibrous silicates such as talc and kaolin (Short and Petsonk 1993). However, mines may contain a mixture of minerals and the primary substance mined may not in some cases form the primary health hazard for mine workers in those mines. A lead-zinc-copper mine will create a complex set of occupational exposures and it is difficult to separate individual mineral impacts for all minerals. Further, for some mined products, health and safety hazards do not come from the product itself but from the use of hazardous materials in the extraction and processing stages. We have chosen 4 minerals to illustrate the complex pattern of occupational risks associated with different stages of the mining cycle: asbestos, coal, gold and uranium. Finally, it is difficult to separate health from safety in a mineral specific review since, to an extent, safety issues are generic to mine type and scale, and less to mineral or metal mined. Where this is not the case studies are cited to show mineral specific safety issues (for example in coal mining).

2.1.1 Asbestos

Asbestos is the name for a group of naturally occurring silicate minerals that can be separated into fibres. The fibres are strong, durable, and resistant to heat and fire. There are several types of asbestos fibres, of which three have been used for commercial applications: Chrysotile, or white asbestos, comes mainly from Canada, and has been very widely used in the U.S. It is white-gray in colour and found in serpentine rock. Amosite, or brown asbestos, comes from southern Africa. Crocidolite, or blue asbestos, comes from southern Africa and Australia. We selected "asbestos" as a whole, since it has been studied as a key mineral for its properties as a dangerous fibrous silicates. Dusts from other silicates show similar occupational health impacts, but have not achieved the notoriety of asbestos.

See Armstrong, De Clerk et al 1988

Asbestos has been mined for centuries and known to be hazardous since the beginning of the 20th century. Since 1999 the Collegium Ramazzini has called for a ban on all mining and use of asbestos, supported by international journals of occupational and environmental health(1999a; 1999b). Currently health outcomes related to occupational and "community" or environmental exposures to asbestos form one of the most significant insurance claims in the world, and have been responsible for the collapse of a major British insurance group, and the loss of an international law suit at the World Trade Organisation.

59 studies in this review focus on asbestos mining and principally occupational exposures. Studies are international, including from South Africa (Sluis-Cremer 1970; Davies, Landau et al. 1988; Zwi, Reid et al. 1989; Sluis-Cremer 1991), Russia (Tossavainen, Riala et al. 1999), Brazil (Berman 1986), Quebec (McDonald, McDonald et al. 1971; McDonald, Becklake et al. 1974; Becklake, Thomas et al. 1982; McDonald, McDonald et al. 1999), and Australia (Armstrong, de Klerk et al. 1988). Both men and women have been employed in asbestos mining. For example one study found was of 6505 men and 411 women were employed in the mining and milling of crocidolite at Wittenoom in the Pilbara region of Western Australia between 1943 and 1966. Employment was usually brief (median duration four months) and exposure intense (median estimated cumulative exposure 6 fibres/cc years). Statistically significant excess death rates were observed in men for neoplasms, particularly malignant mesothelioma (32 deaths), neoplasms of the trachea, bronchus, and lung (SMR 2.64), and neoplasms of the stomach (SMR 1.90); respiratory diseases, particularly pneumoconiosis (SMR 25.5); infections, particularly tuberculosis (SMR 4.09); mental disorders particularly alcoholism (SMR 4.87); digestive diseases, particularly peptic ulceration (SMR 2.46) and cirrhosis of the liver (SMR 3.94); and injuries and poisonings, particularly non- transport accidents (SMR 2.36) (Armstrong, de Klerk et al. 1988).

Asbestos mining internationally has been found to create occupational health risks for miners and mineworkers in related processing industries. The earliest data on the hazards of asbestos came from mine workers in the extraction process, but gradually it became clear that workers in all asbestos-using industries also showed signs of health impacts. The majority of studies focus on asbestos as a hazardous mined product and safety issues relate to exposure through breathing in asbestos particles in and around the mines. The most severe occupational exposure is that with the greatest contact with the asbestos particles in respirable form. Along with coal and other silicate dusts, the dangers of asbestos mining relate largely to damage to respiratory function and lungs.

Specialists continue to debate over which is the most hazardous of the 3 main asbestos types (Churg 1988) (Hwang 1983; Orenstein and Schenker 2000), but there is a growing scientific consensus that asbestos, in all forms, can be linked to acute and chronic health outcomes. Reduced respiratory performance, pleural plaques and gradual disability are the subject of several studies (Enarson, Embree et al. 1988; Case and Sebastien 1989; Kullman, Doak et al. 1989; Fitzgerald, Stark et al. 1991; Phoon 1998; Range 1998; 1999a; 1999b; Orenstein and Schenker 2000).

Asbestosis is an irreversible, progressive lung condition resulting from the inhalation of asbestos fibres over an extended period. In asbestosis, lung tissue is scarred and thickened by the abrasive action of the asbestos fibres in the alveoli (or air sacks). The latency period for asbestosis is usually at least ten years and the higher the exposure, the greater the chances of developing the disease. Asbestosis tends to be linked to heavy occupational exposure, not just within the extraction stage of the mining cycle, but also in mineral use, trade and consumption (Sluis-Cremer 1970; McDonald, Becklake et al. 1974; Case 1991; Sluis-Cremer 1991) (McDonald 1985). Mesotheliomas and lung cancers are the third group of asbestos-related impacts (Churg 1988; Zwi, Reid et al. 1989; Lippmann 1994).

Studies focus not only on asbestos mines, but on mines extracting other minerals in which asbestos has been encountered (Fitzgerald, Stark et al. 1991; Kullman, Greife et al. 1995) (Case 1991; Nolan, Langer et al. 1999). In these studies the complex links of asbestos with other minerals particularly silicates such as talc, confound study findings on health impacts. However, some studies do find health impacts in workers (McDonald, McDonald et al. 1988) and others show levels of ambient contamination that could lead to such impacts (Nolan, Langer et al. 1999) .

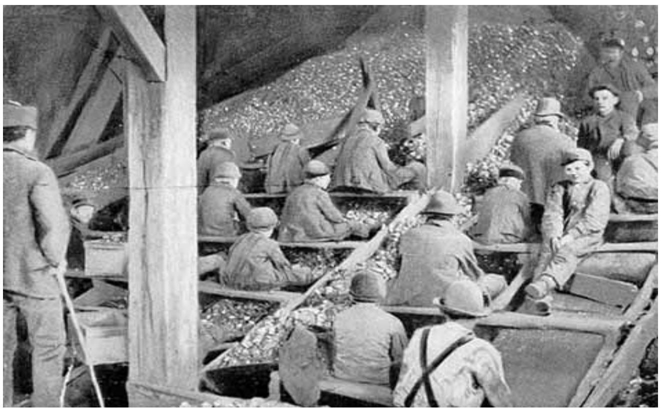
2.1.2 Coal

Coal mining has been known as harmful to workers' health for at least a century. Coal is another mineral whose dust, particularly in the process of extraction, has severe impacts on worker health. Coal mining is the subject of a huge range of studies. These are principally, but not exclusively, focused on Europe and North America.

Over two hundred and fifty studies in this review discuss coal mining and its risks to occupational health and safety. 25 studies look at the history of coal mining and health (Shtrom 1979; Smith 1981; Brozek 1984; Kirchgessner 2000).

One historical study looks at changes over time in the risk "from explosions to black lung", highlighting the changing nature of health and safety risks for coal miners (Weeks 1993). Explosions in coalmines were common historically, due to release of gases. So-called "pit canaries" were used to detect these gases and warn the miners. Often young children were employed in the mines, as today they still are in some countries in the South.

Gradually over time, the birds were replaced by other technologies and fatalities due to explosions were replaced by the chronic diseases due to coal (and other silicates) dust inhalation during mineral extraction.



Coal Breaker Boys in Ohio Early 20th Century
Source: http://www.history.ohio-state.edu/projects/coal/BreakerBoys/breakerboys.htm

Although fatalities and injuries have declined over time, they are still the subject of several studies (Watson and White 1984; Asogwa 1988; Hunting and Weeks 1993; Lee, Anderson et al. 1993; Bell, Gardner et al. 2000). These show a variety of findings: one study (Hunting and Weeks 1993) reports on age-related injuries with younger men more likely to be injured, another study (Bell, Gardner et al. 2000) found that cold exacerbated risk of injury for coal miners, and another (Hunting and Weeks 1993) found that smaller coal mines showed higher risks, linked to length of experience of the miners in these mines.

Despite the continued importance of occupational injuries in coal mining, it is respiratory impacts due to inhaled mined coal dust particles which now form the bulk of studies and the key health risk related to coal mining. 40 studies and reviews look at the major short and long term respiratory impacts associated with coal mining. Coal mine dust exposure is associated with accelerated loss of lung function (Soutar and Hurley 1986; Henneberger and Attfield 1997; Love, Miller et al. 1997; Beeckman, Wang et al. 2001). Chronic Bronchitis is the subject of several studies (Gilson 1970; Love, Miller et al. 1997) but Pneumoconiosis and Silicosis are the most severe outcomes related to coal dust exposure by mine workers. Studies show that up to 12% of coal miners develop these fatal diseases. For example, the U.S National Study of Coal Workers' Pneumoconiosis (NSCWP) (Attfield and Morring 1992) found that between 2% and 12% of miners exposed to a 2-mg/m3 dust environment in bituminous coal mines would be expected to have Category 2 or greater coal workers Pneumonconiosis after a 40-yr working life; and progressive massive fibrosis would be expected for between 1.3% and 6.7%. The risks for anthracite miners appeared to be greater. Another U.S study of 3,365 autopsied underground miners found classical silicotic nodules in 12.5% of the miners. There was a significant relationship between length of underground mining and prevalence and severity of silicosis consistent with a dose-response effect. The study also showed that job category and geographic location of the mine were important determinants of silicosis prevalence and that silicosis was strongly associated with higher categories of coal workers' pneumoconiosis (Green, Althouse et al. 1989). Although some studies report declines in prevalence of both pneumoconiosis and silicosis in the U.S, the burden remains high (Goodwin and Attfield 1998).

