COAL AND METAL (SURFACE AND UNDERGROUND) MINING

AN OVERVIEW

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1. PRELUDE

Minerals and mineral products are the backbone of most industries. Some form of mining or quarrying is carried out in virtually every country in the world.

**Challenges before Mining Industry**

Products of the mining industry generate the majority of energy used, from electricity in homes to fuel in vehicles. Mined resources also serve as inputs for consumer goods and the processes and services provided by nearly all other industries, particularly in agriculture, manufacturing, transportation, utilities, communication, and construction.

The mining industry contains five main industry segments, which are defined by the resources they produce: oil and gas extraction, coal mining, metal ore mining, non-metallic mineral mining & quarrying, and support activities for mining.

Mining industry faces a number of challenges in the near future. Working conditions in mines, quarries, and well sites can be unusual and sometimes dangerous. Some of the mining challenges including quarrying closer to cities and civil structures and greater quarry depths with highwalls subjected to more rock stress and water pressure. In addition, more underground operations that are inherently more dangerous. They are damp and dark, and some can be very hot and noisy. In underground mining operations, unique dangers include the possibility of cave-in, mine fire, explosion, or exposure to harmful gases. In addition, dust generated by drilling in mines still places miners at risk of developing serious lung diseases.

In mechanized system of mining, large, powerful sophisticated equipment moving thousands of tons of ore and rock, round the clock operation, poorly lighted entries, and adverse weather conditions all contribute to the hazardous nature of mining. Hazards arise from equipment design flaws, deficient mine design, or human error. The potential for health and safety risks introduced by new technologies must be addressed proactively. Of particular concern is to understand the system requirements and specifications and to address human interface issues involving the operation, maintenance, and repair of the equipment as well as the computerized control of equipment. Since a truly autonomous mining system is still a future vision, current mining machines will be used for many years. A continuous need exists to reduce equipment hazards, improve component and system reliabilities, and minimize the occurrence of unplanned catastrophic accidents.

Moreover, loss of experienced mine workers due to retirement, an influx of new, inexperienced workers in more challenging mining conditions is one of the most important aspects. Effective training is needed to reduce injuries of both experienced and inexperienced workers from ever increasing diverse background. Mining challenges can be met with better training, using interactive mediums or even virtual reality techniques. The awareness and involvement of the whole workforce needs to be fostered by management, labour and government jointly identifying risk factors, selecting mining practices, implementing mining plans and engineering and administrative controls.

Surface mining requires large areas of land to be temporarily disturbed. This raises a number of environmental challenges, including soil erosion, dust, noise and water pollution, and impacts on local biodiversity. Environmental clearance of Mining, Oil and Gas Fields Projects etc., is becoming more stringent everyday. That is understandable and acceptable, but what is more alarming is the lack of skill sets required to handle such challenges that can come from different agencies such as the department of environment, department of forest etc. By carefully pre-planning projects, implementing pollution control measures, monitoring the effects of mining and rehabilitating mined areas, the mining industry minimises the impact of its activities on the neighbouring community, the immediate environment and on long-term land capability.

Recently, the mining agenda has changed, as the world has taken the carbon-cutting culture to its heart. New challenge is to implement measures to ensure mining operations sustainable, around the world.
Mining has important economic, environmental, labour and social effects—both in the countries or regions where it is carried out and beyond. For many developing countries, mining accounts for a significant proportion of GDP and, often, for the bulk of foreign exchange earnings and foreign investment.

The environmental impact of mining can be significant and long-lasting. There are many examples of good and bad practice in the management and rehabilitation of mined areas. The environmental effect of the use of minerals is becoming an important issue for the industry and its workforce. The debate on global warming, for example, could affect the use of coal in some areas; recycling lessens the amount of new material required; and the increasing use of non-mineral materials, such as plastics, affects the intensity of use of metals and minerals per unit of GDP.

Competition, declining mineral grades, higher treatment costs, privatization and restructuring are each putting pressure on mining companies to reduce their costs and increase their productivity. The high capital intensity of much of the mining industry encourages mining companies to seek the maximum use of their equipment, calling in turn for more flexible and often more intensive work patterns. Employment is falling in many mining areas due to increased productivity, radical restructuring and privatization. These changes not only affect mineworkers who must find alternative employment; those remaining in the industry are required to have more skills and more flexibility. Finding the balance between the desire of mining companies to cut costs and those of workers to safeguard their jobs has been a key issue throughout the world of mining. Mining communities must also adapt to new mining operations, as well as to downsizing or closure.

Mining is often considered to be a special industry involving close-knit communities and workers doing a dirty, dangerous job. Mining is also a sector where many at the top—managers and employers—are former miners or mining engineers with wide, first-hand experience of the issues that affect their enterprises and workforces. Moreover, mineworkers have often been the elite of industrial workers and have frequently been at the forefront when political and social changes have taken place faster than was envisaged by the government of the day.

About 23 billion tonnes of minerals, including coal, are produced each year. For high-value minerals, the quantity of waste produced is many times that of the final product. For example, each ounce of gold is the result of dealing with about 12 tonnes of ore; each tonne of copper comes from about 30 tonnes of ore. For lower value materials (e.g., sand, gravel and clay)—which account for the bulk of the material mined—the amount of waste material that can be tolerated is minimal. It is safe to assume, however, that the world’s mines must produce at least twice the final amount required (excluding the removal of surface “overburden”, which is subsequently replaced and therefore handled twice). Globally, therefore, some 50 billion tonnes of ore are mined each year. This is the equivalent of digging a 1.5 metre deep hole the size of Switzerland every year.

Employment

Mining is not a major employer. It accounts for about 1% of the world’s workforce—some 30 million people, 10 million of whom produce coal. However, for every mining job there is at least one job that is directly dependent on mining. In addition, it is estimated that at least 6 million people not included in the above figure work in small-scale mines. When one takes dependants into account, the number of people relying on mining for a living is likely to be about 300 million.
Safety and Health

Mineworkers face a constantly changing combination of workplace circumstances, both daily and throughout the work shift. Some work in an atmosphere without natural light or ventilation, creating voids in the earth by removing material and trying to ensure that there will be no immediate reaction from the surrounding strata. Despite the considerable efforts in many countries, the toll of death, injury and disease among the world’s mineworkers means that, in most countries, mining remains the most hazardous occupation when the number of people exposed to risk is taken into account.

Although only accounting for 1% of the global workforce, mining is responsible for about 8% of fatal accidents at work (around 15,000 per year). No reliable data exist as far as injuries are concerned, but they are significant, as is the number of workers affected by occupational diseases (such as pneumoconioses, hearing loss and the effects of vibration) whose premature disability and even death can be directly attributed to their work.

The ILO and Mining

The International Labour Organization (ILO) has been dealing with labour and social problems of the mining industry since its early days, making considerable efforts to improve work and life of those in the mining industry—from the adoption of the Hours of Work (Coal Mines) Convention (No. 31) in 1931 to the Safety and Health in Mines Convention (No. 176), which was adopted by the International Labour Conference in 1995. For 50 years tripartite meetings on mining have addressed a variety of issues ranging from employment, working conditions and training to occupational safety and health and industrial relations. The results are over 140 agreed conclusions and resolutions, some of which have been used at the national level; others have triggered ILO action—including a variety of training and assistance programmes in member States. Some have led to the development of codes of safety practice and, most recently, to the new labour standard.

In 1996 a new system of shorter, more focused tripartite meetings was introduced, in which topical mining issues will be identified and discussed in order to address the issues in a practical way in the countries and regions concerned, at the national level and by the ILO. The first of these, in 1999, will deal with social and labour issues of small-scale mining.

Labour and social issues in mining cannot be separated from other considerations, whether they be economic, political, technical or environmental. While there can be no model approach to ensuring that the mining industry develops in a way that benefits all those involved, there is clearly a need that it should do so. The ILO is doing what it can to assist in the labour and social development of this vital industry. But it cannot work alone; it must have the active involvement of the social partners in order to maximize its impact. The ILO also works closely with other international organizations, bringing the social and labour dimension of mining to their attention and collaborating with them as appropriate.

Because of the hazardous nature of mining, the ILO has been always deeply concerned with the improvement of occupational safety and health. The ILO’s International Classification of Radiographs of Pneumoconiosis is an internationally recognized tool for recording systematically radiographic abnormalities in the chest provoked by the inhalation of dusts. Two codes of practice on safety and health deal exclusively with underground and surface mines; others are relevant to the mining industry.
The adoption of the Convention on Safety and Health in Mines in 1995, which has set the principle for national action on the improvement of working conditions in the mining industry, is important because:

- Special hazards are faced by mineworkers.
- The mining industry in many countries is assuming increasing importance.
- Earlier ILO standards on occupational safety and health, as well as the existing legislation in many countries, are inadequate to deal with the specific needs of mining.

The first two ratifications of the Convention occurred in mid-1997.

Training

In recent years the ILO has carried out a variety of training projects aimed at improving the safety and health of miners through greater awareness, improved inspection and rescue training. The ILO’s activities to date have contributed to progress in many countries, bringing national legislation into conformity with international labour standards and raising the level of occupational safety and health in the mining industry.

Industrial relations and employment

The pressure to improve productivity in the face of intensified competition can sometimes result in basic principles of freedom of association and collective bargaining being called into question when enterprises perceive that their profitability or even survival is in doubt. But sound industrial relations based on the constructive application of those principles can make an important contribution to productivity improvement. This issue was examined at length at a meeting in 1995. An important point to emerge was the need for close consultation between the social partners for any necessary restructuring to be successful and for the mining industry as a whole to obtain lasting benefits. Also, it was agreed that new flexibility of work organization and work methods should not jeopardize workers’ rights, nor adversely affect health and safety.

Small-scale Mining

Small-scale mining falls into two broad categories. The first is the mining and quarrying of industrial and construction materials on a small scale, operations that are mostly for local markets and present in every country. Regulations to control and tax them are often in place but, as for small manufacturing plants, lack of inspection and lax enforcement mean that informal or illegal operations persist.

The second category is the mining of relatively high-value minerals, notably gold and precious stones. The output is generally exported, through sales to approved agencies or through smuggling. The size and character of this type of small-scale mining have made what laws there are inadequate and impossible to apply.

Small-scale mining provides considerable employment, particularly in rural areas. In some countries, many more people are employed in small-scale, often informal, mining than in the formal mining sector. The limited data that exist suggest that upwards of six million people engage in small-scale mining. Unfortunately, however, many of these jobs are precarious and are far from conforming to international and national labour standards. Accident rates in small-scale mines are routinely six of seven times higher than in larger operations, even in industrialized countries. Illnesses, many due to
unsanitary conditions are common at many sites. This is not to say that there are no safe, clean, small-scale mines—there are, but they tend to be a small minority.

A special problem is the employment of children. As part of its International Programme for the Elimination of Child Labour, the ILO is undertaking projects in several countries in Africa, Asia and Latin America to provide educational opportunities and alternative income-generating prospects to remove children from coal, gold and gemstone mines in three regions in these countries. This work is being coordinated with the international mineworkers union (ICEM) and with local non-governmental organizations (NGOs) and government agencies.

NGOs have also worked hard and effectively at the local level to introduce appropriate technologies to improve efficiency and mitigate the health and environmental impact of small-scale mining. Some International Governmental Organizations (IGOs) have undertaken studies and developed guidelines and programmes of action. These address child labour, the role of women and indigenous people, taxation and land title reform, and environmental impact but, so far, they appear to have had little discernible effect. It should be noted, however, that without the active support and participation of governments, the success of such efforts is problematic.

Also, for the most part, there seems to be little interest among small-scale miners in using cheap, readily-available and effective technology to mitigate health and environmental effects, such as retorts to recapture mercury. There is often no incentive to do so, since the cost of mercury is not a constraint. Moreover, particularly in the case of itinerant miners, there is frequently no long-term interest in preserving the land for use after the mining has ceased. The challenge is to show small-scale miners that there are better ways to go about their mining that would not unduly constrain their activities and be better for them in terms of health and wealth, better for the land and better for the country. The “Harare Guidelines”, developed at the 1993 United Nations Interregional Seminar on Guidelines for the Development of Small/Medium Scale Mining, provide guidance for governments and for development agencies in tackling the different issues in a complete and coordinated way. The absence of involvement by employers’ and workers’ organizations in most small-scale mining activity puts a special responsibility on the government in bringing small-scale mining into the formal sector, an action that would improve the lot of small-scale miners and markedly increase the economic and social benefits of small-scale mining. Also, at an international roundtable in 1995 organized by the World Bank, a strategy for artisanal mining that aims to minimize negative side effects—including poor safety and health conditions of this activity—and maximize the socio-economic benefits was developed.

The Safety and Health in Mines Convention and its accompanying Recommendation (No. 183) set out in detail an internationally agreed benchmark to guide national law and practice. It covers all mines, providing a floor—the minimum safety requirement against which all changes in mine operations should be measured. The provisions of the Convention are already being included in new mining legislation and in collective agreements in several countries and the minimum standards it sets are exceeded by the safety and health regulations already promulgated in many mining countries. It remains for the Convention to be ratified in all countries (ratification would give it the force of law), to ensure that the appropriate authorities are properly staffed and funded so that they can monitor the implementation of the regulations in all sectors of the mining industry. The ILO will also monitor the application of the Convention in countries that ratify it.
2. EXPLORATION

Mineral exploration is the precursor to mining. Exploration is a high-risk, high-cost business that, if successful, results in the discovery of a mineral deposit that can be mined profitably. In 1992, US$1.2 billion was spent worldwide on exploration; this increased to almost US$2.7 billion in 1995 and today this figure has increased many fold. Many countries encourage exploration investment and competition is high to explore in areas with good potential for discovery. Almost without exception, mineral exploration today is carried out by interdisciplinary teams of prospectors, geologists, geophysicists and geochemists who search for mineral deposits in all terrain throughout the world.

Mineral exploration begins with a reconnaissance or generative stage and proceeds through a target evaluation stage, which, if successful, leads to advanced exploration. As a project progresses through the various stages of exploration, the type of work changes as do health and safety issues.

Reconnaissance field work is often conducted by small parties of geoscientists with limited support in unfamiliar terrain. Reconnaissance may comprise prospecting, geologic mapping and sampling, wide-spaced and preliminary geochemical sampling and geophysical surveys. More detailed exploration commences during the target testing phase once land is acquired through permit, concession, lease or mineral claims. Detailed field work comprising geologic mapping, sampling and geophysical and geochemical surveys requires a grid for survey control. This work frequently yields targets that warrant testing by trenching or drilling, entailing the use of heavy equipment such as back-hoes, power shovels, bulldozers, drills and, occasionally, explosives. Diamond, rotary or percussion drill equipment may be truck-mounted or may be hauled to the drill site on skids. Occasionally helicopters are used to sling drills between drill sites.

Some project exploration results will be sufficiently encouraging to justify advanced exploration requiring the collection of large or bulk samples to evaluate the economic potential of a mineral deposit. This may be accomplished through intensive drilling, although for many mineral deposits some form of trenching or underground sampling may be necessary. An exploration shaft, decline or adit may be excavated to gain underground access to the deposit. Although the actual work is carried out by miners, most mining companies will ensure that an exploration geologist is responsible for the underground sampling programme.