Studies show that the occupational hazards related to coal mining have caused massive losses to worker health status and excess mortality both in the short and long term. Several studies question the use of this energy source on the basis of its health impacts (1980; Beeckman, Wang et al. 2001) despite the employment benefits the sector has always brought. The next section looks at a precious metal where the hazard lies in the processing stages of the mineral cycle and not in the extraction of a hazardous mineral product.

2.1.3 Gold

More than 45 studies look at gold mining and worker health internationally: from Australia, the U.S, South Africa, Brazil, the Philippines, Tanzania, Venezuela, and Ecuador (Alexander 1970; Bradshaw, McGlashan et al. 1982; de Klerk and Musk 1998; Malm 1998; Tirado, Garcia et al. 2000; Drasch, Bose-O'Reilly et al. 2001; Rojas, Drake et al. 2001).

Gold mining and the processes of extraction of the gold from ore have been in existence for centuries. Unlike the products that we have looked at so far, gold *extraction* is not the only stage of the mining process to create hazardous exposures for workers (and communities as we will discuss later). According to Malm (Malm 1998) in his study of mercury intoxication in Brazilian gold-mining "amalgamation has been used for more than 4500 years in mining processes. Mercury has been extensively used in South America by Spanish colonizers for precious metal recovery. It is estimated that between 1550 and 1880, nearly 200,000 metric tonnes of mercury was released to the environment. During the present gold rush, Brazil is first in South America and second in the world in gold production (with 90% coming from informal mining or garimpos). At least 2000 tonnes of mercury has been released to the environment in the present gold rush".

Conditions in goldmining vary considerably from country to country. In several countries of the South, a substantial proportion of gold-mining occurs in small scale operations and in informal work settings. For example, in the Philipines "the ore is dug in small-scale mines and ground to a powder by ball-mills. The gold is then extracted by adding liquid mercury (Hg), forming gold-amalgam. To separate the gold from the Hg, in most cases the amalgam is simply heated in the open by blow-torches" (Drasch, Bose-O'Reilly et al. 2001).

Due to the informal nature of gold-mining in the South, most studies focus on mercury exposure and intoxication incurred in the extraction and processing stage of mining (Camara, Filhote et al. 1997; Malm 1998; Harada, Nakachi et al. 1999; Tirado, Garcia et al. 2000; van Straaten 2000a; Rojas, Drake et al. 2001). Results of studies indicate patterns of mercury intoxication during the gold amalgamation process (Camara, Filhote et al. 1997; Tirado, Garcia et al. 2000; van Straaten 2000a; Drasch, Bose-O'Reilly et al. 2001). Most studies involve small numbers and are thus vulnerable to bias, but some attempt more rigorous design. For example, in one site in the Philippines a study of 102 workers (occupationally Hg burdened ball-millers and amalgam- smelters), 63 other inhabitants (exposed from the environment), 100 persons, living downstream of the mine, and 42 inhabitants of another site (serving as controls) was undertaken. Bio-monitors and medical scores for both workers and the surrounding communities were taken. The authors report that "By this method, 0% of the controls, 38% downstream, 27% from Mt. Diwata, non-occupational exposed and 71.6% of the workers were classified as Hg intoxicated"(Drasch, Bose-O'Reilly et al. 2001). Another study in Tanzania with a similar design found lower levels of intoxication and a more complex mix of mining related and environmental exposures to mercury through household items such as soap (Harada, Nakachi et al. 1999). One study in Ecuador reports levels of intoxication in children involved in "gold washing" (Harari, Forastiere et al. 1997). One study in Venezuela found no mercury intoxication, despite occupational and community exposures (Rojas, Drake et al. 2001).

Gold mining has also received attention in terms of the risks of overall mine environment conditions, particularly related to AIDS in South African gold miners (Campbell 1997; Corbett, Churchyard et al. 2000). Gold miners do not escape the risks of silica dusts in mines and several studies deal with this. In one major U.S study, (Steenland and Brown 1995) of 3330 gold miners who worked at least 1 year underground from 1940 to 1965 (average 9 years) and were exposed to a median silica level of 0.05 mg/m3 (0.15 mg/m3 for those hired before 1930), 170 cases of silicosis were determined from either death certificates or two cross-sectional radiographic surveys. After adjustment for competing risks of death, the authors calculate that a 45- year exposure under the current U.S standards (OSHA) would lead to a lifetime risk of silicosis of 35% to 47%. Some older studies do not show this relationship (Hessel, Sluis-Cremer et al. 1990), but detailed studies from Australia, on a cohort of 2,397 goldminers, show a similar relationship of gold-mine exposure to silica and silicosis (de Klerk, Musk et al. 1995; de Klerk and Musk 1998). One recent South Africa study of 2255 gold mine workers reports the complex interaction of long term exposure to silicon dust, silicosis and pulmonary tuberculosis (PTB). The researchers found that exposure to silica dust is a risk factor for the development of PTB in the absence of silicosis, even after exposure to silica dust ends. The risk of PTB increases with the presence of silicosis, and in miners without radiological silicosis, with quartiles of exposure to dust (Hnizdo and Murray 1998).

A final study in this section links gold mining to radiation risks and shows the complexity of the occupational risks faced by miners, both from the products they mine, the processes they use and the other products they encounter as they mine. Kusiak et al studied mortality in 54,128 men who worked in Ontario mines between 1955 and 1986. Most of these men worked in nickel, gold, or uranium mines; a few worked in silver, iron, lead/zinc, or other ore mines. The researchers excluded deaths that occurred after a man had started to mine uranium, and found "an excess of lung cancer among the 13,603 Ontario gold miners in the study (standardised mortality ratio (SMR) 129, 95% confidence interval (95% CI) 115-145), and in men who began to mine nickel before 1936 (SMR 141, 95% CI 105- 184). The excess mortality from lung cancer in the gold miners was confined to men who began gold mining before 1946. In the gold mines each year of employment before the end of 1945 was associated with a 6.5% increase in mortality from lung cancer ***20 or more years after the miner began working the mines*** (95% CI 1.6-11.4%); each year of employment before the end of 1945 in mines in which the host rock contained 0.1% arsenic was associated with a 3.1% increase in lung cancer ***20 years or more after exposure began*** (95% CI 1.1-5.1%).....The excess of lung cancer mortality in Ontario gold miners is associated with exposure to high dust concentrations before 1946, with exposure to arsenic before 1946, and with exposure to radon decay products" (Kusiak, Springer et al. 1991). In terms of this review, the most disturbing feature of this study is its evidence of the complex and long term impacts of multiple exposures of miners on their health, and the fact that the impacts of past exposures may be felt long into the future of a miner's life.

2.1.4 Uranium

Uranium mining merits over 50 international studies, many from Eastern Europe and the former Soviet Union (Nedvidek, Cermak et al. 1982; Fatkova 1989; Schuttmann 1993; Enderle and Friedrich 1995), and from the United States (Newcombe, Smith et al. 1983; Hornung and Meinhardt 1987; Roscoe 1997; Hornung, Deddens et al. 1998; Langholz, Thomas et al. 1999). One study covers the risks of uranium mining in Namibia (Zaire, Griffin et al. 1996; Zaire, Notter et al. 1997) and another in New Mexico (Lerchen, Wiggins et al. 1987).

Uranium mining has a long history, but most scientists recognise that it is only for the last 30 years that the health effects of occupational exposures to radiation in mines has been discussed fully. Many of the studies focus around lung cancer, the risks of which are only now being evaluated more fully. This type of radiation-induced occupational cancer now appears to be one of the most important radiation injuries known to occur among workers occupationally exposed to ionizing radiation. Uranium mining creates risks in 2 ways, through dusts and through released radon - a radioactive gas of natural origin. Radon's principal isotope is radon-222, stemming from uranium-238 present at various concentrations in all soils. Radon is found everywhere in the earth's atmosphere but has low reactivity by itself. However in the process of mining, dusts get inhaled by miners. For example, as one study reports on East German Uranium mines "In some mines in the past there was drilling with air floating and a lack of forced ventilation. Dust levels were very high and there was a significant inhalative incorporation of alpha- radiating substances, mostly from short-lived radon progeny. However, long-lived alpha-radiating substances such as uranium-238 contributed considerably to the radiation dose" (Enderle and Friedrich 1995). Radon particulate daughters are responsible for alpha irradiation of the bronchial epithelium. Epidemiological studies on miners indicate that radon exposure causes an increased risk of lung cancer in these workers but "how much?" and "how?" is still under investigation.

Uranium mining presents a complex worker health and safety problem: studies in the 1990s and to date are only **now** finding out the nature of risks that men experienced in mines in the 1940s. Several studies look rates of lung cancer in men who were working in uranium mines more than 20 years before the onset of their disease (Roscoe, Steenland et al. 1989; Woodward, Roder et al. 1991; Enderle and Friedrich 1995; Roscoe 1997; Kreuzer, Grosche et al. 1999; Langholz, Thomas et al. 1999). Several authors highlight the fact that the health impacts they evaluate today reflect exposures during times of lower standards. Papers discuss that standards for uranium mining have changed incrementally as more evidence has been brought to bear on the dangerous nature of the uranium mining for workers – Pearson call this the changing nature of "hazard visibility"(Pearson 1980; Lambert 1991; Enderle and Friedrich 1995). Only one study in this review reports nonconclusive findings of uranium mining and lung cancer and other risks (Polednak and Frome 1981) and even this paper calls for more long term studies.

One historical paper on the Soviet uranium mines in the Erzgebirge of Saxony in the former German Democratic Republic tracks the long history of occupational injury from radiation in uranium mines (Schuttmann 1993). The paper discusses bronchial or alveolar carcinomas caused by effects of the radioactive gas radon and of its radioactive short half-life daughter products. Schuttman reports that "the history of disease in these miners extends over five centuries; the first observations of their health hazard start in the Middle Ages. The discovery of the lung cancer component was made toward the end of the nineteenth century, and the suspicion that a connection might exist between this cancer type and exposure to ionizing radiation was voiced at the beginning of the twentieth century. In the first half of this [20th] century, further research was carried out on this disease in the Schneeberg area of the Erzgebirge. Before the end of World War II, guidelines were set up to define the acceptable limits of radon exposure in the ore mines of Saxony. After World War II, the American uranium mines in the Colorado Plateau used the German research results as a basis for working out their own radiation protection standard. The uranium mines under Soviet occupation in the former GDR, on the contrary, paid no attention to these research findings. For many years, no precautions were taken for the miners' working conditions. The consequence of this serious omission was an estimated 9,000 fatal cases of lung cancer among these underground miners". Enderle and Friedrich report that in an East German Uranium mine "more than 5,000 cases of bronchial carcinoma are accepted as compensable occupational diseases and more are expected"(Enderle and Friedrich 1995).

A recent review paper (Hornung 2001) of the heath risks of uranium mining reports that "lung cancer caused by exposure to radon decay products is the primary hazard to underground uranium miners". The review summarises studies of eight cohorts of radium miners, and several pooled analyses. As with many of the cohort studies, the author finds that relative risk of lung cancer is linearly related to cumulative exposure to radon decay products. The review finds that excess risk decreases with attained age and time since exposure. In addition, prolonged exposure at low levels of radon appears to be more hazardous than shorter exposures to higher levels (Hornung 2001). This review is only one of several huge cohort studies, of up to 60,000 miners in each study from Autralia, Germany and the United States (Kusiak, Springer et al. 1991; Woodward, Roder et al. 1991; Kreuzer, Grosche et al. 1999). Many of studies report the extreme complexity of assessing historical exposures, and differ in their assessment of the extent of excess risk experienced by uranium miners in comparison to the general population or to other industries. Most find relative risks of lung cancer between ***2 and 5 times higher*** in uranium workers who have been exposed to higer levels of radon, or to longer periods of low exposure (Kusiak, Springer et al. 1991; Woodward, Roder et al. 1991; Tomasek, Darby et al. 1994). Some studies put these risks at levels much higher (Gilliland, Hunt et al. 2000)

A small number of studies explore a further health impact associated with uranium mining: effects on genetic integrity of workers. There are very few studies of this. However, one study in Namibia followed a cohort of 75 non-smoking, HIV-negative miners and compared them to a control group of 31 individuals with no occupational history in mining. A sixfold increase in uranium excretion among the miners compared to the controls was recorded. The authors also determined "a significant reduction in testosterone levels (P 0.008) and neutrophil count (P 0.004) in miners compared to the unexposed controls. A threefold increase in chromosome aberrations in the miners compared to the nonexposed controls was recorded (P 0.0001). Most remarkably, cells with multiple aberrations such as "rogue" cells were observed for the first time in miners; these cells had previously been found only after short-term high-dose radiation exposure, e.g. from the Hiroshima atomic bomb or the Chernobyl accident. We conclude that the miners exposed to uranium are at an increased risk to acquire various degrees of genetic damage, and that the damage may be associated with an increased risk for malignant transformation. As expected, the chronic radiation injury of the hematopoietic system resulted in low neutrophil counts. Also, low hormone levels probably reflect damage to the gonadal endocrine system"(Zaire, Notter et al. 1997). The Namibia study is based on small numbers. However, other authors mirror the concerns of Zaire et al. and reflect on the uncertain long-term implications for both workers and communities of mining uranium and of processing and using it as an energy source (Kerr 1977; Reif and Andrews 1995; Bard, Tirmarche et al. 2000; George and Bredhoff 2001).

2.2 Health and safety risks related to different scales of mining operation (small and large)

There are very few peer-reviewed studies focused on the differences in health and safety according to scale of mining operations. The studies that exist tend to focus on mining operations that are, by their nature and location, currently small scale and hazardous. Thus many of the papers reported in the section on gold-mining, report health and safety risks in small scale surface gold mining (van Straaten 2000a; Drake, Rojas et al. 2001; Drasch, Bose-

O'Reilly et al. 2001). This appears to reflect both technical and scientific issues related to small scale mining. For example small scale mining tends to be informal and located in remote regions. Many longitudinal or largescale studies of workers health use routine statistics, which, of course, are not available and/or not reliable in many settings of small scale mining. Health and safety risks according to scale of mine also link to the next section on types of mine – and both relate to the mineral-metal being extracted. Deep mines tend not to be small scale. The depth of mines is also linked to the mineral mined. Large mines, even deep ones, tend to have better data on health and safety, and sometimes, have better occupational conditions.

The relationship between size of mines and health and safety risks is complex. One study in the U.S reports that smaller mines consistently report lower rates of injuries. But smaller mines also show evidence of higher rates of fatalities suggesting problems with reporting of injuries in smaller mines. Smaller mines also have a higher turnover of staff, and decreased availability of occupational safety services in small companies. Moreover, injury severity, as measured by missed worktime, is greater for workers in small mine operations (Oleinick, Gluck et al. 1995). A U.S study looked at transport related injuries in small-scale coal mines. The results showed higher rates of injury in smaller mines. However on further analysis the authors found "a disproportionately high risk of injury among workers in their first year at a mine and indicated that higher injury risk in small mines might be explained by the fact that workers at small mines have substantially less experience than workers at large mines. An effect of age was not found in these analyses. These results suggest the potential importance of targeted training programs for newly hired miners. Results also point to the need to explore specific factors contributing to the small mine injury risk, and to the necessity for complete and accurate reporting of injury data" (Hunting and Weeks 1993). Another study looking at large and medium scale coal mining in the UK found no differences in risks of respiratory disease between workers in different mines, but did find that different workers experience different dust conditions and those with dustier occupations had higher health risks (Love, Miller et al. 1997).

Going back to gold mining, in which both small and large scale mines exist, the evidence reveals the inter-relationship of scale of mines, to nature of mine and involvement of workers in the mining cycle. Studies on small scale gold mines tend to focus on the extraction-processing nexus where workers both extract then work on processing with mercury. These small scale mines do not tend to be underground, and health and safety risks focus on the processing stages (Camara, Filhote et al. 1997; Malm 1998; Harada, Nakachi et al. 1999; Drasch, Bose-O'Reilly et al. 2001). In the larger-scale gold mines, the studies do not deal with mercury exposure at all as the workers in the mines are separated from this processing stage. Studies instead focus on underground exposure to other products, such as silica, in the gold extraction stage and discuss risks of silicosis and lung cancers (Hessel, Sluis-Cremer et al. 1990; Amandus and Costello 1991; Kusiak, Springer et al. 1991; de Klerk and Musk 1998). In these cases it is the interaction of scale of mine with nature of mine that is most relevant to health and safety risks.

This complexity is not true of all minerals extraction processes. Coal mining for example can operate at a range of scales, but the process is roughly similar. In this case the health and safety risks differ by nature of mine and scale of mine operation is a less important issue.

2.3 *Health and safety related different types of mine (open cast and deep)*

Studies do not divide easily into clear "typologies" of mine process, with differentiation into open cast or deep mines. Health and safety issues relate more to the minerals encountered in the mine, and the worker protection from risks, particularly from respirable hazardous dusts whether in deep mines or surface ones. But one can see patterns of studies and health risks: surface mine studies concentrate on dust and respiratory risks; deep mine studies look at heat and pressure and link this to a range of health outcomes including occupational heat stress, blood pressure and hypertension.

Staffordshire Coal Mining, UK Source: http://www.archive.sln.org.uk/exhibit/coal/default.htm

There are around 20 studies looking specifically at occupational health in deep mines. Many of these studies come from the ex Soviet Union and Eastern Europe where deep copper, diamond and ore mines are common. Authors report severe problems for workers in terms of their risks of high blood pressure; heat exhaustion; myocardial infarction and nervous system disorders (Onopko, Vinarik et al. 1974; Alekperov, Melkumian et al. 1983; Kobets, Perederii et al. 1990; Kobets, Kopytina et al. 1991) Valutsina and Tkachenko report on heating microclimates in deep coal mines. They found that "individuals of medium and senior age groups appeared to have significantly more frequent cardiovascular and thermoregulatory disorders than in the same age groups in normal climate. High temperature impairs autonomic nervous system, which presents hyperactivity of sympathicus and marked vegetative reactions in all ages, especially in the young workers"(Valutsina and Tkachenko 1994). Donoghue and Bates recently looked at body mass index and heat exhaustion in deep underground metalliferous mines (Donoghue and Bates 2000). They found that heat exhaustion correlated with BMI but recommended that refrigeration and air conditioning were the solutions to the health risks of heat in deep mines – rather than the selection of lower BMI miners. Another study corroborates this, looking at air conditioned cabins and resting chambers in deep copper mines. The results of their examinations (Holter heart rate and continuous blood pressure recordings, external and core temperature measurements) revealed that during the work (particularly during the increased work- load) all parameters recorded were significantly lower in air- conditioning cabins as compared with the group working without air- condition (Borodulin-Nadzieja, Janocha et al. 2001).