Health and Safety

In the past, employers seldom implemented or monitored exploration safety programmes and procedures. Even today, exploration workers frequently have a cavalier attitude towards safety. As a result, health and safety issues may be overlooked and not considered an integral part of the explorer’s job. Fortunately, many mining exploration companies now strive to change this aspect of the exploration culture by requiring that employees and contractors follow established safety procedures.

Exploration work is often seasonal. Consequently there are pressures to complete work within a limited time, sometimes at the expense of safety. In addition, as exploration work progresses to later stages, the number and variety of risks and hazards increase. Early reconnaissance field work requires only a small field crew and camp. More detailed exploration generally requires larger field camps to accommodate a greater number of employees and contractors. Safety issues—especially training on personal health issues, camp and worksite hazards, the safe use of equipment and traverse safety—become very important for geoscientists who may not have had previous field work experience.
Because exploration work is often carried out in remote areas, evacuation to a medical treatment centre may be difficult and may depend on weather or daylight conditions. Therefore, emergency procedures and communications should be carefully planned and tested before field work commences.

While outdoor safety may be considered common sense or “bush sense”, one should remember that what is considered common sense in one culture may not be so considered in another culture. Mining companies should provide exploration employees with a safety manual that addresses the issues of the regions where they work. A comprehensive safety manual can form the basis for camp orientation meetings, training sessions and routine safety meetings throughout the field season.

Preventing personal health hazards

Exploration work subjects employees to hard physical work that includes traversing terrain, frequent lifting of heavy objects, using potentially dangerous equipment and being exposed to heat, cold, precipitation and perhaps high altitude. It is essential that employees be in good physical condition and in good health when they begin field work. Employees should have up-to-date immunizations and be free of communicable diseases (e.g., hepatitis and tuberculosis) that may rapidly spread through a field camp. Ideally, all exploration workers should be trained and certified in basic first aid and wilderness first-aid skills. Larger camps or worksites should have at least one employee trained and certified in advanced or industrial first-aid skills.

Outdoor workers should wear suitable clothing that protects them from extremes of heat, cold and rain or snow. In regions with high levels of ultraviolet light, workers should wear a broad-brimmed hat and use a sunscreen lotion with a high sun protection factor (SPF) to protect exposed skin. When insect repellent is required, repellent that contains DEET (N,N-diethylmeta-toluamide) is most effective in preventing bites from mosquitoes. Clothing treated with permethrin helps protect against ticks.

Training - All field employees should receive training in such topics as lifting, the correct use of approved safety equipment (e.g., safety glasses, safety boots, respirators, appropriate gloves) and health precautions needed to prevent injury due to heat stress, cold stress, dehydration, ultraviolet light exposure, protection from insect bites and exposure to any endemic diseases. Exploration workers who take assignments in developing countries should educate themselves about local health and safety issues, including the possibility of kidnapping, robbery and assault.

Preventive measures for the campsite

Potential health and safety issues will vary with the location, size and type of work performed at a camp. Any field campsite should meet local fire, health, sanitation and safety regulations. A clean, orderly camp will help reduce accidents.

Location - A campsite should be established as close as safely possible to the worksite to minimize travel time and exposure to dangers associated with transportation. A campsite should be located away from any natural hazards and take into consideration the habits and habitat of wild animals that may invade a camp (e.g., insects, bears and reptiles). Whenever possible, camps should be near a source of clean drinking water. When working at very high altitude, the camp should be located at a lower elevation to help prevent altitude sickness.
Fire control and fuel handling - Camps should be set up so that tents or structures are well spaced to prevent or reduce the spread of fire. Fire-fighting equipment should be kept in a central cache and appropriate fire extinguishers kept in kitchen and office structures. Smoking regulations help prevent fires both in camp and in the field. All workers should participate in fire drills and know the plans for fire evacuation. Fuels should be accurately labelled to ensure that the correct fuel is used for lanterns, stoves, generators and so on. Fuel caches should be located at least 100 m from camp and above any potential flood or tide level.

Sanitation - Camps require a supply of safe drinking water. The source should be tested for purity, if required. When necessary, drinking water should be stored in clean, labelled containers separate from non-potable water. Food shipments should be examined for quality upon arrival and immediately refrigerated or stored in containers to prevent invasions from insects, rodents or larger animals. Hand-washing facilities should be located near eating areas and latrines. Latrines must conform to public health standards and should be located at least 100 m away from any stream or shoreline.

Camp equipment, field equipment and machinery - All equipment (e.g., chain saws, axes, rock hammers, machetes, radios, stoves, lanterns, geophysical and geochemical equipment) should be kept in good repair. If firearms are required for personal safety from wild animals such as bears, their use must be strictly controlled and monitored.

Communication - It is important to establish regular communication schedules. Good communication increases morale and security and forms a basis for an emergency response plan.

Training - Employees should be trained in the safe use all equipment. All geophysicists and helpers should be trained to use ground (earth) geophysical equipment that may operate at high current or voltage. Additional training topics should include fire prevention, fire drills, fuel handling and firearms handling, when relevant.

**Preventive measures at the worksite**

The target testing and advanced stages of exploration require larger field camps and the use of heavy equipment at the worksite. Only trained workers or authorized visitors should be permitted onto worksites where heavy equipment is operating.

Heavy equipment - Only properly licensed and trained personnel may operate heavy equipment. Workers must be constantly vigilant and never approach heavy equipment unless they are certain the operator knows where they are, what they intend to do and where they intend to go.

Drill rigs. Crews should be fully trained for the job. They must wear appropriate personal protective equipment (e.g., hard hats, steel-toed boots, hearing protection, gloves, goggles and dust masks) and avoid wearing loose clothing that may become caught in machinery. Drill rigs should comply with all safety requirements (e.g., guards that cover all moving parts of machinery, high pressure air hoses secured with clamps and safety chains). Workers should be aware of slippery, wet, greasy, or icy conditions underfoot and the drill area kept as orderly as possible.

Excavations - Pits and trenches should be constructed to meet safety guidelines with support systems or the sides cut back to 45° to deter collapse. Workers should never work alone or remain alone in a pit or trench, even for a short period of time, as these excavations collapse easily and may bury workers.
Explosives - Only trained and licensed personnel should handle explosives. Regulations for handling, storage and transportation of explosives and detonators should be carefully followed.

Preventive measures in traversing terrain

Exploration workers must be prepared to cope with the terrain and climate of their field area. The terrain may include deserts, swamps, forests, or mountainous terrain of jungle or glaciers and snowfields. Conditions may be hot or cold and dry or wet. Natural hazards may include lightning, bush fires, avalanches, mudslides or flash floods and so on. Insects, reptiles and/or large animals may present life-threatening hazards.

Workers must not take chances or place themselves in danger to secure samples. Employees should receive training in safe traversing procedures for the terrain and climate conditions where they work. They need survival training to recognize and combat hypothermia, hyperthermia and dehydration. Employees should work in pairs and carry enough equipment, food and water (or have access in an emergency cache) to enable them to spend an unexpected night or two out in the field if an emergency situation arises. Field workers should maintain routine communication schedules with the base camp. All field camps should have established and tested emergency response plans in case field workers need rescuing.

Preventive measures in transportation

Many accidents and incidents occur during transportation to or from an exploration worksite. Excessive speed and/or alcohol consumption while driving vehicles or boats are relevant safety issues.

Vehicles - Common causes of vehicle accidents include hazardous road and/or weather conditions, overloaded or incorrectly loaded vehicles, unsafe towing practices, driver fatigue, inexperienced drivers and animals or people on the road—especially at night. Preventive measures include following defensive driving techniques when operating any type of vehicle. Drivers and passengers of cars and trucks must use seatbelts and follow safe loading and towing procedures. Only vehicles that can safely operate in the terrain and weather conditions of the field area, e.g., 4-wheel drive vehicles, 2-wheel motor bikes, all-terrain vehicles (ATVs) or snowmobiles should be used. Vehicles must have regular maintenance and contain adequate equipment including survival gear. Protective clothing and a helmet are required when operating ATVs or 2-wheel motor bikes.

Aircraft - Access to remote sites frequently depends on fixed wing aircraft and helicopters. Only charter companies with well-maintained equipment and a good safety record should be engaged. Aircraft with turbine engines are recommended. Pilots must never exceed the legal number of allowable flight hours and should never fly when fatigued or be asked to fly in unacceptable weather conditions. Pilots must oversee the proper loading of all aircraft and comply with payload restrictions. To prevent accidents, exploration workers must be trained to work safely around aircraft. They must follow safe embarkation and loading procedures. No one should walk in the direction of the propellers or rotor blades; they are invisible when moving. Helicopter landing sites should be kept free of loose debris that may become airborne projectiles in the downdraft of rotor blades.

Slinging - Helicopters are often used to move supplies, fuel, drill and camp equipment. Some major hazards include overloading, incorrect use of or poorly maintained slinging equipment, untidy worksites with debris or equipment that may be blown about, protruding vegetation or anything
that loads may snag on. In addition, pilot fatigue, lack of personnel training, miscommunication between parties involved (especially between the pilot and groundman) and marginal weather conditions increase the risks of slinging. For safe slinging and to prevent accidents, all parties must follow safe slinging procedures and be fully alert and well briefed with mutual responsibilities clearly understood. The sling cargo weight must not exceed the lifting capacity of the helicopter. Loads should be arranged so they are secure and nothing will slip out of the cargo net. When slinging with a very long line (e.g., jungle, mountainous sites with very tall trees), a pile of logs or large rocks should be used to weigh down the sling for the return trip because one should never fly with empty slings or lanyards dangling from the sling hook. Fatal accidents have occurred when unweighted lanyards have struck the helicopter tail or main rotor during flight.

Boats - Workers who rely on boats for field transportation on coastal waters, mountain lakes, streams or rivers may face hazards from winds, fog, rapids, shallows, and submerged or semi-submerged objects. To prevent boating accidents, operators must know and not exceed the limitations of their boat, their motor and their own boating capabilities. The largest, safest boat available for the job should be used. All workers should wear a good quality personal flotation device (PFD) whenever travelling and/or working in small boats. In addition, all boats must contain all legally required equipment plus spare parts, tools, survival and first aid equipment and always carry and use up-to-date charts and tide tables.

3. TYPES OF COAL MINING

The rationale for selecting a method for mining coal depends on such factors as topography, geometry of the coal seam, geology of the overlying rocks and environmental requirements or restraints. Overriding these, however, are the economic factors. They include: availability, quality and costs of the required work force (including the availability of trained supervisors and managers); adequacy of housing, feeding and recreational facilities for the workers (especially when the mine is located at a distance from a local community); availability of the necessary equipment and machinery and of workers trained to operate it; availability and costs of transportation for workers, necessary supplies, and for getting the coal to the user or purchaser; availability and the cost of the necessary capital to finance the operation (in local currency); and the market for the particular type of coal to be extracted (i.e., the price at which it may be sold). A major factor is the stripping ratio, that is, the amount of overburden material to be removed in proportion to the amount of coal that can be extracted; as this increases, the cost of mining becomes less attractive. An important factor, especially in surface mining that, unfortunately, is often overlooked in the equation is the cost of restoring the terrain and the environment when the mining operation is closed down.

Health and Safety

Another critical factor is the cost of protecting the health and safety of the miners. Unfortunately, particularly in small-scale operations, instead of being weighed in deciding whether or how the coal should be extracted, the necessary protective measures are often ignored or short-changed.

Actually, although there are always unsuspected hazards—they may come from the elements rather than the mining operations—any mining operation can be safe providing there is a commitment from all parties to a safe operation.

Surface Coal Mines
Surface mining of coal is performed by a variety of methods depending on the topography, the area in which the mining is being undertaken and environmental factors. All methods involve the removal of overburden material to allow for the extraction of the coal. While generally safer than underground mining, surface operations do have some specific hazards that must be addressed. Prominent among these is the use of heavy equipment which, in addition to accidents, may involve exposure to exhaust fumes, noise and contact with fuel, lubricants and solvents. Climatic conditions, such as heavy rain, snow and ice, poor visibility and excessive heat or cold may compound these hazards. When blasting is required to break up rock formations, special precautions in the storage, handling and use of explosives are required.

Surface operations require the use of huge waste dumps to store overburden products. Appropriate controls must be implemented to prevent dump failure and to protect the employees, the general public and the environment.

Underground Coal Mining

There is also a variety of methods for underground mining. Their common denominator is the creation of tunnels from the surface to the coal seam and the use of machines and/or explosives to extract the coal. In addition to the high frequency of accidents—coal mining ranks high on the list of hazardous workplaces wherever statistics are maintained—the potential for a major incident involving multiple loss of life is always present in underground operations. Two primary causes of such catastrophes are cave-ins due to faulty engineering of the tunnels and explosion and fire due to the accumulation of methane and/or flammable levels of airborne coal dust.

Methane

Methane is highly explosive in concentrations of 5 to 15% and has been the cause of numerous mining disasters. It is best controlled by providing adequate air flow to dilute the gas to a level that is below its explosive range and to exhaust it quickly from the workings. Methane levels must be continuously monitored and rules established to close down operations when its concentration reaches 1 to 1.5% and to evacuate the mine promptly if it reaches levels of 2 to 2.5%.

Coal dust

In addition to causing black lung disease (anthracosis) if inhaled by miners, coal dust is explosive when fine dust is mixed with air and ignited. Airborne coal dust can be controlled by water sprays and exhaust ventilation. It can be collected by filtering re-circulating air or it can be neutralized by the addition of stone dust in sufficient quantities to render the coal dust/air mixture inert.

4. TECHNIQUES IN UNDERGROUND MINING

There are underground mines all over the world presenting a kaleidoscope of methods and equipment. There are approximately 650 underground mines, each with an annual output that exceeds 150,000 tonnes, which account for 90% of the ore output of the western world. In addition, it is estimated that there are 6,000 smaller mines each producing less than 150,000 tonnes. Each mine is unique with workplace, installations and underground workings dictated by the kinds of minerals being sought and the location and geological formations, as well as by such economic considerations as the market for the particular mineral and the availability of funds for investment. Some mines have been in continuous operation for more than a century while others are just starting up.
Mines are dangerous places where most of the jobs involve arduous labour. The hazards faced by the workers range from such catastrophes as cave-ins, explosions and fire to accidents, dust exposure, noise, heat and more. Protecting the health and safety of the workers is a major consideration in properly conducted mining operations and, in most countries, is required by laws and regulations.

**The Underground Mine**

The underground mine is a factory located in the bedrock inside the earth in which miners work to recover minerals hidden in the rock mass. They drill, charge and blast to access and recover the ore, i.e., rock containing a mix of minerals of which at least one can be processed into a product that can be sold at a profit. The ore is taken to the surface to be refined into a high-grade concentrate.

Working inside the rock mass deep below the surface requires special infrastructures: a network of shafts, tunnels and chambers connecting with the surface and allowing movement of workers, machines and rock within the mine. The shaft is the access to underground where lateral drifts connect the shaft station with production stopes. The internal ramp is an inclined drift which links underground levels at different elevations (i.e., depths). All underground openings need services such as exhaust ventilation and fresh air, electric power, water and compressed air, drains and pumps to collect seeping ground water, and a communication system.

**Hoisting plant and systems**

The headframe is a tall building which identifies the mine on the surface. It stands directly above the shaft, the mine’s main artery through which the miners enter and leave their workplace and through which supplies and equipment are lowered and ore and waste materials are raised to the surface. Shaft and hoist installations vary depending on the need for capacity, depth and so on. Each mine must have at least two shafts to provide an alternate route for escape in case of an emergency.

Hoisting and shaft travelling are regulated by stringent rules. Hoisting equipment (e.g., winder – Drum or Koepe, brakes and rope) is designed with ample margins of safety and is checked at regular intervals. The shaft interior is regularly inspected by people standing on top of the cage, and stop buttons at all stations trigger the emergency brake.

The gates in front of the shaft barricade the openings when the cage is not at the station. When the cage arrives and comes to a full stop, a signal clears the gate for opening. After miners have entered the cage and closed the gate, another signal clears the cage for moving up or down the shaft. Practice varies: the signal commands may be given by a cage tender or, following the instructions posted at each shaft station, the miners may signal shaft destinations for themselves. Miners are generally quite aware of the potential hazards in shaft riding and hoisting and accidents are rare.

**Diamond drilling**

A mineral deposit inside the rock must be mapped before the start of mining. It is necessary to know where the orebody is located and define its width, length and depth to achieve a three-dimensional vision of the deposit.

Diamond drilling is used to explore a rock mass. Drilling can be done from the surface or from the drift in the underground mine. A drill bit studded with small diamonds cuts a cylindrical core that is captured in the string of tubes that follows the bit. The core is retrieved and analysed to find out
what is in the rock. Core samples are inspected and the mineralized portions are split and analysed for metal content. Extensive drilling programmes are required to locate the mineral deposits; holes are drilled at both horizontal and vertical intervals to identify the dimensions of the ore body.

Mine development

Mine development involves the excavations needed to establish the infrastructure necessary for stope production and to prepare for the future continuity of operations. Routine elements, all produced by the drill-blast-excavation technique, include horizontal drifts, inclined ramps and vertical or inclined raises.

Shaft sinking

Shaft sinking involves rock excavation advancing downwards and is usually assigned to contractors rather than being done by mine’s personnel. It requires experienced workers and special equipment, such as a shaft-sinking headframe, a special hoist with a large bucket hanging in the rope and a cactus-grab shaft mucking device.

The shaft-sinking crew is exposed to a variety of hazards. They work at the bottom of a deep, vertical excavation. People, material and blasted rock must all share the large bucket. People at the shaft bottom have no place to hide from falling objects. Clearly, shaft sinking is not a job for the inexperienced.

Drifting and ramping

A drift is a horizontal access tunnel used for transport of rock and ore. Drift excavation is a routine activity in the development of the mine. In mechanized mines, two-boom, electro-hydraulic drill jumbos are used for face drilling. Typical drift profiles are 16.0 m² in section and the face is drilled to a depth of 4.0 m. The holes are charged pneumatically with an explosive, usually bulk ammonium nitrate fuel oil (ANFO), from a special charging truck. Short-delay non-electric (Nonel) detonators are used.

Mucking is done with (load-haul-dump) LHD vehicles with a bucket capacity of about 3.0 m³. Muck is hauled directly to the ore pass system and transferred to truck for longer hauls. Ramps are passageways connecting one or more levels at grades ranging from 1:7 to 1:10 (a very steep grade compared to normal roads) that provide adequate traction for heavy, self-propelled equipment. The ramps are often driven in an upward or downward spiral, similar to a spiral staircase. Ramp excavation is a routine in the mine’s development schedule and uses the same equipment as drifting.

Raising

A raise is a vertical or steeply-inclined opening that connects different levels in the mine. It may serve as a ladder-way access to stopes, as an ore pass or as an airway in the mine’s ventilation system. Raising is a difficult and dangerous, but necessary job. Raising methods vary from simple manual drill and blast to mechanical rock excavation with raise boring machines (RBMs).

Manual raising - Manual raising is difficult, dangerous and physically demanding work that challenges the miner’s agility, strength and endurance. It is a job to be assigned only to experienced miners in good physical condition. As a rule the raise section is divided into two

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compartments by a timbered wall. One is kept open for the ladder used for climbing to the face, air pipes, etc. The other fills with rock from blasting which the miner uses as a platform when drilling the round. The timber parting is extended after each round. The work involves ladder climbing, timbering, rock drilling and blasting, all done in a cramped, poorly ventilated space. It is all performed by a single miner, as there is no room for a helper. Mines search for alternatives to the hazardous and laborious manual raising methods.

The raise climber - The raise climber is a vehicle that obviates ladder climbing and much of the difficulty of the manual method. This vehicle climbs the raise on a guide rail bolted to the rock and provides a robust working platform when the miner is drilling the round above. Very high raises can be excavated with the raise climber with safety much improved over the manual method. Raise excavation, however, remains a very hazardous job.

The raise boring machine - The RBM is a powerful machine that breaks the rock mechanically. It is erected on top of the planned raise and a pilot hole about 300 mm in diameter is drilled to break through at a lower level target. The pilot drill is replaced by a reamer head with the diameter of the intended raise and the RBM is put in reverse, rotating and pulling the reamer head upward to create a full-size circular raise.

Ground control

Ground control is an important concept for people working inside a rock mass. It is particularly important in mechanized mines using rubber-tyred equipment where the drift openings are 25.0 m² in section, in contrast to the mines with rail drifts where they are usually only 10.0 m². The roof at 5.0 m is too high for a miner to use a scaling bar to check for potential rock falls.
Different measures are used to secure the roof in underground openings. In smooth blasting, contour holes are drilled closely together and charged with a low-strength explosive. The blast produces a smooth contour without fracturing the outside rock.

Nevertheless, since there are often cracks in the rock mass which do not show on the surface, rock falls are an ever-present hazard. The risk is reduced by rock bolting, i.e., insertion of steel rods in bore holes and fastening them. The rock bolt holds the rock mass together, prevents cracks from spreading, helps to stabilize the rock mass and makes the underground environment safer.

Methods for Underground Mining

The choice of mining method is influenced by the shape and size of the ore deposit, the value of the contained minerals, the composition, stability and strength of the rock mass and the demands for production output and safe working conditions (which sometimes are in conflict). While mining methods have been evolving since antiquity, this article focuses on those used in semi- to fully-mechanized mines during the late twentieth century. Each mine is unique, but they all share the goals of a safe workplace and a profitable business operation.

Flat room-and-pillar mining

Room-and-pillar mining is applicable to tabular mineralization with horizontal to moderate dip at an angle not exceeding 20°. The deposits are often of sedimentary origin and the rock is often in both hanging wall and mineralization in competent (a relative concept here as miners have the option to install rock bolts to reinforce the roof where its stability is in doubt). Room-and-pillar is one of the principal underground coal-mining methods.

Room-and-pillar extracts an orebody by horizontal drilling advancing along a multi-faced front, forming empty rooms behind the producing front. Pillars, sections of rock, are left between the rooms to keep the roof from caving. The usual result is a regular pattern of rooms and pillars, their relative size representing a compromise between maintaining the stability of the rock mass and extracting as much of the ore as possible. This involves careful analysis of the strength of the pillars, the roof strata span capacity and other factors. Rock bolts are commonly used to increase the strength of the rock in the pillars. The mined-out stopes serve as roadways for trucks transporting the ore to the mine’s storage bin.

The room-and-pillar stope face is drilled and blasted as in drifting. The stope width and height correspond to the size of the drift, which can be quite large. Large productive drill jumbos are used in normal height mines; compact rigs are used where the ore is less than 3.0 m thick. The thick orebody is mined in steps starting from the top so that the roof can be secured at a height convenient for the miners. The section below is recovered in horizontal slices, by drilling flat holes and blasting against the space above. The ore is loaded onto trucks at the face. Normally, regular front-end loaders and dump trucks are used. For the low-height mine, special mine trucks and LHD vehicles are available.

Room-and-pillar is an efficient mining method. Safety depends on the height of the open rooms and ground control standards. The main risks are accidents caused by falling rock and moving equipment.

Inclined room-and-pillar mining
Inclined room-and-pillar applies to tabular mineralization with an angle or dip from 15° and 30° to the horizontal. This is too steep an angle for rubber-tyred vehicles to climb and too flat for a gravity assist rock flow.

The traditional approach to the inclined orebody relies on manual labour. The miners drill blast holes in the stopes with hand-held rock drills. The stope is cleaned with slusher scrapers.

The inclined stope is a difficult place to work. The miners have to climb the steep piles of blasted rock carrying with them their rock drills and the drag slusher pulley and steel wires. In addition to rock falls and accidents, there are the hazards of noise, dust, inadequate ventilation and heat.

Where the inclined ore deposits are adaptable to mechanization, “step-room mining” is used. This is based on converting the “difficult dip” footwall into a “staircase” with steps at an angle convenient for trackless machines. The steps are produced by a diamond pattern of stopes and haulage-ways at the selected angle across the orebody.

Ore extraction starts with horizontal stope drives, branching out from a combined access-haulage drift. The initial stope is horizontal and follows the hanging wall. The next stope starts a short distance further down and follows the same route. This procedure is repeated moving downward to create a series of steps to extract the orebody.

Sections of the mineralization are left to support the hanging wall. This is done by mining two or three adjacent stope drives to the full length and then starting the next stope drive one step down, leaving an elongated pillar between them. Sections of this pillar can later be recovered as cut-outs that are drilled and blasted from the stope below.

Modern trackless equipment adapts well to step-room mining. The stoping can be fully mechanized, using standard mobile equipment. The blasted ore is gathered in the stopes by the LHD vehicles and transferred to mine truck for transport to the shaft/ore pass. If the stope is not high enough for truck loading, the trucks can be filled in special loading bays excavated in the haulage drive.

**Shrinkage stoping**

Shrinkage stoping may be termed a “classic” mining method, having been perhaps the most popular mining method for most of the past century. It has largely been replaced by mechanized methods but is still used in many small mines around the world. It is applicable to mineral deposits with regular boundaries and steep dip hosted in a competent rock mass. Also, the blasted ore must not be affected by storage in the slopes (e.g., sulphide ores have a tendency to oxidize and decompose when exposed to air).

Its most prominent feature is the use of gravity flow for ore handling: ore from stopes drops directly into rail cars via chutes obviating manual loading, traditionally the most common and least liked job in mining. Until the appearance of the pneumatic rocker shovel in the 1950s, there was no machine suitable for loading rock in underground mines.

Shrinkage stoping extracts the ore in horizontal slices, starting at the stope bottoms and advancing upwards. Most of the blasted rock remains in the stope providing a working platform for the miner drilling holes in the roof and serving to keep the stope walls stable. As blasting increases the volume of the rock by about 60%, some 40% of the ore is drawn at the bottom during stoping in order to
maintain a work space between the top of the muckpile and the roof. The remaining ore is drawn after blasting has reached the upper limit of the stope.

The necessity of working from the top of the muckpile and the raise-ladder access prevents the use of mechanized equipment in the stope. Only equipment light enough for the miner to handle alone may be used. The air-leg and rock drill, with a combined weight of 45 kg, is the usual tool for drilling the shrinkage stope. Standing on top of the muckpile, the miner picks up the drill/feed, anchors the leg, braces the rock drill/drill steel against the roof and starts drilling; it is not easy work.

Cut-and-fill mining

Cut-and-fill mining is suitable for a steeply dipping mineral deposit contained in a rock mass with good to moderate stability. It removes the ore in horizontal slices starting from a bottom cut and advances upwards, allowing the stope boundaries to be adjusted to follow irregular mineralization. This permits high-grade sections to be mined selectively, leaving low-grade ore in place.

After the stope is mucked clean, the mined out space is backfilled to form a working platform when the next slice is mined and to add stability to the stope walls.

Development for cut-and-fill mining in a trackless environment includes a footwall haulage drive along the orebody at the main level, undercut of the stope provided with drains for the hydraulic backfill, a spiral ramp excavated in the footwall with access turn-outs to the stopes and a raise from the stope to the level above for ventilation and fill transport.

Overhand stoping is used with cut-and-fill, with both dry rock and hydraulic sand as backfill material. Overhand means that the ore is drilled from below by blasting a slice 3.0 m to 4.0 m thick. This allows the complete stope area to be drilled and the blasting of the full stope without interruptions. The “uppers” holes are drilled with simple wagon drills.

Up-hole drilling and blasting leaves a rough rock surface for the roof; after mucking out, its height will be about 7.0 m. Before miners are allowed to enter the area, the roof must be secured by trimming the roof contours with smooth-blasting and subsequent scaling of the loose rock. This is done by miners using hand-held rock drills working from the muckpile.

In front stoping, trackless equipment is used for ore production. Sand tailings are used for backfill and distributed in the underground stopes via plastic pipes. The stopes are filled almost completely, creating a surface sufficiently hard to be traversed by rubber-tyred equipment. The stope production is completely mechanized with drifting jumbos and LHD vehicles. The stope face is a 5.0 m vertical wall across the stope with a 0.5 m open slot beneath it. Five-meter-long horizontal holes are drilled in the face and ore is blasted against the open bottom slot.

The tonnage produced by a single blast depends on the face area and does not compare to that yielded by the overhand stope blast. However, the output of trackless equipment is vastly superior to the manual method, while roof control can be accomplished by the drill jumbo which drills smooth-blast holes together with the stope blast. Fitted with an oversize bucket and large tyres, the LHD vehicle, a versatile tool for mucking and transport, travels easily on the fill surface. In a double face stope, the drill jumbo engages it on one side while the LHD handles the muckpile at the other end, providing efficient use of the equipment and enhancing the production output.

Sublevel Stoping

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Sublevel stoping removes ore in open stopes. Backfilling of stopes with consolidated fill after the mining allows the miners to return at a later time to recover the pillars between the stopes, enabling a very high recovery rate of the mineral deposit.

Development for sublevel stoping is extensive and complex. The orebody is divided into sections with a vertical height of about 100 m in which sublevels are prepared and connected via an inclined ramp. The orebody sections are further divided laterally in alternating stopes and pillars and a mail haulage drive is created in the footwall, at the bottom, with cut-outs for drawpoint loading.

When mined out, the sublevel stope will be a rectangular opening across the orebody. The bottom of the stope is V-shaped to funnel the blasted material into the draw-points. Drilling drifts for the long-hole rig are prepared on the upper sublevels.

Blasting requires space for the rock to expand in volume. This requires that a slot a few metres wide be prepared before the start of long-hole blasting. This is accomplished by enlarging a raise from the bottom to the top of the stope to a full slot.