There are around 20 studies of surface mining and its hazards. Many studies of surface mining focus on coal, granite and rock mining and health risks related to dust inhalation. In all levels of mining health risks occur with dust exposure. There has been some controversy over whether surface mining such creates dust hazards for workers. In 1977, a

U.S study found little evidence of respiratory impacts for surface coal miners (Fairman, O'Brien et al. 1977). However, 10 years later other studies of surface coal miners found that men working in particularly “dusty” occupations were at potential risk of silicosis and respiratory impairment due to respirable quartz fragments. The studies found that drillers, and to a lesser extent, bulldozer drivers, were at highest risk (Banks, Bauer et al. 1983; Amandus and Piacitelli 1987; Amandus, Petersen et al. 1989; Piacitelli, Amandus et al. 1990). One study in Labrador in an iron ore surface mine, found similar results for risk of pneumoconiosis in surface mine workers (Martin, Muir et al. 1988). Peterson and Henmar found that oral health of surface workers in a Danish granite quarry was extremely poor due to abrasion by quartz dust leading to high levels of oral disease and decay in miners (Petersen and Henmar 1988).

2.4 Direct and indirect impacts on workers and their health

Having looked at occupational health and safety from the perspective of mines and their characteristics, this section looks at the overall mining sector and at the key occupational health impacts incurred in the sector.

2.4.1 Respiratory impacts

Around 130 studies look at respiratory impacts related to mining of a variety of minerals including asbestos (McDonald, McDonald et al. 1971; McDonald, Becklake et al. 1974; Hobbs, Woodward et al. 1980; Beritic-Stahuljak, Valic et al. 1991), or silica in different forms(Elmes 1981). A small number of studies discuss the importance of smoking as a risk factor that exacerbates respiratory impacts in mineworkers. For example, in the UK until new regulations were introduced in the late 1970s conditions existed among asbestos workers in which the combined effect of cigarette smoking and dust exposure led to a loss of life expectation of over 10 years in moderate smokers (Elmes 1981). Several studies focus on the respiratory problems related to asbestos or silica exposure to miners mining other products (Raithel, Weltle et al. 1989; Sebastien, McDonald et al. 1989; Short and Petsonk 1993).

A recent U.S study looked at coal mine dust exposure, which is associated with accelerated loss of lung function (Beeckman, Wang et al. 2001). The study determined vital status for 561 miners, and obtained a follow-up questionnaire for 121 cases and 143 referents. Cases showed a greater incidence of symptoms than did referents for cough, phlegm production, Grades II and III dyspnea, and wheezing, and greater incidences than referents of chronic bronchitis and self- reported asthma and emphysema. More cases than referents (15% versus 4%) left mining before retirement because of chest illnesses. After controls were applied for age and smoking, cases had twice the risk of dying of cardiovascular and non-malignant respiratory diseases and a 3.2-fold greater risk of dying of chronic obstructive pulmonary disease than did referents. Rapid declines in FEV1[3] experienced by some coal miners are associated with subsequent increases in respiratory symptoms, illnesses, and mortality from cardiovascular and non-malignant respiratory diseases (Beeckman, Wang et al. 2001).

[3] A measure of forced expiratory volume in 1 second

One interesting study from Chile looked at medical and non-medical absenteeism among male workers performing rotative shifts in a high altitude mining company. The study found a general rate of absenteeism of 8.8 absent days per 100 labour days, which means that 31.8% of the total labour force was absent every month. Absenteeism due to medical causes corresponded to a mean of 85% of total lost days during the four years of the study. Common diseases (digestive, respiratory, and osteo-muscular diseases, traumatisms and poisonings) accounted for 84.3% of lost days. Among these, ***respiratory diseases*** had the higher prevalence and traumatisms and osteo-muscular diseases the higher severity (with values over 10 days off). The production areas and people working in shifts had the higher prevalence of medical absenteeism. The numbers of days off for medical causes almost doubled during the four-year period and in 1988 represented 14% of all the salaries paid during the year (Cantuarias and Cornejo 1993).

2.4.2 Injuries

Studies on miners' health show a consistent decline in injuries internationally. However, although chronic long-term occupational health impacts are among the most critical to both workers and, perhaps, industry sustainability, it is injuries that have always produced the greatest burden in mining in terms of fatalities *in* mines.

Over fifty studies look at injuries in mines and the extent of death and disability these bring. The majority were from Europe and the U.S, with a few outside this region (1973; Bellucci, Ligeri et al. 1989; Fatchett 1989; 1993a; 2001). In the U.S, mining continued to have the highest fatality rate of all industries according to 1990 studies of the trend, despite overall improvements in rates over time (Bell, Stout et al. 1990). In another study the same team found that proportionate injury ratios of slips and fall-related injuries increased as temperature declined for all three work locations studied. Proportion of slips and fall-related injuries that occurred while running/walking increased with declining temperature, with the ground outside as the most common source of these injuries (Bell, Gardner et al. 2000).

In one of the few studies outside Europe, Asogwa looked at injury trends in the Nigerian Coal Corporation, which started operations in 1916. In October 1977 introduced full mechanisation at its coal mine in Enugu. An appraisal of the mining accidents between 1975-1980 showed an overall downward trend following mechanisation, from 1073 per 1000 in 1975 to 425 in 1980 (a 60% reduction). The underground accidents were reduced from a monthly average of 63 to 26 but those at the surface remained basically unaffected. Changes were also recorded in sickness absence indices, with the most significant occurring with respect to the severity index, which dropped from 9.2 in 1975 to 3.0 in 1980. The distribution of injury remained essentially the same except that injuries to the upper limbs became more common than the more serious pelvic injury prior to mechanisation (Asogwa 1988). There are few other studies that look at injuries in African settings – and authors point to the extreme difficulty of using information on injuries in all settings – particularly in the context of changing policies and interventions (Loewenson 1999).

One study looked at injuries for women miners in the U.S (Watson and White 1984). This study analysed the 1978-1980 accident history of female coal miners collected by the Mine

Safety and Health Administration (MSHA). It found that approximately 4% of all female coal workers were involved in a lost-time accident as compared to 7% for males; female workers lost approximately 1.1 days each as compared to 2.4 days for males; and 0.01% of the female work force were fatally injured as compared to 0.05% among males. Most injuries to both female and male workers involved back sprains. The majority of remaining injuries are sprains and fractures to joints and bones of the limbs (Watson and White 1984).

Several studies look at the transition of occupational health in mines from injuries to respiratory and other long-term occupational health impacts. Studies in Morocco report falls in injuries and increases in respiratory impacts (Laraqui, Caubet et al. 1999). Studies in the U.S.A and Europe report the same trend. However, several authors continue to cite in injuries as one of the most important occupational health and safety issues in mines (Kotania, Janik et al. 1981; Pratt 1990; Hodous and Layne 1993; Lee, Anderson et al. 1993). One study looking at injuries also addresses the problem that it is younger miners who experience injuries, working in smaller mines (Hunting and Weeks 1993).

2.4.3 Cancers

Neoplasms are studied internationally, with over 140 studies, many focused on lung cancer (Davies, Landau et al. 1988; Fabrikant 1990; Carta, Cocco et al. 1994; Cocco, Carta et al. 1994; Dupree, Watkins et al. 1995). The bulk of the data relate to Europe and North America. Many studies focus on asbestos exposure, or coal mining and several address uranium mining (Dupree, Watkins et al. 1995; Tomasek and Darby 1995; Gilliland, Hunt et al. 2000; Hornung 2001). Some studies focus on risk of neoplasms for men and women working in mining. For example a cohort mortality study of rock salt workers was carried out in Volterra, Italy and found mesothelioma. In women, two cases of malignant ovarian cancer were observed vs. 0.42 expected on the basis of the regional rates. Increased mortality from lung and pleural tumors was consistent with the exposure to asbestos, which has also been shown to play a role in the development of ovarian tumors, but small numbers made the authors caution against over-interpretation (Tarchi, Orsi et al. 1994).

In one study of miners in southern China, Dachang Tin Mine in Guangxi province, cases of lung cancer occurring from 1973-1989 were obtained from local comprehensive medical records covering workers employed at the mine. These were matched approximately 3 to 1 with miners randomly chosen from the district surrounding the mine within the same birth decade. The study found matched odds ratios of 2.42 (95% confidence limits) for underground employment, 3.52 for smoking, and 2.04 for silicosis. Further analysis showed that, among the risk factors for excess mortality from lung cancer, only the years spent drilling underground and the cumulative smoking index (product of daily cigarette consumption and number of years smoking) were independent contributors to risk and there was no interaction observed. The presence of silicosis did not contribute to predicting risk independently of the years spent underground.(Fu, Gu et al. 1994)

Cancers are among the most important occupational health impacts as the miners may develop problems many years after they finish working, and not enough is known about many of the impacts workers may experience in the long term. These long term impacts are particularly notable in miners who have worked in coal, asbestos and uranium mines.

However, excess rates of occupational cancer also affect the many miners who have been exposed to a mixture of different silica and other dusts in other mines, for e.g of copper, gold and zinc (Checkoway, Heyer et al. 1993; de Klerk and Musk 1998; Rice, Park et al. 2001) (Polednak and Frome 1981; Lerchen, Wiggins et al. 1987; Tomasek and Darby 1995; Roscoe 1997).

2.4.4 Mental Health

There are few studies of mental health of miners in comparison to studies of other overall occupational health problems. Studies that do exist are principally, once again from Northern countries. They cover mental health in isolated mining communities where evidence on poor mental health for miners in this situation is disputed over time (Burvill 1975; Neil, Brealey et al. 1983). Other studies look at mental health after pit closure. One study evaluated the health of 79 miners in one Swedish iron-ore mine, and 226 age-matched controls from the general population, during one year after the closure of the mine. Statistically significant negative effects on self-reported health attributable to unemployment were not found, although neuropsychiatric symptoms were more common among the unemployed miners. The miners reported a statistically significant improvement in grip force ($p = 0.031$). They had a significantly higher prevalence of symptoms associated with mining related exposures when compared with the population controls – over twice as high for some symptoms (Friis, Carter et al. 1998). In Nottinghamshire in the UK another study of mental health in 1994, 2 years after pit closure found higher rates of psychological distress and morbidity in unemployed miners compared to working miners and to workers in other professions (Avery, Betts et al. 1998)

With this brief review of mental health we conclude the rapid review of occupational health and safety and move the less studied and more complex literature related to community health impacts of mining activities.