After opening the slot, the long-hole rig begins production drilling in sublevel drifts following precisely a detailed plan designed by blasting experts which specifies all the blast holes, the collaring position, depth and direction of the holes. The drill rig continues drilling until all the rings on one level are completed. It is then transferred to the next sublevel to continue drilling. Meanwhile the holes are charged and a blast pattern which covers a large area within the stope breaks up a large volume of ore in one blast. The blasted ore drops to the stope bottom to be recovered by the LHD vehicles mucking in the draw-point beneath the stope. Normally, the long-hole drilling stays ahead of the charging and blasting providing a reserve of ready-to-blast ore, thus making for an efficient production schedule.

Sublevel stoping is a productive mining method. Efficiency is enhanced by the ability to use fully mechanized productive rigs for the long-hole drilling plus the fact that the rig can be used continuously. It is also relatively safe because doing the drilling inside sublevel drifts and mucking through draw-points eliminates exposure to potential rock falls.

**Vertical crater retreat (VCR) mining**

Like sublevel stoping and shrinkage stoping, vertical crater retreat (VCR) mining is applicable to mineralization in steeply dipping strata. However, it uses a different blasting technique breaking the rock with heavy, concentrated charges placed in holes (“craters”) with very large diameter (about 165 mm) about 3 m away from a free rock surface. Blasting breaks a cone-shaped opening in the rock mass around the hole and allows the blasted material to remain in the stope during the production phase so that the rock fill can assist in supporting the stope walls. The need for rock stability is less than in sublevel stoping.

The development for VCR mining is similar to that for sublevel stoping except for requiring both over-cut and under-cut excavations. The over-cut is needed in the first stage to accommodate the rig drilling the large-diameter blast holes and for access while charging the holes and blasting. The under-cut excavation provided the free surface necessary for VCR blasting. It may also provide access for a LHD vehicle (operated by remote control with the operator remaining outside the stope) to recover the blasted ore from the draw-points beneath the stope.
The usual VCR blast uses holes in a $4.0 \times 4.0 \text{ m}$ pattern directed vertically or steeply inclined with charges carefully placed at calculated distances to free the surface beneath. The charges cooperate to break off a horizontal ore slice about $3.0 \text{ m}$ thick. The blasted rock falls into the stope underneath. By controlling the rate of mucking out, the stope remains partly filled so that the rock fill assists in stabilizing the stope walls during the production phase. The last blast breaks the over-cut into the stope, after which the stope is mucked clean and prepared for back filling.

VCR mines often uses a system of primary and secondary stopes to the orebody. Primary stopes are mined in the first stage, then backfilled with cemented fill. The stope is left for the fill to consolidate. Miners then return and recover the ore in the pillars between the primary stopes, the secondary stopes. This system, in combination with the cemented backfill, results in close to a 100% recovery of the ore reserves. For more on VCR mining method refer: [Blasting in High Production UG Metal Mines workings - Vertical Crater Retreat (VCR) method](http://miningandblasting.wordpress.com/)

**Sublevel caving**

Sublevel caving is applicable to mineral deposits with steep to moderate dip and large extension at depth. The ore must fracture into manageable block with blasting. The hanging wall will cave following the ore extraction and the ground on the surface above the orebody will subside. (It must be barricaded to prevent any individuals from entering the area.)

Sublevel caving is based on gravity flow inside a broken-up rock mass containing both ore and rock. The rock mass is first fractured by drilling and blasting and then mucked out through drift headings underneath the rock mass cave. It qualifies as a safe mining method because the miners always work inside drift-size openings.

Sublevel caving depends on sublevels with regular patterns of drifts prepared inside the orebody at rather close vertical spacing (from 10.0 m to 20 0 m). The drift layout is the same on each sublevel (i.e., parallel drives across the orebody from the footwall transport drive to the hanging wall) but the patterns on each sublevel are slightly off-set so that the drifts on a lower level are located between the drifts on the sublevel above it. A cross section will show a diamond pattern with drifts in regular vertical and horizontal spacing. Thus, development for sublevel caving is extensive. Drift excavation, however, is a straightforward task which can readily be mechanized. Working on multiple drift headings on several sublevels favours high utilization of the equipment.

When the development of the sublevel is completed, the long-hole drill rig moves in to drill a blast holes in a fan-spread pattern in the rock above. When all of the blast holes are ready, the long-hole drill rig is moved to the sublevel below.

The long-hole blast fractures the rock mass above the sublevel drift, initiating a cave that starts at the hanging wall contact and retreats toward the footwall following a straight front across the orebody on the sublevel. A vertical section would show a staircase where each upper sublevel is one step ahead of the sublevel below.

The blast fills the sublevel front with a mix of ore and waste. When the LHD vehicle arrives, the cave contains 100% ore. As loading continues, the proportion of waste rock will gradually increase until the operator decides that the waste dilution is too high and stops loading. As the loader moves to the next drift to continue mucking, the blaster enters to prepare the next ring of holes for blasting.
Mucking out on sublevels is an ideal application for the LHD vehicle. Available in different sizes to meet particular situations, it fills the bucket, travels some 200 m, empties the bucket into the ore pass and returns for another load.

Sublevel caving features a schematic layout with repetitive work procedures (development drifting, long-hole drilling, charging and blasting, loading and transport) that are carried out independently. This allows the procedures to move continuously from one sublevel to another, allowing for the most efficient use of work crews and equipment. In effect the mine is analogous to a departmentalized factory. Sublevel mining, however, being less selective than other methods, does not yield particularly efficient extraction rates. The cave includes some 20 to 40% of waste with a loss of ore that ranges from 15 to 25%. For more refer: **SUBLEVEL CAVING TECHNIQUE**

**Block-caving**

Block-caving is a large-scale method applicable to mineralization on the order of 100 million tonnes in all directions contained in rock masses amenable to caving (i.e., with internal stresses which, after removal of the supporting elements in the rock mass, assist the fracturing of the mined block). An annual output ranging from 10 to 30 million tonnes is the anticipated yield. These requirements limit block-caving to a few specific mineral deposits. Worldwide, there are block-caving mines exploiting deposits containing copper, iron, molybdenum and diamonds.

Block refers to the mining layout. The orebody is divided into large sections, blocks, each containing a tonnage sufficient for many years of production. The caving is induced by removing the supporting strength of the rock mass directly underneath the block by means of an undercut, a 15 m high section of rock fractured by long-hole drilling and blasting. Stresses created by natural tectonic forces of considerable magnitude, similar to those causing continental movements, create cracks in the rock mass, breaking the blocks, hopefully to pass draw-point openings in the mine. Nature, though, often needs the assistance of miners to handle oversize boulders.

Preparation for block-caving requires long-range planning and extensive initial development involving a complex system of excavations beneath the block. These vary with the site; they generally include undercut, drawbells, grizzlies for control of oversize rock and ore passes that funnel the ore into train loading.

Drawbells are conical openings excavated underneath the undercut which gather ore from a large area and funnel it into the drawpoint at the production level below. Here the ore is recovered in LHD vehicles and transferred to ore passes. Boulders too large for the bucket are blasted in draw-points, while smaller ones are dealt with on the grizzly. Grizzlies, sets of parallel bars for screening coarse material, are commonly used in block-caving mines although, increasingly, hydraulic breakers are being preferred.

Openings in a block-caving mine are subject to high rock pressure. Drifts and other openings, therefore, are excavated with the smallest possible section. Nevertheless, extensive rock bolting and concrete lining is required to keep the openings intact.

Properly applied, block-caving is a low-cost, productive mass mining method. However, the amenability of a rock mass to caving is not always predictable. Also, the comprehensive development that is required results in a long lead-time before the mine starts producing; the delay in earnings can have a negative influence on the financial projections used to justify the investment.
Longwall mining

Longwall mining is applicable to bedded deposits of uniform shape, limited thickness and large horizontal extension (e.g., a coal seam, a potash layer or the reef, the bed of quartz pebbles exploited by gold mines in South Africa). It is one of the main methods for mining coal. It recovers the mineral in slices along a straight line that are repeated to recover materials over a larger area. The space closest to the face in kept open while the hanging wall is allowed to collapse at a safe distance behind the miners and their equipment.

Preparation for longwall mining involves the network of drifts required for access to the mining area and transport of the mined product to the shaft. Since the mineralization is in the form of a sheet that extends over a wide area, the drifts can usually be arranged in a schematic network pattern. The haulage drifts are prepared in the seam itself. The distance between two adjacent haulage drifts determines the length of the longwall face.

Backfilling

Backfilling of mine stopes prevents rock from collapsing. It preserves the inherent stability of the rock mass which promotes safety and allows more complete extraction of the desired ore. Backfilling is traditionally used with cut-and-fill but it is also common with sublevel stoping and VCR mining.

Traditionally, miners have dumped waste rock from development in empty stopes instead of hauling it to the surface. For example, in cut-and-fill, waste rock is distributed over the empty stope by scrapers or bulldozers.

Hydraulic backfilling uses tailings from the mine’s dressing plant which are distributed underground through bore holes and plastic tubing. The tailings are first de-slimed, only the coarse fraction being used for filling. The fill is a mix of sand and water, about 65% of which is solid matter. By mixing cement into the last pour, the fill’s surface will harden into a smooth roadbed for rubber-tyred equipment.

Backfilling is also used with sublevel stoping and VCR mining, with crushed rock introduced as a complement to sand fill. The crushed and screened rock, produced in a nearby quarry, is delivered underground through special backfill raises where it is loaded on trucks and delivered to the stopes where it is dumped into special fill raises. Primary stopes are backfilled with cemented rock fill produced by spraying a cement-fly ash slurry on the rockfill before it is distributed to the stopes. The cemented rockfill hardens into a solid mass forming an artificial pillar for mining the secondary stope. The cement slurry is generally not required when secondary stopes are backfilled, except for the last pours to establish a firm mucking floor.

5. EQUIPMENT FOR UNDERGROUND MINING

Underground mining is becoming increasingly mechanized wherever circumstances permit. The rubber-tyred, diesel-powered, four-wheel traction, articulated steer carrier is common to all mobile underground machines.

Face drill jumbo for development drilling - This is an indispensable workhorse in mines that is used for all rock excavation work. It carries one or two booms with hydraulic rock drills. With one worker at the control panel, it will complete a pattern of 60 blast holes 4.0 m deep in a few hours.
**Long-hole production drill rig** - This rig drills blast holes in a radial spread around the drift which cover a large area of rock and break off large volumes of ore. It is used with sublevel stoping, sublevel caving, block-caving and VCR mining. With a powerful hydraulic rock drill and carousel storage for extension rods, the operator uses remote controls to perform rock drilling from a safe position.

**Charging truck** - The charging truck is a necessary complement to the drifting jumbo. The carrier mounts a hydraulic service platform, a pressurized ANFO explosive container and a charging hose that permit the operator to fill blast holes all over the face in a very short time. At the same time, Nonel detonators may be inserted for the correct timing of the individual blasts.

**LHD vehicle** - The versatile load-haul-dump vehicle is used for a variety of services including ore production and materials handling. It is available in a choice of sizes allowing miners to select the model most appropriate for each task and each situation. Unlike the other diesel vehicles used in mines, the LHD vehicle engine is generally run continuously at full power for long periods of time generating large volumes of smoke and exhaust fumes. A ventilation system capable of diluting and exhausting these fumes is essential to compliance with acceptable breathing standards in the loading area.

**Underground haulage** - The ore recovered in stopes spread along an orebody is transported to an ore dump located close to the hoisting shaft. Special haulage levels are prepared for longer lateral transfer; they commonly feature rail track installations with trains for ore transport. Rail has proved to be an efficient transport system carrying larger volumes for longer distances with electric locomotives that do not contaminate the underground atmosphere like diesel-powered trucks used in trackless mines.

**Ore handling** - On its route from the stopes to the hoisting shaft, the ore passes several stations with a variety of materials-handling techniques.

The slusher uses a scraper bucket to draw ore from the stope to the ore pass. It is equipped with rotating drums, wires and pulleys, arranged to produce a back and forth scraper route. The slusher does not need preparation of the stope flooring and can draw ore from a rough muckpile.

The LHD vehicle, diesel powered and travelling on rubber tyres, takes the volume held in its bucket (sizes vary) from the muckpile to the ore pass.

The ore pass is a vertical or steeply inclined opening through which rock flows by gravity from upper to lower levels. Ore passes are sometimes arranged in a vertical sequence to collect ore from upper levels to a common delivery point on the haulage level.

The chute is the gate located at the bottom of the ore pass. Ore passes normally end in rock close to the haulage drift so that, when the chute is opened, the ore can flow to fill cars on the track beneath it.

Close to the shaft, the ore trains pass a dump station where the load may be dropped into a storage bin, A grizzly at the dump station stops oversized rocks from falling into the bin. These boulders are split by blasting or hydraulic hammers; a coarse crusher may be installed below the grizzly for further size control. Under the storage bin is a measure pocket which automatically verifies that the load’s volume and weight do not exceed the capacities of the skip and the hoist. When an empty skip, a container for vertical travel, arrives at the filling station, a chute opens in the bottom of the
measure pocket filling the skip with a proper load. After the hoist lifts the loaded skip to the
headframe on the surface, a chute opens to discharge the load into the surface storage bin. Skip
hoisting can be automatically operated using closed-circuit television to monitor the process.

6. UNDERGROUND COAL MINING

Underground coal production first began with access tunnels, or adits, being mined into seams from
their surface outcrops. However, problems caused by inadequate means of transport to bring coal to
the surface and by the increasing risk of igniting pockets of methane from candles and other open
flame lights limited the depth to which early underground mines could be worked.

Increasing demand for coal during the Industrial Revolution gave the incentive for shaft sinking to
access deeper coal reserves, and by the mid-twentieth century by far the greater proportion of
world coal production came from underground operations. During the 1970s and 1980s there was
widespread development of new surface coal mine capacity, particularly in countries such as the
United States, South Africa, Australia and India. In the 1990s, however, renewed interest in
underground mining resulted in new mines being developed (in Queensland, Australia, for instance)
from the deepest points of former surface mines. In the mid-1990s, underground mining accounted
for perhaps 45% of all the hard coal mined worldwide. The actual proportion varied widely, ranging
from under 30% in Australia and India to around 95% in China. For economic reasons, lignite and
brown coal are rarely mined underground.

An underground coal mine consists essentially of three components: a production area; coal
transport to the foot of a shaft or decline; and either hoisting or conveying the coal to the surface.
Production also includes the preparatory work that is needed in order to permit access to future
production areas of a mine and, in consequence, represents the highest level of personal risk.

Mine Development

The simplest means of accessing a coal seam is to follow it in from its surface outcrop, a still widely
practised technique in areas where the overlying topography is steep and the seams are relatively
flat-lying. An example is the Appalachian coalfield of southern West Virginia in the United States. The
actual mining method used in the seam is immaterial at this point; the important factor is that
access can be gained cheaply and with minimal construction effort. Adits are also commonly used in
areas of low-technology coal mining, where the coal produced during mining of the adit can be used
to offset its development costs.

Other means of access include declines (or ramps) and vertical shafts. The choice usually depends on
the depth of the coal seam being worked: the deeper the seam, the more expensive it is to develop
a graded ramp along which vehicles or belt conveyors can operate.

Shaft sinking, in which a shaft is mined vertically downwards from the surface, is both costly and
time-consuming and requires a longer lead-time between the commencement of construction and
the first coal being mined. In cases where the seams are deep-lying, as in most European countries
and in China, shafts often have to be sunk through water-bearing rocks overlying the coal seams. In
this instance, specialist techniques, such as ground freezing or grouting, have to be used to prevent
water from flowing into the shaft, which is then lined with steel rings or cast concrete to provide a
long-term seal.

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Declines are typically used to access seams that are too deep for open-cast mining, but which are still relatively near-surface. In the Mpumalanga (eastern Transvaal) coalfield in South Africa, for instance, the mineable seams lie at a depth of no more than 150 m; in some areas, they are mined from opencasts, and in others underground mining is necessary, in which case declines are often used to provide access for mining equipment and to install the belt conveyors used to carry the cut coal out of the mine.

Declines differ from adits in that they are usually excavated in rock, not coal (unless the seam dips at a constant rate), and are mined to a constant gradient to optimize vehicle and conveyor access. An innovation since the 1970s has been the use of belt conveyors running in declines to carry deep-mine production, a system that has advantages over traditional shaft hoisting in terms of capacity and reliability.

Mining Methods

Underground coal mining encompasses two principal methods, of which many variations have evolved to address mining conditions in individual operations. Room-and-pillar extraction involves mining tunnels (or roadways) on a regular grid, often leaving substantial pillars for long-term support of the roof. Longwall mining achieves total extraction of large parts of a coal seam, causing the roof rocks to collapse into the mined-out area.

Room-and-pillar mining

Room-and-pillar mining is the oldest underground coal mining system, and the first to use the concept of regular roof support to protect mine workers. The name room-and-pillar mining derives from the pillars of coal that are left behind on a regular grid to provide in situ support to the roof. It has been developed into a high-production, mechanized method that, in some countries, accounts for a substantial proportion of the total underground output. For instance, 60% of underground coal production in the United States comes from room-and-pillar mines. In terms of scale, some mines in South Africa have installed capacities exceeding 10 million tonnes per year from multi-production section operations in seams up to 6 m thick. By contrast, many room-and-pillar mines in the United States are small, operating in seam thicknesses as low as 1 m, with the ability to stop and restart production quickly as market conditions dictate.

Room-and-pillar mining is typically used in shallower seams, where the pressure applied by overlying rocks on the support pillars is not excessive. The system has two key advantages over longwall mining: its flexibility and inherent safety. Its major disadvantage is that recovery of the coal resource is only partial, the precise amount depending on factors such as the depth of the seam below.
surface and its thickness. Recoveries of up to 60% are possible. Ninety per cent recovery is possible if pillars are mined out as a second phase of the extraction process.

The system is also capable of various levels of technical sophistication, ranging from labour-intensive techniques (such as “basket mining” in which most stages of mining, including coal transport, are manual), to highly mechanized techniques. Coal can be excavated from the tunnel face by using explosives or continuous mining machines. Vehicles or mobile belt conveyors provide mechanized coal transport. Roofbolts and metal or timber strapping are used to support the roadway roof and the intersections between roadways where the open span is greater.

A continuous miner, which incorporates a cutting head and coal loading system mounted on crawler tracks, typically weighs from 50 to 100 tonnes, depending on the operating height in which it is designed to work, the installed power and the width of cut required. Some are equipped with on-board rockbolt installation machines that provide roof support simultaneously with coal cutting; in other cases, separate continuous miner and roofbolter machines are used sequentially.

Coal carriers can be supplied with electric power from an umbilical cable or can be battery or diesel-engine powered. The latter provides greater flexibility. Coal is loaded from the rear of the continuous miner into the vehicle, which then carries a payload, typically between 5 and 20 tonnes, a short distance to a feed hopper for the main belt conveyor system. A crusher may be included in the hopper feeder to break oversize coal or rock that could block chutes or damage conveyor belts further along the transport system.

An alternative to vehicular transport is the continuous haulage system, a crawler-mounted, flexible sectional conveyor that transports cut coal directly from the continuous miner to the hopper. These offer advantages in terms of personnel safety and productive capacity, and their use is being extended to longwall gateroad development systems for the same reasons.

Roadways are mined to widths of 6.0 m, normally the full height of the seam. Pillar sizes depend on the depth below surface; 15.0 m square pillars on 21.0 m centres would be representative of pillar design for a shallow, low-seam mine.

**Longwall mining**

Longwall mining is widely perceived to be a twentieth century development; however, the concept is actually believed to have been developed over 200 years earlier. The main advance is that earlier operations were principally manual, while, since the 1950s, the level of mechanization has increased to the stage that a longwall face is now a high-productivity unit which can be operated by a very small crew of workers.

Longwalling has one overriding advantage compared to room-and-pillar mining: it can achieve full extraction of the panel in one pass and recovers a higher overall proportion of the total coal resource. However, the method is relatively inflexible and demands both a large mineable resource and guaranteed sales to be viable, because of the high capital costs involved in developing and equipping a modern longwall face (over US$20 million in some cases).

While in the past individual mines often simultaneously operated several longwall faces (in countries such as Poland, over ten per mine in a number of cases), the current trend is towards consolidation of mining capacity into fewer, heavy-duty units. The advantages of this are reduced labour
requirements and the need for less extensive underground infrastructure development and maintenance.

In longwall mining the roof is deliberately collapsed as the seam is mined out; only major access routes underground are protected by support pillars. Roof control is provided on a longwall face by two- or four-leg hydraulic supports which take the immediate load of the overlying roof, permitting its partial distribution to the unmined face and the pillars on either side of the panel, and protect the face equipment and personnel from collapsed roof behind the line of supports. Coal is cut by an electric-powered shearer, usually equipped with two coal-cutting drums, that mines a strip of coal up to 1.1 m thick from the face with each pass. The shearer runs along and loads the cut coal onto an armoured conveyor that snakes forward after each cut by sequential movement of the face supports.

At the face end, the cut coal is transferred to a belt conveyor for transport to the surface. In an advancing face, the belt must be extended regularly as the distance from the face starting point increases, while in retreat-longwalling the opposite applies.

Over the past 40 years, there have been substantial increases in both the length of the longwall face mined and the length of the individual longwall panel (the block of coal through which the face progresses). By way of illustration, in the United States the average longwall face length rose from 150 m in 1980 to 227 m in 1993. In Germany the mid-1990s average was 270 m and face lengths of over 300 m are being planned. Now, in the United States, United Kingdom and Poland, faces are mined up to 300 m long. Panel lengths are largely determined by geological conditions, such as faults, or by mine boundaries, but are now consistently over 2.5 km in good conditions. The possibility of panels up to 6.7 km long is being discussed in the United States.

Retreat mining is becoming the industry standard, although it involves higher initial capital expenditure in roadway development to the furthest extent of each panel before longwalling can begin. Where possible, roadways are now mined in-seam, using continuous miners, with rockbolt support replacing the steel arches and trusses that were used previously in order to provide positive support to the overlying rocks, rather than passive reaction to rock movements. It is limited in applicability, however, to competent roof rocks.
Longwall mining is a highly productive underground coal mining technique. System consists of multiple coal shearsers mounted on a series of self-advancing hydraulic ceiling supports. The entire process is mechanized. A typical longwall mining system is capable of extracting between 10,000 and 30,000 tons of coal in a day from a panel. Productivity is now higher for longwall mining than for other underground production methods, and productivity is expected to keep growing as new technological advances are introduced.

Longwall mining also offers improved safety through better roof control, more predictable surface subsidence, and better opportunity for full automation.

The primary downside to this very productive technique is a prohibitive initial investment.

Two key factors contributing to the dramatic rise in longwall productivity over the past decade are (1) changes in longwall panel dimensions, and (2) improvements in longwall equipment. Longwall panels have become significantly wider and longer. The use of larger panels also reduced the frequency with which the longwall equipment must be moved from a mined-out panel to a new panel. The move towards larger panels was made possible by improvements in longwall production equipment.

In addition to changes in panel dimensions and longwall equipment, there have been changes in the geologic conditions under which longwalls operate. Particularly important has been the clear trend away from thinner seam longwall mining. Since thin seam longwalls tend to be less productive than thicker seam operations, this development contributed to the overall improvement in longwall productivity.

Thus, merits of Longwall mining Comprises of

- Enhanced resource recovery (about 80% contrasted with about 60 percent for Room and pillar method),
- Less roof support consumables required,
- Elevated volume coal clearance systems,
- Less amount of manual handling,
- Subsidence is mainly instant, allowing for enhanced planning and more responsibility by the mining concern,
- Safety of the miners is enhanced by the reality that they are for all time under the hydraulic roof supports when they are tacking out the coal.

Safety Precautions

Statistics from the ILO indicate a wide geographical variation in the rate fatalities occur in coal mining, although these data have to take into account the level of mining sophistication and the number of workers employed on a country-by-country basis. Conditions have improved in many industrialized countries.

Major mining incidents are now relatively infrequent, as engineering standards have improved and fire-resistance has been incorporated into materials such as the conveyor belting and hydraulic fluids.
used underground. Nonetheless, the potential for incidents capable of causing either personal or structural damage remains. Methane gas and coal dust explosions still occur, despite vastly improved ventilation practices, and roof falls account for the majority of serious accidents on a world-wide basis. Fires, either on equipment or occurring as a result of spontaneous combustion, represent a particular hazard.

Considering the two extremes, labour-intensive and highly mechanized mining, there are also wide differences in both accident rates and the types of incident involved. Workers employed in a small-scale, manual mine are more likely to incur injury through falls of rock or coal from the roadway roof or sidewalls. They also risk greater exposure to dust and flammable gas if ventilation systems are inadequate.

Both room-and-pillar mining and the development of roadways to provide access to longwall panels require support to the roof and sidewall rocks. The type and density of support varies according to the seam thickness, competence of the overlying rocks and the depth of the seam, among other factors. The most hazardous place in any mine is beneath an unsupported roof, and most countries impose strict legislative constraints on the length of roadway that may be developed before support is installed. Pillar recovery in room-and-pillar operations presents specific hazards through the potential for sudden roof collapse and must be scheduled carefully to prevent increased risk to workers.

Modern high-productivity longwall faces require a team of six to eight operators, so the number of people exposed to potential hazards is markedly reduced. Dust generated by the longwall shearer is a major concern. Coal cutting is thus sometimes restricted to one direction along the face to take advantage of the ventilation flow to carry dust away from the shearer operators. The heat generated by increasingly powerful electric machines in the confines of the face also has potentially deleterious effects on face workers, especially as mines become deeper.

The speed at which shearers work along the face is also increasing. Cutting rates of up to 45 m/minute are in vogue in developed countries. The ability of workers physically to keep up with the coal cutter moving repeatedly over a 300 m-long face for a full working shift is doubtful, and increasing shearer speed is thus a major incentive to the wider introduction of automation systems for which miners would act as monitors rather than as hands-on operators.

The recovery of face equipment and its transfer to a new worksite offers unique hazards for workers. Innovative methods have been developed for securing the longwall roof and face coal in order to minimize the risk of rock falls during the transfer operation. However, the individual items of machinery are extremely heavy (over 20 tonnes for a large face support and considerably more for a shearer), and despite the use of custom-designed transporters, there remains the risk of personal crushing or lifting injuries during longwall salvage.

7. SURFACE MINING METHODS

a. Mine Development

Pit planning and layout

The overall economic goal in surface mining is to remove the least amount of material while gaining the greatest return on investment by processing the most marketable mineral product. The higher the grade of the mineral deposit, the greater the value. To minimize capital investment while
accessing the highest valued material within a mineral deposit, a mine plan is developed that precisely details the manner in which the ore body will be extracted and processed. As many ore deposits are not a uniform shape, the mine plan is preceded by extensive exploratory drilling to profile the geology and position of the ore body. The size of the mineral deposit dictates the size and layout of the mine. The layout of a surface mine is dictated by the mineralogy and geology of the area. The shape of most open-pit mines approximates a cone but always reflects the shape of the mineral deposit being developed. Open-pit mines are constructed of a series of concentric ledges or benches that are bisected by mine access and haulage roads angling down from the rim of the pit to the bottom in a spiral or zigzag orientation. Regardless of size, the mine plan includes provisions for pit development, infrastructure, (e.g., storage, offices and maintenance) transportation, equipment, mining ratios and rates. Mining rates and ratios influence the life of the mine which is defined by depletion of the ore body or realization of an economic limit.

Contemporary open-pit mines vary in scale from small privately-operated enterprises processing a few hundred tonnes of ore per day to expanded industrial complexes operated by governments and multinational corporations that mine more than one million tonnes of material per day. The largest operations can involve many square kilometres in area.

**Stripping overburden**

Overburden is waste rock consisting of consolidated and unconsolidated material that must be removed to expose the underlying ore body. It is desirable to remove as little overburden as possible in order to access the ore of interest, but a larger volume of waste rock is excavated when the mineral deposit is deep. Most removal techniques are cyclical with interruption in the extraction (drilling, blasting and loading) and removal (hauling) phases. This is particularly true for hard rock overburden which must be drilled and blasted first. An exception to this cyclical effect are dredges used in hydraulic surface mining and some types of loose material mining (e.g., Lignite etc.) with bucket wheel excavators. The fraction of waste rock to ore excavated is defined as the stripping ratio. Stripping ratios of 2:1 up to 4:1 are not uncommon in large mining operations. Ratios above 6:1 tend to be less economically viable, depending on the commodity. Once removed, overburden can be used for road and tailings construction or may have non-mining commercial value as fill dirt.

**Mining equipment selection**

The selection of mining equipment is a function of the mine plan. Some of the factors considered in the selection of mine equipment include the topography of the pit and surrounding area, the amount of ore to be mined, the speed and distance the ore must be transported for processing and the estimated mine life, among others. In general, most contemporary surface mining operations rely on mobile drill rigs, hydraulic shovels, front-end loaders, scrapers and haul trucks to extract ore and initiate ore processing. The larger the mine operation, the larger the capacity of equipment required to maintain the mine plan.

Equipment is generally the largest available to match the economy of scale of surface mines with consideration for matching the capacities of equipment. For example, a small front-end loader can fill a large haul truck but the match is not efficient. Similarly, a large shovel can load smaller trucks but requires the trucks to decrease their cycle times and does not optimize utilization of the shovel since one shovel bucket may contain enough ore for more than one truck. Safety may be compromised by attempting to load only half of a bucket or if a truck is overloaded. Also, the scale of equipment selected must match the available maintenance facilities. Large equipment is often maintained where it malfunctions due to the logistical difficulties associated with transporting it to

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established maintenance facilities. When possible, the mine’s maintenance facilities are designed to accommodate the scale and quantity of the mine equipment. Therefore, as new larger equipment is introduced into the mine plan, the supporting infrastructure, including the size and quality of haul roads, tools and maintenance facilities, must also be addressed.