3 Community Health Impacts

For “communities” related to mine operations, or non-occupationally exposed populations, mining activities can impact on health at various levels. First, there are adverse health effects that result from environmental exposures to air, water, soil, and noise pollution. Second, and equally important for community health, are non-environmental exposures such as mining disasters and pit closures, which can affect the community indirectly and directly. Mental health problems are one example of the adverse health effects in the wider community.

Third, there is the issue of scale and the need to define ‘community’. The exposed ‘community’ is less well defined than the occupationally exposed mine worker population. At the level of mine operations, the ‘community’ may include those residents who live in immediate proximity to the mine. However, the ‘community’ may extend far beyond this local scale, as occurs with the transportation of pollutants from mining operations via various environmental media to more distant locations.

Equally, adverse non-environmental effects may also occur at these different scales. For example, migration is an important aspect of gold mining in the South African context, with many workers coming from neighbouring countries. In the event of a mining disaster, pit closure or incapacitation from contracting HIV/AIDS the community that may be affected could be international in scale. For this review we consider ‘community’ in the broadest possible sense, but within the confines of the peer-reviewed literature available.

In this review, we have included those studies that focused on the community health impacts from the extraction process, and these are described in Section 3.1. However, the dividing line between extraction and other parts of the mining and minerals cycle (see Figure 1.) are not always so clearly defined. For example, in the case of small-scale gold mining the main adverse health effects relate to the processing of the gold with mercury amalgam, which is often done in-situ with the extraction process. We have also included a number of papers that relate explicitly to the processing part of the cycle, and these are described in Section 3.2. These latter papers primarily deal with smelting, and have been included in the review as they provide important lessons in terms of the adverse effects on community health.

There are relatively few studies of community health impacts of mining operations internationally, with only 80 studies in this review covering aspects of community health around mines. In terms of geographical spread, the majority of studies come from Europe and North America. There are few community studies from Africa, Asia and Latin America relative to the numbers (although also not extensive) of studies in the occupational health literature. As a consequence, the following sections tend to look at examples of community health issues raised by individual studies or reviews of studies. The next section looks at community health organised by mineral mined.

3.1 Risks related to community health in mining areas (by type of mineral)

3.1.1 Asbestos

Several studies report on community health related to living close to asbestos mines (Munan, Thouez et al. 1981). One review article (Koike 1992), of the health effects of non-occupational exposure to asbestos found that the health impacts on communities varied. Mesothelioma has occurred among non-occupationally exposed persons living in the north-western region of Cape State of South Africa, where Crocidolite is mined and transported. However, the long-term residents of Thetford Mines in Quebec Province, Canada, who have never engaged in mining and milling of chrysolite have not shown an excess mortality of respiratory disease or impairment (Koike 1992). Although the results of these studies are conflicting, it is important to note that many of the adverse effects on community health result from the use of asbestos, and that this part of the mining and minerals cycle has not been covered in this review.

3.1.2 Coal

The community studies (Charpin, Kleisbauer et al. 1988; Pless Mulloli, Howel et al. 2000) in coal mining regions were predominantly concerned with respiratory illness caused by air pollution from mining activities.

In their study of the Gardanne coal-basin Charpin et al (1988) evaluated the long-term effects of exposure to air pollutants in school children. The prevalence of pulmonary and ear, nose and throat symptoms was higher in the polluted communities, but a statistically significant difference was only observed for the symptom "wheezing in the chest". Pless Mulloli and colleagues (2000) investigated whether living near open cast coal mining sites affects acute and chronic respiratory health. Patterns of the daily variation of PM_{10} were similar in open cast and control communities, but PM_{10} was higher in open cast areas. Little evidence was found for associations between living near an open cast coal mine site and an increased prevalence of respiratory illnesses, or asthma severity, but children in open cast coal mine communities had significantly more respiratory consultations compared to children in the control communities.

3.1.3 Copper

Two studies (Bjerre, Berglund et al. 1993; Pawson, Huicho et al. 2001) investigated non-occupational exposures in copper mining areas. Bjerre et al (1993) in their study in Falun, Sweden found that children up to four years of age showed significantly increased blood lead levels during the period of the study, but there was a significant decrease in older children. The authors concluded that lead from mine waste in soil and dust fall out did not constitute a significant health hazard for pre-school children. A second study by Pawson and colleagues (2001) was conducted in Peru found that in the community directly associated with mining operations, nutritional health conditions were believed to be relatively favourable as a result of the substantial mine-related infrastructure that had developed over the previous 12 years. In contrast, few such benefits were available in the other community, which provided limited part-time labour at the mine.

3.1.4 Gold

Most of the studies in this section relate to artisanal or small-scale mining (SSM). Although there are risks associated with the extraction of gold, in the context of SSM the predominant concern is in relation to exposure to the mercury that is used in winning the gold from the extracted ore. In the 1980's a modern "gold rush" began in developing countries and millions of people have become artisanal miners, despite these risks. In the interim at least 2000 tonnes of mercury have been released into the environment (Malm 1998), and this new "gold rush" is reflected in the world-wide demand for gold, which is currently 44% above the total annual production of the world's gold mines (UNIDO 2001a).

The United Nations Industrial Development Organisation (UNIDO) consider unemployment and landlessness to have forced people into small-scale gold mining, and UNIDO estimate that there are over a million people directly involved in small-scale gold mining operations in Latin America. If Africa and Asia are included there could be as many as six million artisanal miners world-wide.

Children are among six million artisanal miners worldwide. *Source:* UNIDO

As there were many studies on small-scale gold mining we have divided these on a geographical basis, and begin with studies from Brazil.

3.1.4.a. Brazil

Brazil produces more gold than any other South American country, and on a global scale is second in terms of production, with 90% of the gold coming from informal mining or *garimpos* (Malm, 1998). Several studies (Moreira 1996; Malm 1998; Grandjean, White et al. 1999; da Silva Brabo, de Oliveira Santos et al. 2000; de Souza Lima, Sarkis Muller et al. 2000; Santos, Jesus et al. 2000) investigated artisanal or small-scale mining activities that were predominately situated in the Amazonian region, and focused on exposure to mercury. Although these studies do not always provide conclusive results in terms of the health effects on communities, they do nonetheless raise concerns about environmental contamination from mercury.

The study by da Silva Brabo et al (2000) was conducted in Para State, where food resources are limited and fish is a major source of protein for local communities. The authors found that the levels of mercury (Hg) in fish consumed were below the Brazilian limit for consumption. Grandjean et al (1999) conducted their study in four comparable Amazonian communities where releases of mercury to the environment have resulted in the contamination of freshwater fish with methylmercury. In three Tapajos villages with the highest exposures, more than 80% of 246 children had hair-mercury concentrations above 10 mg/g, a limit above which adverse effects on brain development are likely to occur. Neuropsychological tests of motor function, attention, and visiospatial performance showed decrements associated with the hair-mercury concentrations, and the authors concluded that the mercury pollution seemed sufficiently severe to cause adverse effects on brain development.

Malm (1998) studied the river basins of Tapajos, Madeira, and Negro, in addition to some man-made reservoirs and areas in central Brazil. Although the results show high variability, perhaps related to biological diversity, biogeochemical differences in the river basins, and seasonal changes, high mercury values were found in areas with no known history of gold mining. The results show a considerable impact on environmental mercury concentrations and frequent occurrence of human exposure levels that may lead to adverse health effects.

In their investigation Santos and colleagues (2000) conducted cross-sectional studies in three riverside communities. Two of these communities, Brasilia Legal and Sao Luis do Tapajos, are located in a watershed exposed to mercury pollution from artisanal gold mining, and the third, Santana do Ituqui, is outside this area. Mercury was measured in human hair and fish. Although no signs or symptoms of overt mercury intoxication were observed, persons in Brasilia Legal and Sao Luis do Tapajos had higher levels of mercury in hair than residents of Santana de Ituqui, located out of the risk area did. Levels of mercury in fish were below Brazilian health guidance limits, but the high rates of fish consumption among these populations raise concerns for the possible effects of chronic exposure, especially among young children and women of childbearing age.

3.1.4 b Canada and Papua New Guinea

One article (Mackenzie and Kyle 1984), described two studies. The first study was concerned with the effects of arsenic contamination from gold mining in the town of Yellowknife, North West Territories, Canada. Correlation between hair arsenic levels and nerve velocity, although not striking, was observed. The second study was concerned with mercury contamination of fish in Lake Murray, Western Province, Papua New Guinea, where elevated levels of Hg contamination were reflected in hair and urine levels in the local inhabitants. An attempt was made to determine the effects of mercury, and 40% of those tested had albumen in their urine.

3.1.4. c. French Guiana

In a study of mercury exposure, Cordier et al (Cordier, Grasmick et al. 1998) found that dietary factors, especially the consumption of freshwater fish and livers from game, contributed the most to mercury levels. Other factors, including residence near a gold mining community, did not contribute significantly to mercury levels. Overall, 12% of the samples contained mercury levels in excess of 10mg/g. However, in some Amerindian communities up to 79% of the children had hair mercury levels that exceeded 10mg/g. The authors concluded that diet played a predominant role in total mercury burden, and that in some communities, mercury contamination exceeded safe levels.

In a second study on diet and mercury contamination, Frery et al (Frery, Maury-Brachet et al. 2001) confirmed that mercury exposure of the Wayana population related to a diet rich in fish, which are relatively highly contaminated for certain species. Results from hair samples showed that 57% of the Amerindians had Hg levels above the World Health Organization (WHO) safety limit (10mg/g); all those over 1 year of age had a Hg intake greater than the WHO safety limit. The authors concluded that the study revealed excessive exposure to mercury in the population, which related to the consumption of contaminated fish.