**Conventional Methods of Surface Mining**

Open-pit mining and strip mining are the two major categories of surface mining which account for more than 90% worldwide surface mining production. The primary differences between these mining methods are the location of the ore body and the mode of mechanical extraction. For loose rock mining, the process is essentially continuous with extraction and haulage steps running in series. Solid rock mining requires a discontinuous process of drilling and blasting prior to the loading and hauling stages. Strip mining (or open-cast mining) techniques relate to the extraction of ore bodies that are near the surface and relatively flat or tabular in nature and mineral seams. It uses a variety of different types of equipment including shovels, trucks, drag lines, bucket wheel excavators and scrapers. Most strip mines process non-hard rock deposits. **Coal is the most common commodity that is strip mined from surface seams.** In contrast, open-pit mining is employed to remove hard rock ore (mostly metallic ore) that is disseminated and/or located in deep seams and is typically limited to extraction by shovel and truck equipment. Many metals are mined by the open-pit technique: gold, silver and copper, to name a few.

Quarrying is a term used to describe a specialized open-pit mining technique wherein solid rock with a high degree of consolidation and density is extracted from localized deposits. Quarried materials are either crushed and broken to produce aggregate or building stone, such as dolomite and limestone, or combined with other chemicals to produce cement and lime. Construction materials are produced from quarries located in close proximity to the site of material use to reduce transportation costs. Dimension stone such as flagstone, granite, limestone, marble, sandstone and slate represent a second class of quarried materials. Dimension stone quarries are found in areas having the desired mineral characteristics which may or may not be geographically remote and require transportation to user markets.

Many ore bodies are too diffuse and irregular, or too small or deep to be mined by strip or open-pit methods and must be extracted by the more surgical approach of underground mining. To determine when open-pit mining is applicable, a number of factors must be considered, including the terrain and elevation of the site and region, its remoteness, climate, infrastructure such as roads, power and water supply, regulatory and environmental requirements, slope stability, overburden disposal and product transportation, among others.

Terrain and elevation: Topography and elevation also play an important role in defining the feasibility and scope of a mining project. In general, the higher the elevation and rougher the terrain, the more difficult mine development and production are likely to be. A higher grade of mineral in an inaccessible mountainous location may be mined less efficiently than a lower grade of ore in a flat location. Mines located at lower elevations generally experience less inclement weather-related problems for exploration, development and production of mines. As such, topography and location affect the mining method as well as economic feasibility.

The decision to develop a mine occurs after exploration has characterized the ore deposit and feasibility studies have defined the options for mineral extraction and processing. Information that is necessary to establish a development plan may include the shape, size and grade of minerals in the ore body, the total volume or tonnage of material including overburden and other factors, such as
hydrology and access to a source of process water, availability and source of power, waste rock storage sites, transportation requirements and infrastructure features, including the location of population centres to support the labour force or the need to develop a townsite.

Transportation requirements may include roads, highways, pipelines, airports, railroads, waterways and harbours. For surface mines, large land areas are generally required that may have no existing infrastructure. In such instances roads, utilities and living arrangements must be established first. The pit would be developed in connection with other processing elements such as waste rock storage areas, crushers, concentrators, smelters and refineries, depending on the degree of integration required. Due to the large amount of capital necessary to finance these operations, development may be conducted in phases to take advantage of the earliest possible saleable or leasable mineral to help finance the remainder of the development.

b. Production and Equipment

Drilling and blasting

Mechanical drilling and blasting are the first steps in extracting ore from most developed open-pit mines and are the most common method used to remove hard rock overburden. While there are many mechanical devices capable of loosening hard rock, explosives are the preferred method as no mechanical device can currently match the fracturing capability of energy contained in explosive charges. A commonly used hard rock explosive is Ammonium Nitrate-Fuel Oil (ANFO). Drilling equipment is selected on the basis of the nature of the ore and the speed and depth of the holes necessary to fracture a specified tonnage of ore per day. For example, in mining a 15-m bench of ore, 60 or more holes will generally be drilled 15 m back from the current muck face depending on the length of the bench to be mined. This must occur with enough lead-time to allow for site preparation for subsequent loading and haulage activities.

Loading

Surface mining is now typically conducted utilizing table shovels, front-end loaders or hydraulic shovels. In open-pit mining loading equipment is matched with haul trucks that can be loaded in three to five cycles or passes of the shovel; however, various factors determine the preference of loading equipment. With sharp rock and/or hard digging and/or wet climates, tracked shovels are preferable. Conversely, rubber-tyred loaders have much lower capital cost and are preferred for loading material that is low volume and easy to dig. Additionally, loaders are very mobile and well-suited for mining scenarios requiring rapid movements from one area to another or for ore blending requirements. Loaders are also frequently used to load, haul and dump material into crushers from blending stock piles deposited near crushers by haul trucks.

Hydraulic shovels and cable shovels have similar advantages and limitations. Hydraulic shovels are not preferred for digging hard rock and cable shovels are generally available in larger sizes. Therefore, large cable shovels with payloads of about 50 cubic metres and greater are the preferred equipment at mines were production exceeds 200,000 tonnes per day. Hydraulic shovels are more versatile on the mine face and allow greater operator control to selectively load the from either the bottom or top half of the mine face. This advantage is helpful where separation of waste from ore can be achieved at the loading zone thereby maximizing the ore grade that is hauled and processed.

Hauling
Haulage in open-pit and strip mines is most commonly accomplished by haul trucks. The role of haul trucks in many surface mines is restricted to cycling between the loading zone and the transfer point such as an in-pit crushing station or conveyance system. Haul trucks are favoured based on their flexibility of operation relative to railroads, which were the preferred haulage method until the 1960s. However, the cost of transporting materials in surface metal and non-metal pits is generally greater than 50% of the total operating cost of the mine. In-pit crushing and conveying through belt conveyor systems has been a primary factor in reducing haulage costs. Technical developments in haul trucks such as diesel engines and electrical drives have lead to much larger capacity vehicles. Several manufactures currently produce 240 tonne capacity trucks with expectation for greater than 310 tonne capacity trucks in the near future. In addition, the use of computerized dispatch systems and global satellite positioning technology allow vehicles to be tracked and scheduled with improved efficiency and productivity.

Haul road systems may use single or dual direction traffic. Traffic may be either left or right lane configuration. Left lane traffic is frequently preferred to improve operator visibility of tyre position on very large trucks. Safety is also improved with left hand traffic by reducing the potential for driver-side collision in the centre of a road. Haul road gradients are typically limited to between 8 and 15% for sustained hauls and optimally are about 7 to 8%. Safety and water drainage requires long gradients to include at least 45-m sections with a maximum gradient of 2% for every 460 m of severe gradient. Road berms (elevated dirt borders) located between roads and adjacent excavations are standard safety features in surface mines. They may also be placed in the middle of the road to separate opposing traffic. Where switch-back haul roads exist, increasing elevation escape lanes may be installed at the end of long steep grades. Road edge barriers such as berms are standard and should be located between all roads and adjacent excavations. High-quality roads enhance maximum productivity by maximizing safe truck speeds, reduced down-time for maintenance and reduced driver fatigue. Haul-truck road maintenance contributes to reduced operating costs through reduced fuel consumption, longer tyre life and reduced repair costs.

Rail haulage, under the best of conditions, is superior to other methods of haulage for transport of ore over long distances outside the mine. However, as a practical matter, rail haulage is no longer widely used in open-pit mining since the advent of electrical and diesel-powered trucks. Rail haulage was replaced to capitalize on the greater versatility and flexibility of haul trucks and in-pit conveyor systems. Railroads requires very gentle grades of 0.5 to a maximum of 3% for up-hill hauls. Capital investment for railroad engines and track requirements is very high and requires a long mine life and large production outputs to justify return on investment.

Ore handling (conveyance)

In-pit crushing and conveying is a methodology that has grown in popularity since first being implemented in the mid-1950s. Location of a semi-mobile crusher in the mine pit with the subsequent transport out of the pit by a conveyor system has resulted in significant production advantages and cost savings over traditional vehicle haulage. High cost haulage road construction and maintenance is reduced and labour costs associated with haul truck operation and truck maintenance and fuel are minimized.

The purpose of the in-pit crusher system is primarily to allow transport of ore by conveyor. In-pit crusher systems may range from permanent facilities to fully mobile units. However, more commonly, crushers are constructed in a modular form to allow some portability within the mine.
Conveyors’ advantages over haul trucks include instantaneous start up, automatic and continuous operation and a high degree of reliability with up 90 to 95% availability. They are generally not impaired by inclement weather. Conveyors also have much lower labour requirements relative to haul trucks; operating and maintaining a truck fleet may require ten times as many crew members as an equivalent-capacity conveyor system. Also, conveyors can operate at grades up to 30% while maximum grades for trucks are generally 10%. Using steeper grades lowers the need to remove low-grade overburden material and may reduce the need to establish high cost haulage roads. Conveyors systems are also integrated into bucket wheel shovels in many surface coal operations, which eliminate the need for haulage trucks.

**Solution Mining Methods**

Solution mining, the most common of two types of aqueous mining, is employed to extract soluble ore where conventional mining methods are less efficient and/or less economical. Also known as leaching or surface leaching, this technique can be a primary mining method, as with gold and silver leach mining, or it can supplement the conventional pyrometallurgical steps of smelting and refining, as in the case of leaching low-grade copper oxide ores.

Regardless of the necessity or economic advantage, all surface solution methods share two common characteristics: (1) ore is mined in the usual way and then stockpiled; and, (2) an aqueous solution is applied to the top of the ore stock which reacts chemically with the metal of interest from which the resulting metal salt solution is channelled through the stock pile for collection and processing. The application of surface solution mining is dependent on the volume, the metallurgy of the mineral(s) of interest and the related host rock, and available area and drainage to develop sufficiently large leach dumps to make the operation economically viable.

The development of leach dumps in a surface mine in which solution mining is the primary production method is the same as all open-pit operations with the exception that the ore is destined solely for the dump and not a mill. In mines with both milling and solution methods, ore is segregated into milled and leached portions. For example, most copper sulphide ore is milled and purified to market grade copper by smelting and refining. Copper oxide ore, which is not generally amenable to pyrometallurgical processing, is routed to leach operations. Once the dump is developed, the solution leaches the soluble metal from the surrounding rock at a predictable rate that is controlled by the design parameters of the dump, the nature and volume of the solution applied, and the concentration and mineralogy of the metal in the ore. The solution used to extract the soluble metal is referred to as a lixiviant. The most common lixiviants used in this mining sector are dilute solutions of alkaline sodium cyanide for gold, acidic sulphuric acid for copper, aqueous sulphur dioxide for manganese and sulphuric acid-ferric sulphate for uranium ores; however, most leached uranium and soluble salts are collected by in-situ mining in which the lixiviant is injected directly into the ore body without prior mechanical extraction. This latter technique enables low-grade ores to be processed without extracting the ore from the mineral deposit.

**Health and safety aspects** - The occupational health and safety hazards associated with mechanical extraction of the ore in solution mining are essentially similar to those of conventional surface mine operations. An exception to this generalization is the need for non-leaching ore to undergo primary crushing in the surface mine pit before being conveyed to a mill for conventional processing, whereas ore is generally transported by haul truck directly from the extraction site to the leach dump in solution mining. Solution mining workers would therefore have less exposure to primary crushing hazards such as dust, noise and physical hazards.
The leading causes of injuries in surface mine environments include materials handling, slips and falls, machinery, hand-tool use, power haulage and electrical source contact. However, unique to solution mining is the potential exposure to the chemical lixiviants during transportation, leach field activities and chemical and electrolytic processing. Acid mist exposures may occur in metal electrowinning tankhouses. Ionizing radiation hazards, which increase proportionally from extraction to concentration, must be addressed in uranium mining.

Hydraulic Mining Methods

In hydraulic mining, or “hydraulicking”, high pressure water spray is used to excavate loosely consolidated or unconsolidated material into slurry for processing. Hydraulic methods are applied primarily to metal and aggregate stone deposits, although coal, sandstone and metal mill tailings are also amenable to this method. The most common and best known application is placer mining in which concentrations of metals such as gold, titanium, silver, tin and tungsten are washed from within an alluvial deposit (placer). Water supply and pressure, ground slope gradient for runoff, distance from the mine face to the processing facilities, degree of consolidation of the mineable material and the availability of waste disposal areas are all primary considerations in the development of a hydraulic mining operation. As with other surface mining, the applicability is location specific. Inherent advantages of this method mining include relatively low operating costs and flexibility resulting from the use of simple, rugged and mobile equipment. As a result, many hydraulic operations develop in remote mining areas where infrastructure requirements are not a limitation.

Unlike other types of surface mining, hydraulic techniques rely on water as the medium for both mining and conveyance of the mined material (“sluicing”). High pressure water sprays are delivered by monitors or water cannons to a placer bank or mineral deposit. They disintegrate gravel and unconsolidated material, which washes into collection and processing facilities. Water pressures may vary from a normal gravity flow for very loose fine materials to thousands of kilograms per square centimetre for unconsolidated deposits. Bulldozers and graders or other mobile excavating equipment are sometimes employed to facilitate mining of more compacted materials. Historically, and in modern small-scale operations, the collection of the slurry or runoff is managed with small volume sluice boxes and catches. Commercial-scale operations rely on pumps, containment and settling basins and separation equipment that can process very large volumes of slurry per hour. Depending on the size of the deposit to be mined, the operation of the water monitors may be manual, remotely controlled or computer controlled.

When hydraulic mining occurs underwater it is referred to as dredging. In this method a floating processing station extracts loose deposits such as clay, silt, sand, gravel and any associated minerals using a bucket line, drag line and/or submerged water jets. The mined material is transported hydraulically or mechanically to a washing station which may be part of the dredging rig or physically separate with subsequent processing steps to segregate and complete processing. While dredging is used to extract commercial minerals and aggregate stone, it is best known as a technique used to clear and deepen water channels and floodplains.

Health and safety - Physical hazards in hydraulic mining differ from those in surface mining methods. Due to the minimal application of drilling, explosives, haulage and reduction activities, safety hazards tend to be associated mostly often with high pressure water systems, manual movement of mobile equipment, proximity issues involving power supplies and water, proximity issues associated with collapse of the mine face and maintenance activities. Health hazards primarily involve exposure to noise and dusts and ergonomic hazards related to equipment handling. Dust
exposure is generally less of an issue than in traditional surface mining due to the use of water as the mining medium. Maintenance activities such as uncontrolled welding may also contribute to worker exposures.

Environmental aspects of surface mining

The significant environmental effects of surface mines attract attention wherever the mines are located. Alteration of terrain, destruction of plant life and adverse effects on indigenous animals are inevitable consequences of surface mining. Contamination of surface and underground waters often presents problems, particularly with the use of lixiviants in solution mining and the run-off from hydraulic mining.