3.1.4. d Ghana

Ghana produces 80 tons (10% of which is produced by small-scale mining) of gold annually, and after South Africa is Africa's second largest producer of gold (UNIDO 2001b).

As artisanal mining does not require sophisticated technology and provides better income than subsistence agricultural activities, the sector has been expanding in recent years. The positive side of this increase has been the creation of employment, especially in rural and remote areas and income for the poor. According to UNIDO the number of people benefiting from small-scale mining could be as high as 1 million. The negative side of the story is clearly evident in a recently completed UNIDO project on small-scale "hard rock" surface gold mining activities in Ghana.

Woman selling mercury on small-scale mine. *Source:* UNIDO

The UNIDO project looked at the effects of small-scale hard-rock mining on the environment and on the health of the mining community. Inorganic and organic samples taken in the village of Dumasi, Western Ghana, showed a diffuse mercury contamination of all the environmental media in the village. Fish caught locally had a mercury content above the U.S-FDA action level, meaning that they should not be consumed. The study on human health revealed that the entire community of Dumasi, whether directly involved in mining or not, was over-exposed to mercury. Phase two of the project, due to commence in October 2001, will focus on alluvial mining. It is anticipated that the environmental contamination in alluvial mining is even worse than in hard rock mining.

3.1.4 e. The Philippines

There were two studies in the Philippines. The first (Akagi, Castillo et al. 2000) investigated the effects of mercury pollution and found that the health complaints among schoolchildren were attributed to this mercury pollution. Elevated mercury concentrations were also noted in some of the river systems up to 15 km from the mining areas.

The second study (Drasch, Bose-O'Reilly et al. 2001) investigated the influence of gold mining operations in Mount Diwata on the community of Monkayo, a downstream fertile plain. Subjects from Davao were used as a control group. Blood, urine and hair samples were taken from each participant and analysed for total Hg. In comparison to the surprisingly high Hg concentration in blood and in hair of the control group, only the workers in Mount Diwata showed elevated levels. The mercury urine concentrations of the occupationally exposed and non-exposed population on Mount Diwata was significantly higher than in the control group. The participants, living downstream on the plain of Monkayo, showed no statistically significant difference in Hg- blood, Hg-urine or Hg-hair in comparison with the control group.

However, it is important to note that only some of the clinical data, characteristic of Hg intoxication (for example, tremor, loss of memory, bluish discoloration of the gingiva), correlate with Hg in blood or urine, but not with Hg in hair. The authors point out that poor correlation between Hg in blood, urine and hair do not adequately monitor the Hg burden of the target tissues, especially the brain. Therefore, a 'Hg intoxication', that should be treated, may not be diagnosed by the Hg concentration in the bio-monitors alone, but by a balanced combination of Hg values and a medical score sum. In principle, this means the higher the Hg concentration in the bio-monitors, the lower the number of characteristic adverse effects are required for a positive diagnosis.

3.1.4 f Tanzania and Zimbabwe

In Eastern and Southern Africa mercury contamination associated with small-scale mining and processing represents a major environmental and human health concern (van Straaten 2000a). Studies in Tanzania (where there are approximately 200,000-300,000 persons involved in small-scale mining) and Zimbabwe (more than 200, 000 miners) have had mixed results.

In their study Harada et al (Harada, Nakachi et al. 1999) investigated mercury contamination around Lake Victoria, and a total of 150 gold miners, 103 fishermen and their families, and 19 residents of Mwanza City volunteered for the study. A high total mercury level of 48.3 ppm (near to 50 ppm, a critical level of Minamata disease) and over, in the head hair was observed in six gold miners (highest value, 953 ppm), four fishermen and their families (highest value, 416 ppm), and four Mwanza people (highest value, 474 ppm). With the exception of these 14 subjects, however, each mean total mercury level was well within the normal range (below 10 ppm). Neither inorganic-mercury poisoning nor methylmercury poisoning (Minamata disease) was noted in the fishermen and their families or in the Mwanza people. In addition, some subjects who showed a high total mercury level made habitual use of toilet soap containing much mercury. The findings obtained suggest that the mercury pollution in Tanzania is not very serious, however, it should be observed continuously.

Other studies (van Straaten 2000a; van Straaten 2000b) in a hair survey of fishermen and farmers found that at present, the fish-eating population close to the southern tip of Lake Victoria is at low risk with regard to Hg exposure. Concentrations in fish were low and > 90% of the hair samples from the fish-eating population were below 2 mg/g.

3.1.5 Lead

Several studies in Australia investigated the effect of leaded dust on blood lead levels (PbB). One study (Chiaradia, Gulson et al. 1997) sought to evaluate the pathway of leaded dust from a lead-zinc-copper mine to houses of employees, and the impact on blood lead concentrations of children. Data from the occupationally exposed families were compared with those from occupationally non-exposed control families living in the same city. The mean PbB in the children of the mine employees was 5.7 (SD 1.7) mg/dl compared with 4.1 (SD 1.4) mg/dl for the control children ($P = 0.02$). The PbB of all children was always < 10 mg/dl, which is the Australian National Health and Medical Research Council goal for all Australians.

Gulson and colleagues conducted several studies in the mining community of Broken Hill, New South Wales. In one study (Gulson 1996) determined the sources and intensity of lead exposure in-utero and in early childhood and the results reflect an increased exposure to lead from the lead-zinc-silver mineral deposit (orebody lead) during early childhood, probably associated with hand-to-mouth activity. In one study, (Gulson, Mizon et al. 1996) non-orebody sources were found to be significant contributors to blood lead of some children with low to moderate lead exposure. Even though the orebody lead was the major contributor to PbB in Broken Hill children, other sources of lead such as paint and petrol contributed to the blood lead concentrations. Nonetheless, the identification of elevated PbB in older children is a concern, especially for females, as there is potential for release of endogenous lead during pregnancy and lactation. Indeed in (Gulson, Yui et al. 1998) delayed visual maturation of the optic nerve (blindness) in three children born in a period of 19 months was attributed to lead exposure of the foetus during pregnancy.

Meanwhile, another study (Cook, Chappell et al. 1993) conducted an exposure assessment and blood lead screening for children aged 6-71 months living in Leadville, Colorado. High levels of lead had been found in the soil as a result of both past mining and smelting activities and natural mineralization. Three sources of exposure to lead were associated with blood lead levels: lead in a core sample taken from the backyard of the family's home, lead brought home on the clothes of a miner, and lead from soldering in the home. Two pathways of exposure were associated with blood lead levels: the child swallowing things other than food, and taking food or a bottle outside to play.

Another study (Gallacher, Elwood et al. 1984) found that women resident in an area heavily contaminated by spoil from old lead mining had blood lead concentrations that were about 50% higher ($p < 0.001$) than those of women living in a comparison area some distance away. They found that the blood lead concentrations were related to the consumption of home-grown produce, and that those with the highest level of consumption had blood lead concentrations that were 28% higher ($p < 0.001$) than those of women who consumed no locally grown vegetables.

Finally, (Jung and Thornton 1997) investigated the extent and degree of heavy metal contamination of paddy fields from a lead-zinc mine in Korea. Concentrations of copper, cadmium, lead and zinc in paddy soils, rice plants and irrigation waters sampled in the immediate vicinity of the mine were relatively high due to the seepage of metals from mining dump sites. The authors concluded that long-term metal exposure by regular consumption of the rice posed potential health problems to residents in the vicinity of the mine, although no adverse health effects had as yet been observed.

3.1.6 Mercury

Only one study looked specifically at mercury. This study (Harnly, Seidel et al. 1997) assessed the impact of elevated levels of inorganic mercury in soil and dust and organic mercury in fish, by conducting biological monitoring of Native Americans living next to an inactive mercury mine in Clear Lake, California, U.S.A. Of resident tribal members, 46% (n = 56) participated in biomonitoring. Urine mercury levels were equivalent to background, indicating that soil and dust exposures among study participants were not substantial. The average blood organic mercury level among study participants was 15.6 +/- 8.8 mg/l (n = 44), which was higher than levels reported by others among those who do not consume fish (2 mg/l). Consistent with results from other studies, a correlation between fish consumption and blood organic mercury was observed ($p = 0.03$).

3.1.7 Uranium

The effects of uranium mining on human health are not immediate and it may take several years before any adverse consequences are recognised. There are only a few studies that start to unpack this complex issue for health of communities living near uranium mines (Shields, Wiese et al. 1992; Au, Lane et al. 1995; Au, McConnell et al. 1998).

Au et al (1995) and Au et al (1998) investigated whether residents residing near uranium mining operations, who were potentially exposed to toxicants from mining waste, had increased genotoxic effects compared with people residing elsewhere. The authors found that uranium concentrations in soil samples were significantly higher in the target area than those in the control areas. In addition, the concentrations in the surface soil were significantly higher than in the subsurface soil ($p<0.05$) from target areas indicating environmental contamination by the mining activities. Lead isotope data from soil samples taken near a railroad transfer location was significantly different from those of other sites, indicating contamination by non-native ore transported from sources outside of the region to local milling facilities for processing. Therefore, local residents have been exposed to low levels of radioactive contamination from the mining/milling activities on a daily basis for many years. From the cytogenetic analysis, the authors found that the target population had more chromosome aberrations than the controls, although the differences were not significant ($p<0.05$).

However, using a challenge assay, cells from the target population had a significantly abnormal DNA repair response, compared to cells from the same control population. In conclusion, the observed environmental contamination by uranium is consistent with the observed genotoxic effects in the target residents. Therefore, the residents had increased health risk and some of the health problems will most likely be related to exposure to the radioactive contaminants. Since the chromosome aberration frequency revealed increased, but not significant differences between the exposed and the control populations, the authors concluded that the health risk among the exposed residents is similar to those among nuclear workers.