Thanks to the increased attention from environmentalists around the world and the use of planes and aerial photography, mining enterprises are no longer free to “dig and run” when the extraction of the desired ore has been complete. Laws and regulations have been promulgated in most of the developed countries and, through the activities of international organizations, are being urged where they do not yet exist. They establish an environmental management programme as an integral element in every mining project and stipulate such requirements as preliminary environmental impact assessments; progressive rehabilitation programmes, including restoration of land contours, reforestation, replanting of indigenous fauna, restocking of indigenous wild life and so on; as well as concurrent and long-term compliance auditing. It is essential that these be more than statements in the documentation required for the necessary government licenses. The basic principles must be accepted and practised by managers in the field and communicated to workers on all levels. For more on Environmental aspect read: Bringing Sustainability in Coal Mining Operations, Environmental Impacts of Mining, Mining Practices with Objective of Sustainability

8. SURFACE COAL MINING MANAGEMENT

The geological characteristics of surface coal mining which distinguish it from other surface mining are the nature of formation and its relatively low value, which often require surface coal mines to move large volumes of overburden over a large area (i.e., it has a high stripping ratio). As a result, surface coal mines have developed specialized equipment and mining techniques. Examples include a dragline strip mine which mines in strips of 30 to 60 m wide, sidecasting material in pits up to 50 km long. Rehabilitation is an integral part of the mining cycle due to the significant disturbance of the involved areas.

Surface coal mines vary from being small (i.e., producing less than 1 million tonnes per annum) to large (above 10 million tonnes per annum). The workforce required depends on the size and type of the mine, the size and amount of equipment and the amount of coal and overburden. There are some typical measurements which indicate the productivity and size of the workforce. These are:

1. Output per miner expressed as tonnes per miner per year; this would range from 5,000 tonnes per miner per year to 40,000 tonnes per miner per year.

2. Total material moved expressed in tonnes per miner per year. This productivity indicator combines the coal and the overburden; productivity of 100,000 tonnes per miner per year would be low with 400,000 tonnes per miner per year being the very productive end of the scale.

Due to the large capital investment involved, many coal mines operate on a seven day continuous shift roster. This involves four crews: three work three shifts of eight hours each with the fourth crew covering rostered time off.
Mine Planning

Mine planning for surface coal mines is a repetitive process which can be summarized in a checklist. The cycle begins with geology and marketing and finishes with an economic evaluation. The level of detail (and cost) of the planning increases as the project goes through different stages of approval and development. Feasibility studies cover the work prior to development. The same checklist is used after production commences to develop annual and five-year plans as well as plans for closing down the mine and rehabilitating the area when all the coal has been extracted.

Significantly, the need for planning is ongoing and the plans need frequent updating to reflect changes in the market, technology, legislation and knowledge of the deposit learned as the mining progresses.

Geological Influences

Geological features have a major influence in the selection of the mining method and equipment used in a particular surface coal mine.

Seam attitude, commonly known as dip, represents the angle between the seam being mined and the horizontal plane. The steeper the dip the more difficult it is to mine. The dip also affects the stability of the mine; the limiting dip for dragline operations is around 7°.

The strength of coal and waste rock determines what equipment can be used and whether or not the material has to be blasted. Continuous mining equipment, such as bucketwheel excavators commonly used in eastern Europe and Germany, is limited to material of very low strength that does not require blasting. Typically, however, the overburden is too hard to be dug without some blasting to fragment the rock into smaller sized pieces which can then be excavated by shovels and mechanical equipment.

As the depth of coal seams increase, the cost of transporting the waste and coal to the surface or to the dump becomes higher. At some point, it would become more economical to mine by underground methods than by open-cut methods.

Seams as thin as 50 mm can be mined but the recovery of coal becomes more difficult and expensive as seam thickness decreases.

Hydrology refers to the amount of water in the coal and overburden. Significant quantities of water affect stability and the pumping requirements add to the cost.

The magnitude of the coal reserves and the scale of operation influences what equipment can be used. Small mines require smaller and relatively more expensive equipment, whereas large mines enjoy the economies of scale and lower costs per unit of production.

Environmental characteristics refers to the behaviour of the overburden after it has been mined. Some overburden is termed “acid producing” which means that when exposed to air and water it will produce acid which is detrimental to the environment and requires special treatment. For more on Acid Mine Drainage (AMD) read: ACID DRAINAGE FROM MINES AND ITS RELATED PROBLEMS

The combination of the above factors plus others determines which mining method and equipment is appropriate for a particular surface coal mine.
Considerations include: topsoil and planting vegetation to return it to its original state. Other environmental management considerations include:

The Mining Cycle

Surface coal mining methodology can be broken into a series of steps.

Removing topsoil and either storing it or replacing it on areas being rehabilitated is an important part of the cycle as the objective is to return the land use to at least as good a condition as it was before mining began. Topsoil is an important component as it contains plant nutrients.

Ground preparation may involve using explosives to fragment the large rocks. In some instances, this is done by bulldozers with rippers which use mechanical force to break the rock into smaller pieces. Some mines where the strength of the rock is low require no ground preparation as the excavator can dig directly from the bank.

Waste removal is the process of mining the rock overlying the coal seam and transporting it to the dump. In a strip mine where the dump is in an adjacent strip, it is a sidecast operation. In some mines, however, the dump may be several kilometres away due to the structure of the seam and available dump space and transport to the dump by trucks or conveyors is necessary.

Coal mining is the process of removing the coal from the exposed face in the mine and transporting it out of the pit. What happens next depends on the location of the coal market and its end use. If fed to an onsite power station, it is pulverised and goes directly to the boiler. If the coal is low grade it may be upgraded by “washing” the coal in a preparation plant. This separates the coal and overburden to yield a higher grade product. Before it is sent to market, this coal usually needs some crushing to get it to a uniform size, and blending to control variations in quality. It may be transported by road, conveyor, train, barge or ship.

Rehabilitation involves shaping the dump to restore the terrain and meet drainage criteria, replacing topsoil and planting vegetation to return it to its original state.

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• water management: diversion of existing water courses and control of mine water by sediment dams and recycling so that contaminated water is not discharged
• visual planning : ensuring that the visual impact is minimized
• flora and fauna: to restoring trees and vegetation and replace indigenous wild life
• archaeology: preservation and/or restoration of culturally significant sites
• final void: what to do with the hole after mining has stopped (e.g., it may be filled in or turned into a lake)
• air blast and vibration, due to blasting, which need to be managed by specific techniques if buildings are nearby
• noise and dust, which need to be managed to avoid creating a nuisance for nearby dwellings and communities.

The impact of surface coal mining on the overall environment can be significant but with appropriate planning and control throughout all phases of the enterprise, it can be managed to meet all requirements.

Management of topsoil is essential for geo-environmental reclamation: Soil is the non-renewable natural resource, which supports life on earth. Topsoil is an essential component for land reclamation in mining areas. It is seriously damaged if it is not mined out separately without being contaminated, eroded and protected. Systematic handling and storage practices can protect topsoil while in storage and after it has been redistributed onto the re-graded area. Removed topsoil should be reclaimed technically and its shelf-life period should be ascertained. Soil dumps of different age classes in the area are to be identified and analyzed critically to evaluate the deterioration of soil quality with respect to time, and compared with those of unmined areas. Biological reclamation is essential if the soil is to be stored beyond the shelf-life period.

Mining Methods and Equipment

Three main mining methods are used for surface coal mining: truck and shovel; draglines; and conveyor-based systems, such as bucketwheel excavators and in-pit crushers. Many mines use combinations of these, and there are also specialized techniques such as auger mining and continuous highwall miners. These constitute only a small proportion of total surface coal mining production. The dragline and bucketwheel systems were developed specifically for surface coal mining whereas truck and shovel mining systems are used throughout the mining industry.

Shovel-Dumper Mining - The truck and shovel mining method involves an excavator, such as an electric rope shovel, a hydraulic excavator or a front-end loader, to load overburden into trucks. The size of the trucks can vary from 35 tonnes up to 220 tonnes. The truck transports the overburden from the mining face to the dumping area where a bulldozer will push and pile the rock to shape the dump for rehabilitation. The truck and shovel method is noted for its flexibility; examples are found in most countries of the world.

Dragline Mining - Draglines are one of the cheapest methods to mine the overburden, but are limited in their operation by the length of the boom, which is generally 100 m long. The dragline swings on its centre point and can therefore dump the material approximately 100 m from where it is sitting. This geometry requires that the mine be laid out in long narrow strips.

The main limitation of the dragline is that it can only dig to a depth of approximately 60 m; beyond this, another form of supplementary overburden removal such as the truck and shovel fleet is required.
Bucketwheel Excavator Mining - Conveyor-based mining systems use conveyors to transport the overburden instead of trucks. Where the overburden is low strength it can be mined directly from the face by a bucketwheel excavator. It is often called a “continuous” mining method because it feeds the overburden and coal without interruption. Draglines and shovels are cyclical with each bucket load taking 30 to 60 seconds. Harder overburden requires a combination of blasting or an in-pit crusher and shovel loading to feed it onto the conveyor. Conveyor-based surface coal mining systems are most suitable where the overburden has to be transported significant distances or up significant heights.

Conclusion

Surface coal mining involves specialized equipment and mining techniques which allow the removal of large volumes of waste and coal from large areas. Rehabilitation is an integral and important part of the process.

9. BLASTING PRACTICES IN MINES

Most rocks and ores require blasting to break them into smaller particles before an excavation takes place in mining operations. Explosive materials are tools that benefit mankind, when used properly. However, improper use can be disastrous. Blasting is one of the most important parts in any mine because without the appropriate performance, the results are not only the failure of the blasting operation but the mine operation could be jeopardized. The major factors that influence blasting results are:

a. Properties of explosives being used,
b. The initiation systems,
c. The distribution of the explosive in the blast,
d. Rock structure,
e. The overall geometry, and
f. Other factors.

The selection of the proper explosive is based on three criteria -

a. Its ability to function properly in the proposed environment
b. The performance characteristic of explosive
c. Cost

Explosives are different in the following ways -
a. Strength
b. The ability to resist water and water pressure
c. Input energy needed to start the reaction
d. Minimum diameter in which detonation will occur
e. Flammability
f. Generation of toxic fumes
g. Detonation pressure
h. Ability to remain in original configuration
i. Ability to function under different temperature condition
j. Reaction velocity

k. Bulk density

In the explosives selection process, we evaluate each of characteristics to determine which are importance to us and which are not. For instance, if we had a project with dry blast holes, we do not need a product that has a high water resistance; or if we are using large diameter blastholes, it is not important whether the explosive functions reliably in a very small diameter blasthole. We should purchase the explosive product that will function properly for the blast, at the lower cost.

**Conditions that influence the selection of the proper initiation systems—**

a. **Type of explosive used:** Detonation cord used for initiating high explosives may cause disruption of less sensitive explosive. Blasting agents should not be initiated by a No. 6 blasting cap.

b. **Borehole temperature:** Different manufacturers produce products with different ranges of limiting temperatures; mostly the initiation systems should not be used in temperature exceeding 150°C or 60°C.

c. **Geology:** Initiation systems should be fully activated before rock movement occurs to prevent cutoffs and subsequent misfires.

d. **Hydrostatic pressure:** Different manufacturers produce products with different ranges of hydrostatic pressure resistance.

e. **Environmental constraints:** The type of system as well as the delay sequence must be correctly chosen so as to limit ground vibrations and air blast.

f. **Extraneous electricity:** Extraneous electricity is defined as any electrical energy, other than the actual firing current or a test current from a blasting galvanometer, that may be present in the blasting area. Electric detonators are designed to be fired by a pulse of electrical energy, so they may be accidentally fired by extraneous electricity such as a stray current, static electricity, radio frequency energy, electrical storms and high-voltage power lines. Extraneous electricity can be introduced into an electric blasting circuit by either direct contact (stray current or static current) or by electromagnetic radiation (EMR) (inductive coupling, capacitive coupling, electromagnetic microwave, or radio waves). As a result, consideration must be given to the potential hazard from extraneous electricity when using electric detonators.

**Blast design**

Any blast design must encompass the fundamental concepts of an ideal blast design, which are then modified as per geologic conditions. The engineer must select the proper variable to match the specific field conditions during the design of the blast. Uncontrolled or specific field conditions are the one over which we have little control such the geology, rock characteristics, and regulations or specifications (such as the distance to the nearest structures). The controllable variables are:

a. Hole diameter

b. Hole depth
c. Sub-drilling depth

d. Stemming distance

e. Stemming material

f. Burden and spacing

g. Number of holes in the blast

h. Direction of rock movement

i. Timing

j. Types of explosive and initiation system

Delay initiation Sequence

Delay blasting can be used both in a single row round and in a multiple row round. It is also used for tunnel blasting. In this, each charge is given sufficient time to break its quota of burden from the rock mass before the next charge detonates. The basic purpose of it is to create free face for a blast. If a free face is not available, an inner blasthole may crater upward, resulting in poor fragmentation, little forward displacement, and an increase in the possibility of flyrock and overbreak, while increasing ground vibration and air blast.

Use of proper delay sequence, the ground vibration, air blast, flyrock is minimized, and the fragmentation is increased. The delay interval necessary for optimum fragmentation varies with the
type of rock and burden distances. It appears that delay intervals of between 10 and 60 milliseconds between adjacent blastholes in a row provide the best result.

**Opencast blasting**

In opencast multi row blasting, various delay initiation sequences are possible. They are: (i) Instantaneous, (ii) Row Delay and (iii) V1, V2 pattern.

**Overburden Blast SideCasting**

Overburden Blast SideCasting is the procedure of displacement of a portion of overburden horizontally by blasting, to a desired distance in a required direction away from the working area. Generally, the area to which the overburden is directed to throw is in de-coaled area. Overburden Blast Side Casting is directional blasting. It is also called Blast Casting, Side Casting or Throw Blast. The remaining of overburden is handled by mechanical means.
Therefore, this system of overburden side casting by blasting reduces considerable amount of work
on deployment of excavating equipment for removing overburden. Moreover, this technique allows
much improved fragmentation thereby causing the excavating equipment to work more efficiently
and with much ease.

Another important point regarding control of Ground Vibration of Blast Casting is system of Pre-
splitting of Main block of blast. This system reduces the blast induced Ground Vibration greatly;
thereby the nuisances arising due to Vibration is effectively controlled. Therefore, overall efficiency
of working in Mines is improved considerably by adopting Blast Side casting with Pre-splitting.

Advantages of Overburden Blast Casting: Conventionally, the blasted overburden is removed by
Draglines, Shovels or Loaders. Now, Overburden blast Casting has emerged as cheaper alternative to
the conventional method of removal of overburden. In the following ways the overburden blast
casting is advantageous and reduces the cost of removal of overburden in comparison to the
conventional method.

* Saving in operating and capital cost of excavating equipments for removal of overburden.

* Saving in maintenance cost of excavating equipments for removal of overburden.

* Time for removal of casting overburden by excavating machines is reduced and thereby
  productivity is increased.

* The saving in operating, power, capital and maintenance cost of excavating machinery is much
  more in comparison to the cost of additional explosives required for overburden blast casting,
  therefore overall economy is achieved in removal of overburden.