A study in New Mexico, U.S.A (Shields, Wiese et al. 1992), considered the role of environmental radiation in the aetiology of birth defects, stillbirths, and other adverse outcomes of pregnancy for 13,329 North American Navajos born at the Public Health Service/Indian Health Service Hospital (1964-1981). Data on more than 320 kinds of defective congenital conditions were extracted from hospital records. The only statistically significant association between uranium operations and unfavourable birth outcome was identified with the mother living near tailings or mine dumps. Overall, the associations between adverse pregnancy outcome and exposure to radiation were weak and must be interpreted with caution with respect to implying a biogenetic basis.

3.1.8 Zinc

A study in the UK (Carruthers and Smith 1979), considered the evidence of cadmium toxicity in a population living in a zinc-mining area in Shipham, Somerset. Twenty-two of thirty-one residents of the village where soil levels of cadmium were high had raised blood-cadmium levels, and some had clinical and biochemical findings (including hypertension and biochemical evidence of renal tubular damage) indicating toxic effects which could be attributed to the metal. The authors suggested that more detailed studies should be carried out as a matter of urgency and that advice on avoiding local garden produce and not smoking should be emphasised.

3.2 Health and social impacts related to different types of minerals – Smelting Phase

3.2.1 Aluminium

In the U.S.A Ernst et al (Ernst, Thomas et al. 1986) conducted a respiratory survey of North American Indian children living in proximity to an aluminium smelter, and explored the relationship of respiratory symptoms and lung function to exposure to ambient air pollution consisting of particulate and gaseous fluorides. Among boys, closing volume (CV/VC%) was increased in those raised closest to the smelter as opposed to those having lived most of their lives farthest from this source of air pollution. In both sexes, there was a significant linear relationship between increasing CV/VC% and the amount of fluoride contained in a spot urine sample. The authors concluded that exposure to fluoride air pollution in the community may be associated with abnormalities in small airways, and the implication of these abnormalities for future respiratory health is unknown.

3.2.2 Arsenic

In Mexico, one study (Diaz Barriga, Santos et al. 1993) assessed the environmental contamination by arsenic and cadmium in a smelter community, and the possible contribution to an increased body burden of these elements in children. Arsenic and cadmium were found in the environment (air, soil, and household dust, and tap water) as well as in the urine and hair from children. The study was undertaken in three zones, and showed that the town nearest the smelting complex (Morales) was the most contaminated of the zones studied.

Estimates of the arsenic ingestion rate in Morales (1.0-19.8 mg/kg/day) were equal to or higher than the reference dose of 1 mg/kg/day calculated by the Environmental Protection Agency. The range of arsenic levels in urine, and hair, and that of cadmium in hair indicated that environmental exposure has resulted in an increased body burden of these elements in children, suggesting that children living in Morales are at high risk of suffering adverse health effects if exposure continues.

3.2.3 Copper

There are several community studies on copper, all of which were conducted in North America. These showed that residing near copper smelters had adverse effects on human health. For example, in a nation wide survey of heavy metal absorption in children aged 1-5 years of age living near copper-lead-zinc smelters in 19 U.S towns (Baker, Hayes et al. 1977) found increased systemic absorption of arsenic reflected by urine arsenic content, in children near 10 of 11 copper smelters. Meanwhile, a 1975 study (Blot and Fraumeni 1975) showed that average mortality-rates from lung cancer for White males and females in the U.S.A between 1950-69 were significantly increased in counties with copper, lead, or zinc smelting and refining industries, but not in counties where other non-ferrous ores were processed.

A 1983 investigation (Hartwell, Handy et al. 1983) of heavy metal exposure in populations living around copper and zinc smelters indicated that increased environmental levels and body burdens were exhibited at distances closest to the smelters. In turn, a study in around the same period (Mattson and Guidotti 1980) investigated the health risks associated with residence near a primary copper smelter and the results suggested an excess mortality from non-malignant respiratory diseases in copper mining and smelting counties.

In Quebec, Canada Cordier (Cordier, Theriault et al. 1983) investigated the effects of pollution on a community living adjacent to a copper smelter, and showed an excess of deaths by lung cancer, chronic respiratory diseases, and diseases of the digestive system among men. This excess remained even after adjustment for occupational exposure and could not be attributed to smoking habits either. Among women, deaths by endocrine and metabolic diseases and chronic respiratory diseases were also in excess.

3.2.4 Lead

In their study in Mexico, researchers (Garcia Vargas, Rubio Andrade et al. 2001) assessed the level of lead exposure in children aged 6-9 years of age attending three primary schools and living in the vicinity of a lead smelter. The authors concluded that soil and dust ingestion and inhalation were the main routes of exposure, and that environmental contamination resulted in an increased body burden of Pb, suggesting that children living in the vicinity of the smelter complex were at high risk for adverse effects of lead.

3.2.5 Others – mineral not specified

Studies in Sweden (Wulff, Hogberg et al. 1996a; Wulff, Hogberg et al. 1996b) sought to determine whether children born to women living near the Ronnskar smelter in Skelleftea during pregnancy, had an increased risk of childhood cancer. Thirteen cases of childhood cancer were identified among children born in the vicinity of the smelter against 6.7 expected (SIR 195, 95%CI 88-300). Among distant born the observed number of cases (n = 42) was similar to that expected (n = 41.8).

3.3 Indirect health and related social impacts on communities

The mining sector has been affected by the world-wide epidemic of HIV/AIDS, and this is apparent in the studies of South African mines. Several studies (Jochelson, Mothibeli et al. 1991; Campbell 1997; Williams and Campbell 1998; Campbell and Williams 1999; Campbell 2000; Corbett, Churchyard et al. 2000) have focused on the situation in the gold mines of South Africa.

Migrant labour plays an important role in the mining sector of South Africa, and these migrants are believed to play an important role in the transmission of HIV/AIDS. In terms of how the mining industry has dealt with this problem one study (Williams and Campbell 1998; Campbell and Williams 1999) reports that "many mines made substantial efforts to establish HIV-prevention programmes relatively early on in the epidemic, (but) these appear to have had little impact".

Meanwhile, (Corbett, Churchyard et al. 2000) investigated the combined effects of HIV infection and silicosis on mycobacterial disease in a South African gold mine, and concluded that the risks of silicosis and HIV infection combine in a multiplicative manner. This indicates that tuberculosis (TB) remains as much a silica-related occupational disease in HIV-positive as in HIV-negative miners, and HIV- positive silicotics have considerably higher TB incidence rates than those reported from other HIV-positive Africans. The increasing impact of HIV over time may indicate epidemic TB transmission with rapid disease development in HIV-infected miners.

4 Existing Initiatives To Reduce Risk And Maximise Benefits

This section looks briefly at the evidence on existing initiatives reported in the peer-reviewed literature. It is beyond the scope of this review to cover all website materials produced by any of the actors involved in the sector. This limits the scope of the review in this section, since peer-reviewed materials tend to focus on local improvements and clear scientific evidence that such improvements have taken place. Peer-reviewed literature also tends to derive from epidemiological studies of health impacts, either negative or positive of mining sector activities. It is notable that there are very few independent intervention studies of mining sector improvements over time – either towards improved occupational health and safety, or towards improved community health around mines. The advantage of the literature reviewed here is that it comes from independent academic evidence; the disadvantage is that many initiatives never reach the light of independent evaluation, particularly for initiatives undertaken by small scale mine operations, and particularly in the South. However, there were a number of studies in the peer-reviewed literature and we summarise them in this section.

4.1 Existing initiatives to reduce risk and maximise benefits for occupational health and safety

Overall, many initiatives to improve occupational health and safety in mines have come over time. In formal large scale mining, particularly in the Northern countries, improvements have been led by all actors in the industry including workers, unions, NGOs, governments and the industry itself. However, in small scale mining, and overall in mining in the South, improvements have come more slowly, if at all.

In terms of large scale mining historically, several studies of coal mining and occupational health highlight the interesting role of miners in the development of understanding of the risks of mining and safer mining policy. Coal miners have played a unique role in developing worker health and safety and in challenging companies to improve transparency of information and provide clinics and compensation. Worker successes in this challenge date back to the 1930s and 1940s in the UK and U.S. (Derickson 1989; Derickson 1991; Mulcahy 1999)

Mining companies have also been involved in programmes of worker health and safety. In the past these principally entailed improvements in working conditions in the mines. For example, safety measures to reduce injuries or air conditioning to reduce heat stress (Shleifman and Karnaukh 1986; Chebotarev and Afanas'eva 1998; Donoghue and Bates 2000; O'Neill 2000; Boiano and Hull 2001). More recent initiatives have also included programmes to assist miners in their living and social conditions (Williams and Campbell 1998). One or two studies also look at mine rescue workers and their equipment (Kampmann and Bresser 1999).

Unions have played a major role in the development of safer conditions in mines, and in the development of health information and services sponsored by unions(Kerr 1971;

DesJardins, Bigoness et al. 1982; Kerr 1990; Derickson 1991). There have been conflicts of interest over care of miners and over the way that mining companies tried to control access to health services(Sass 1994; Mulcahy 1999). This led to great changes in the way that the health of miners was treated particularly during the mid 20th century in Europe and the U.S. For example, Derrickson reports that "by the mid-1930s, U.S. coal miners could no longer tolerate company doctors. They objected to the misuse of preemployment and periodic medical examinations and to many other facets of employer-controlled health benefit plans. The rank-and-file movement for reform received critical assistance from the Bureau of Cooperative Medicine, which conducted an extensive investigation of health services in 157 Appalachian communities. This study not only substantiated the workers' indictment of prevailing conditions but illuminated new deficiencies in the quality and availability of hospital and medical care as well. The miners' union curtailed the undemocratic, exploitative system of company doctors and proprietary hospitals by establishing the United Mine Workers of America Welfare and Retirement Fund in 1946" (Derickson 1989).

Looking at the same issues and dynamics in South Africa Zwi undertook an interesting study in the late 1980s of all stakeholders. He found that in mining "Although there have been some advances in legislation, conditions are often still poor and enforcement of legislation is lacking" His study reports that "the state is concerned with minimising conflict and disruption of productivity, while ensuring that conditions do not deteriorate too badly; the employers are concerned to maximise profits and to undertake improvements in OHS only insofar as these are profitable and in the interest of stable industrial relations; and the union movement has sought to make work safer. These perspectives are different and conflicting. The only interest group with an unambiguous commitment to improving OHS is the union movement in South Africa. However, many difficulties and problems mitigate against the movement achieving its OHS objectives, including the limited number of workers which have been organised into unions and the many pressing issues which require the movement's immediate attention" (Zwi, Fonn et al. 1988).

More recent studies point to the same complex dynamics of negotiated interests and most conclude on the long term and key role played by organised mine workers in the improvements of all aspects of occupational health and safety in mines (Koplin 1973; Derickson 1991; Snell 1992; 1999c).

Several studies discuss the use of health services by mineworkers. Over time practices have changed considerably: union health care; the use of the law for long term impacts and a general ambivalence towards company doctors (Pearson 1980). One recent study in Australia of back pain in mineral sand miners found that "chiropractors were rated higher than physiotherapists or general practitioners in providing the most effective treatment for low back pain. Mobilising exercises were considered to be better treatment than analgesics or anti-inflammatory medication". The authors concluded that "Low back pain is a common problem among mineral sand mine workers who preferred the services of the chiropractor or the physiotherapist to the general practitioner. Physical treatment modalities with stretching and mobilising exercises were preferred to pharmacological treatment" (Hemsley, Broadhurst et al. 1998).

Interestingly, there is little discussion of the role of international agencies, such as the International Labour Organisation, and most papers discuss the interplay of miners, their unions, management and government. National government shifts towards support of mineworkers and their health has been of significant importance in a number of countries around the world (Key 1972; Boden 1985; Leger and Arkles 1989; Kerr 1990; Weeks 1991; Guizzardi 1998). The effective use of the law to protect workers has been of crucial importance to improved mining conditions, as Weeks reports in his review of legislation in the United States. He argues that "the Mine Safety and Health Act provided for a wide array of basic public health measures to prevent occupational disease and injury in the mining industry. These measures have been effective in reducing both risk of fatal injury and exposure to respirable coal mine dust. They are also associated with temporary declines in productivity. In recent years, however, productivity has increased, while risk of fatal injury and exposure to respirable dust have declined. At individual mines, productivity with longwall mining methods appear to be associated with increases in exposure to respirable dust. These trends are not inconsistent with similar trends following implementation of regulations by OSHA. When the OSHA promulgated regulations to control exposure to vinyl chloride monomer, enforcement of the standard promoted significant efficiencies in vinyl chloride production. Similarly, when OSHA promulgated its standard regulating exposure to cotton dust, this effort provoked modernization in the cotton textile industry. It is not inevitable that occupational health and safety regulations are associated with negative economic performance. On the contrary, in some instances, public health on the job and productivity are complementary" (Weeks 1991).

Finally it was notable that no studies reviewed improvements in small scale mines and very few studies reported on improvements in mines in Latin America, Asia or Africa.

4.2 Existing Initiatives To Reduce Risk And Maximise Benefits in communities

Our search of the peer-reviewed literature produced only a small number of studies that made reference to initiatives that sought to alleviate the adverse health effects that the mining and minerals sector was posing on communities. Several of these studies report on efforts to reduce blood lead levels, and especially in children who lived in the vicinity of extraction or processing activities.

A review by Billig et al (Billig, Gurzau et al. 1999) reports on a programme in Romania. They suggest that an inter-sectoral approach involving community, governmental and non-governmental agencies, and the management of the local copper smelting plant, succeeded in reducing the blood lead levels of plant workers and of young children living in the vicinity of the copper smelter. In Canada (Hilts, Bock et al. 1998) report on a study on the effect of an intervention which also aimed to reduce the blood lead levels in children. The Community Lead Task Force carried out blood lead screening, case management, education programs targeted at early childhood groups and the general community, community dust abatement, exposure pathways studies, and remedial trials. The authors suggested that since there was no concurrent improvement in local environmental conditions during the investigation it is possible that the continuing decline in blood lead levels had been at least partly due to community-wide intervention programs.

Another study (Morales Bonilla and Mauss 1998) described a community-initiated study of blood lead levels of Nicaraguan children living near a battery factory. In response to requests by parents in Managua, Nicaragua, whose neighbourhood bordered a battery factory, 97 children were tested for blood lead, as were 30 children in a neighbourhood without an obvious source of environmental lead. Children living near the battery were found to be at increased risk of lead poisoning, and this enabled the parents to petition the government to control the factory emissions and to improve appropriate health services, with the resultant closure of the factory.

The search also produced a number of studies (Ijsselmuiden, Padayachee et al. 1990; Jochelson, Mothibeli et al. 1991; Williams and Campbell 1998; Campbell and Williams 1999) that focused on the HIV/AIDS epidemic and in particular the associated problems on the gold mines of South Africa. These studies highlight the particular problems with the mines and their reliance on a substantial migrant labour force that is drawn from both within South Africa and from neighbouring states. There is recognition that early on in the HIV/AIDS crisis many mines made substantial efforts to establish HIV/AIDS prevention programmes but that these appear to have had little impact. One possible reason for this is the failure of the prevention programmes to take account of the psychosocial environment of the labour force, and especially those migrants from neighbouring states who spend extended periods away from their immediate family and friends.

In one of the few studies of community health programmes associated with mining in Latin America, Foreit et al (Foreit, Haustein et al. 1991) described the costs and the benefits of implementing child survival services at a private mining company in Peru. Here, despite considerable outlays for medical services, few children under age 5 were vaccinated, and half of their illnesses went untreated. Children who were attended at the company clinic usually received unnecessary medication. As a result of the study, the company hired additional staff to provide integrated maternal-child preventive health care and family planning and contracted for intensive training and periodic on-site supervision. In less than 2 years, vaccination coverage reached 75%, and virtually all children under age 1 were enrolled in growth monitoring. Prescriptions were reduced by 24%, including a 67% drop in anti-microbials.

5 Conclusions

This section looks briefly at our conclusions related to actions needed to move forward and implications for worker, community health and sustainability.

This review has reported on over 350 studies in an overall 996 studies available through PubMed, and on a rapid literature review of web sources and books. However, we are aware that, despite the breadth of this review, we have hardly skimmed the surface of the issues of mining and health.

Health impacts, both for miners and for the communities living around them, are amongst the most important issues for local communities who rely on mining. Even when a mine is gone, the men and women who have worked in the mine may continue to experience health impacts for many years, if not generations. Some mined substances, such as uranium, will continue to create health impacts for miners up to 30 years after the miner has left the mine. It is likely that many impacts related to some of the more carcinogenic minerals are still to be discovered.

The evidence of long-term impacts of mining on health of workers and communities is important in the context of sustainable development. These impacts imply that the mining sector's activities currently undermine the human objectives of sustainable development, which are to protect the health of current and future generations. This is despite the industry's role in economic development in the short term.

Miners and the communities living around mines have fought hard for improvements to their health conditions over many years. This has resulted in great improvements in large-scale formal mining – where organised labour has worked with government and management to improve worker health and safety. Communities have also fought to gain health improvements and reduce health risks associated with living near mines.

However, overall, this review shows that there is still a long way to go before mining becomes a healthy work or a healthy development activity to take place in a community. There is also a long way to go before the industry, the workers and the community agree over the real health impacts of the sector and the real responsibility of each of the actors in the sector. Mining companies have started more recently to put health programmes into place around mines. But it is the long term heath impacts related to the mine activities that will remain long after the company goes and there is little evidence that companies are keen to address these long-term responsibilities. This is despite the fact that health impacts directly related to mined products are more the responsibility of the industry than any other health programmes.

Finally, it was beyond the scope of this review to look at the whole mining and mineral life cycle. Only such a review would be able to identify the extent of health impacts related to mining, both for miners, the local communities around mines and the wider community of users of the mined products. In the future there is much more to be done to ensure that mining is a healthy as well as sustainable development practice. At the moment at least, there is little evidence that mining is a healthy practice in the long term and only limited evidence that miners and their families gain true health benefits from the sector.

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Annex : Terms of Reference

1. To undertake a rapid review of published international literature on worker and community health impacts related to mining operations internationally.
2. To produce a summary of the review, where data is available, covering the following themes and outlining situations in developed and developing countries:

A/ Worker Health and Safety Issues (in a historical perspective)

- health and safety risks related to different type of minerals (e.g. coal, iron, gold, sand and gravel or by category of minerals); different size of mines (e.g. in small-scale and large-scale mining); and different nature of mines (e.g. open cast and underground mines)

- direct and indirect impacts on workers and their health

B/ Community Health Impacts (in a historical perspective)

- risks related to community health in mining areas (by categories laid out in Section A)

- direct health and related social impacts on communities (e.g. air pollution, water pollution, accidents of transport)

- indirect health and related social impacts on communities (e.g. negative: HIV; positive: nutrition improvement)

C/ Existing Initiatives to Reduce Risk and Maximise Benefits

- initiatives of the different concerned actors (workers, communities, unions, companies, governments, international organisations, NGOs)

- constraints facing by the different actors

D/ Findings

- actions needed to move forward

- implications for worker, community health and sustainability