* Because of reduction in requirement of spares for maintenance etc., other hidden cost related to
  inventory management of spares of excavating machine also reduced.

* Smaller size of excavating equipment needed with lesser manpower, as they have to handle
  comparatively lesser volume of overburden.

* In working mines, if there is under capacity of primary stripping unit (i.e., less number of loading
  units to handle overburden), in other words, if there is mismatch of capacities of excavating
  equipment for stripping and coal removal, overburden blast casting can tackle this problem, thereby
  coal production can be improved.
Because of the above economical advantages, more and more opencast projects are experimenting with overburden blast casting in India. This technique has been experimented extensively in open pits in many countries like USA, Russia, South Africa, Australia etc., and found that cost can be reduced considerably in comparison with conventional method of workings. [For more refer ‘Blast Sidecasting’]

**Tunnel blasting**

Tunneling in rocks is currently performed mainly by blasting, as this method only is capable of providing sufficiently high effectiveness and economics in the construction of tunnel in tough rocks. Tunneling by ‘tunnel borers’ is considered to be less effective especially as regards the construction of tunnels of large cross sectional areas.

The prime objective in Tunnel blasting is to obtain maximum advance/pull per round of blast and to keep cost within reasonable limit. Therefore, very cautiously the type of explosives, drilling pattern (Wedge Cut or Parallel Holes with Dia. of empty holes), spacing & burden, number of holes to be drilled per round, Delay sequence etc., are to be selected. Cycle time is to be kept minimum as far as possible. Cycle of operation include Drilling, Charging, Blasting, Ventilation, Scaling, Support work, Grouting, Loading and Transport, and Setting out for the next blast. The factors on which a great deal of tunneling operations depends are:

**a.** Type of explosives used for tunneling blasting operations.

**b.** Blast design and selection of dia. & location of holes in compatible with the geology of strata, designed area of opening, Environment, existing laws etc.

Unlike bench blasting, tunnel blasting has only one free face and holes are drilled normal to the free face surface. In such a situation, the explosives charge will blow out a narrow funnel- shaped crater. But if the hole is drilled at a certain angle to the free face, the result will be better, as the major part of the gasses will break out the rock in the direction of free face.

Alternatively, if large diameter dummy holes parallel to the blast holes are drilled, the breakage performance is better as the large diameter dummy holes provide additional free face.
The initial opening/cut created either by angled holes or by holes drilled parallel to large diameter dummy holes are widen subsequently by the holes fired after cut holes using proper delays. In other words, the main difference between tunnel blasting and bench blasting is that tunnel blasting is done towards one free surface, while bench blasting is done towards two or more free surfaces. The rock is thus more constricted in the case of tunneling, and a second free face has to be created towards which the rock can break and be thrown away from the surface. This second face is produced by a cut in the tunnel face, which can be a parallel hole cut, a V-cut, or a fan-cut. After the cut opening is made, the stopping towards the cut begins. The final shape of the cross section is given by trimmers or contour holes with closer spacing and comparatively smaller charge. [For more refer 'Tunnel Blasting']

Underground metal mining blasting

Method of Mining in Underground Metal mines mainly depend on type of Deposit, i.e., regular or irregular; Extent and depth of deposit, i.e., massive / pocket etc.; Dip and Thickness of deposit; nature of Hanging wall and Foot wall etc.

Sublevel stoping is one of the most important methods of choice for achieving high production rate in Underground Metal mines. The pattern of long hole drilling can be classed under two major categories, i.e., Parallel hole drilling and Ring hole drilling.
COAL AND METAL (SURFACE AND UNDERGROUND) MINING – AN OVERVIEW

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Controlled blasting techniques –

Broadly, controlled blasting for control of overbreak (in opencast and tunnel), ground vibration etc., can be categorised into four types, i.e., Pre-splitting, Trim or cushion blasting, Line drilling and Smooth blasting. Muffle blasting is done to restrict fly-rock.

**a. Pre-splitting:** This method is not a new blasting technique. It became a recognized blasting technique for wall control when it was used in the mid-1950s on the Niagara power project. The purpose of pre-splitting is to form a fracture plane across which the radial cracks from the production blasting cannot travel. This method may cause a fracture plane which may be cosmetically appealing and allow the use of steeper slope with less maintenance. Pre-splitting uses lightly loaded, closely spaced drill holes, and is fired before the production blast.

**b. Trim (or Cushion) Blasting:** Trim blasts are designed to produce a final wall similar to a pre-split blast, but they are fired after the production holes. The idea is to eliminate costly small diameter...
blasthole and work along with the associated hole loading difficulties. The spacing is normally larger than used in pre-splitting because there is relief toward which the holes can break.

c. **Line drilling:** This system involves a single row of closely spaced uncharged holes along the neat excavation line. This provides a plane of weakness to which the primary blast can break. It also causes some of the shock waves generated by the blast to be reflected, which reduces shattering and stressing in the finished wall of the host rock. Thus, preserving, to a great extent, the original strength of the host rock is possible. This system is applied in very sensitive areas where even the light explosive associated with other controlled blasting technique may cause damage beyond excavation line. This technique gives maximum protection to the host rock to preserve its original strength.

d. **Smooth blasting (or contour or perimeter blasting):** A technique used (rarely in surface and mostly in underground blasting) in which a row or closely spaced drill holes are loaded with decoupled charges (charges with a smaller diameter than the drill hole) and fired simultaneously to produce an excavation contour without fracturing or damaging the rock behind or adjacent to the blasted face. In this technique, perimeter or contour holes are drilled along specified final excavation limits and are lightly loaded than that of buffer holes and production holes. The spacing is kept closer than buffer holes and production holes. Unlike production drill hole blast where higher charge concentration is required, contour drill holes require low charge concentration and explosives should be lightly distributed all along the length of the bore hole. Some time use of high grammage Detonating Fuse (about 40 gm/m core wt., to 60 gm/m core wt.) for contour blasting can give effective result in tunneling. This results in an air cushion effect, which prevents over-break and reduces in-situ rock damage for preservation of strength of host rock.
e. **Muffle blast**: In case of blasting in congested areas, **Muffling** or covering of blast holes properly before blasting, is the common solution to prevent **fly-rock** from damaging human habitants and structures.

[For more refer 'Controlled Blasting Techniques' and Wall Control Blasting Techniques]

**Use of in-hole delays in decks**

Charge weight per delay is the most important parameter for controlling blast induced ground vibration and air-blast. More the charge weight per delay in a blast, more is the intensity of blast induced ground vibration and air-blast for a given distance. Combination of in-hole delays in multi-deck with pre-splitting of production blast can mitigate the effect of low frequency vibration to a great extent. Recently, accurate Electronic delay detonator system has been introduced for blasting in opencast mines, resulting better blasting efficiency in terms of better fragmentation, improved over all costs, control of fly-rock & air-blast and effective reduction in blast induced ground vibration with greater safety.
Use of Accurate and Precise Timing Electronic Delay Detonators

By more accurately controlling timing delays, electronic detonator system can increase rock fragmentation, lower vibration levels, reduce oversize; lessen the potential of fly-rock. This translates into faster excavation times and improves downstream processing costs for the mining operation by increasing throughput, reducing crusher wear, and lowering power consumption and maintenance costs.

Apart, accurate delay timing programmable electronic detonators enable to adopt innovative ‘Signature-hole blast analysis’ technique to simulate, predict and control blast induced ground vibration, in order to obtain maximum operational efficiency, such as raising quantity of explosives per delay (kg/delay) etc.

Research studies had indicated that blast vibration could be simulated by detonating a “Signature Hole” with the vibration monitored at critical locations, and then using a computer to superpose the waveforms with varying delays. By choosing delay times ($\Delta t$) that create ‘destructive interference’ at frequencies that are favored by the local geology, the “ringing” vibration that excites structural elements in structures, houses and annoys neighbors could be reduced. Computer analysis determines the application of delay timing between holes and between the rows. [For more refer ‘Programmable Digital Detonator System’]

Blasting Safety

Explosives are tools that, when used properly, benefit mankind. However, improper use can be disastrous. Prevention of explosives accidents depends on careful planning and faithful observance
of proper blasting practices. The users must remember that they are dealing with a powerful force and that various devices and methods have been developed to assist them in directing this force. The slightest abuse or misdirection of explosives may cause serious injury or kill yourself or others. It is impossible to include warnings or approved methods for every conceivable situation. Explosive safety depends on a thorough knowledge of explosives, safe blasting practices and common sense of the users.

EXPLOSIVES AND BLASTING ECONOMICS

The economic analysis of the use of explosives is an important part of blasting operations in mining and construction. Explosives are energy, and the efficient use of this energy is a major factor in keeping rock blasting costs under control. High-energy explosives enhance fragmentation, which ultimately produces a positive effect on production costs. The degree of fragmentation or movement obtained is directly related to the type of operation and amount of explosive energy applied to the surrounding rock. Analysis of the cost of explosives requires that the effects of explosive energy be placed into proper perspective within the entire drilling, blasting, handling and processing operation. This relationship is illustrated in the following figure:

Efficient blast designs combined with the proper choice of explosive can produce better fragmentation with associated lower operating costs compared to blast designs and explosives used under adverse conditions. As a result, the efficient use of explosives, along with the proper borehole diameter selection, is the keys to a successful blasting program.

Cost of Explosives Energy- The only way to evaluate accurately the cost of explosives, is to examine the effects of blasting and to determine the optimum degree of fragmentation. In most cases, the productivity rate is influenced by the degree of fragmentation. To obtain well-fragmented rock by blasting, explosive energy must be well distributed throughout the rock. To be effective in rock blasting, this energy must be applied at the proper millisecond delay interval to allow for optimum rock movement.

The type and cost of explosives will vary from one operation to another, dependent upon many conditions. The geologic formation, such as hard seams, cap rock, hard bottom, or large toes, dictates the use of high-energy explosives. Water-filled boreholes require the use of water-resistant products at a premium cost. The cost of a product upgrade to cope with wet conditions is an obvious
input. Other variables, such as the size of mucking equipment and drilling equipment, fragmentation tolerance, and production demands, will also influence the choice of explosives.

Although a significant recurrent expense, the cost of explosives is usually only a small percentage of the total costs encountered in breaking, moving, and processing rock and ore. The small difference in the cost of a higher energy explosive is insignificant compared to a decrease in production caused by insufficient fragmentation.

10. MINERAL DRESSING AND PROCESSING OF ORE

Almost all the metals and other inorganic materials that have been exploited occur as the compounds that constitute the minerals that make up the earth’s crust. The forces and processes that have shaped the earth’s surface have concentrated these minerals in widely different amounts. When this concentration is sufficiently great so that the mineral can be economically exploited and recovered, the deposit is referred to as an ore or orebody. However, even then the minerals are not usually available in a form with the purity necessary for immediate processing to the desired end product. It is necessary to separate most of the impurities from the ores as far as can be, before they are smelted for recovery of metal.

Valuable minerals must first be separated from those of no commercial value, which are called gangue. Ore processing refers to this initial treatment of mined material to produce a mineral concentrate of a sufficiently high grade to be satisfactorily processed further to the pure metal or other end product. The differing characteristics of the minerals making up the ore are exploited to separate them from each other by a variety of physical methods that generally leave the chemical composition of the mineral unchanged. (The processing of coal is specifically discussed in the article “Coal preparation”.)

Crushing and Grinding

The particle size of the material arriving at the processing plant will depend on the mining operation employed and on the ore type, but it will be relatively large. Comminution, the progressive reduction in the particle size of lumpy ore, is carried out for two reasons: to reduce the material to a more convenient size and to liberate the valuable component from the waste material as a first step towards its effective separation and recovery. In practice, comminution usually consists of the crushing of larger-sized material, followed by the breaking of the material to finer sizes by tumbling it in rotating steel mills.

Crushing

It is not possible to progress from very large lumps to fine material in a single operation or using one machine. Crushing thus is usually a dry operation that typically takes place in stages which are designated as primary, secondary and tertiary.

Primary crushers reduce the ore from anything as large as 1.5 m down to 100 to 200 mm. Machines such as jaw and gyratory crushers apply a fracture force to the large particles, breaking the ore by compression.
In a jaw crusher, ore falls into a wedge-shaped space between a fixed and a moving crushing plate. Material is nipped and squeezed until it breaks and released and nipped again further down as the jaws open and close, until it finally escapes through the gap set at the bottom.

In the gyratory crusher, a long spindle carries a heavy, hard steel conical grinding element that is moved eccentrically by a lower bearing sleeve within the crushing chamber or shell. The relative motion of the crushing faces is produced by the gyration of the eccentrically mounted cone against the outer chamber. Typically this machine is used where a high throughput capacity is required.

Secondary crushing reduces the particle size down to 5 to 20 mm. Cone crushers, rolls and hammer mills are examples of the equipment used. The cone crusher is a modified gyratory crusher with a shorter spindle that is not suspended, but supported in a bearing below the head. A roll crusher consists of two horizontal cylinders rotating towards each other, the rolls drawing the ore into the gap between them and after a single nip discharging the product. The hammer mill is a typical impact crusher mill. Comminution is by the impact of sharp blows applied at high speed by hammers attached to a rotor within the work-space.

**Grinding**

Grinding, the last stage in comminution, is performed in rotating cylindrical steel vessels known as tumbling mills. Here the mineral particles are reduced to between 10 and 300 mm. A grinding medium, such as steel balls, rods or pebbles (pre-sized lumps of ore much larger than the bulk feed of material), is added to the mill so that the ore is broken down to the desired size. The use of pebbles is termed autogenous grinding. Where the ore type is suitable, run-of-mine (ROM) milling may be used. In this form of autogenous milling the entire ore stream from the mine is fed directly to the mill without pre-crushing, the large lumps of ore acting as the grinding medium.

The mill is generally loaded with crushed ore and grinding medium to just under half full. Studies have shown that the breaking produced by milling is a combination of both impact and abrasion. Mill liners are used to protect the mill shell from wear and, by their design, to reduce slip of the grinding media and improve the lifting and impact portion of milling.

There is an optimal size to which ore must be ground for effective separation and recovery of the valuable component. Undergrinding results in incomplete liberation and poor recovery. Overgrinding increases the difficulty of separation, besides using an excess of expensive energy.
Sizing Separation

After crushing and milling, the products are usually separated simply according to their size. The primary purpose is to produce appropriately sized feed material for further treatment. Oversize material is recycled for further reduction.

Screens

Screening is generally applied to fairly coarse material. It may also be used to produce a reasonably uniform feed size for a subsequent operation where this is required. The grizzly is a series of heavy parallel bars set in a frame that screens out very coarse material. The trommel is an inclined rotating cylindrical screen. By use of a number of sections of different sized screens, several sized products can be simultaneously produced. A variety of other screens and screen combinations may be employed.

Classifiers

Classification is the separation of particles according to their settling rate in a fluid. Differences in density, size and shape are effectively utilized. Classifiers are used to separate coarse and fine material, thereby fractionizing a large size distribution. A typical application is to control a closed-circuit grinding operation. While size separation is the primary objective, some separation by mineral type usually occurs due to density differences.

In a spiral classifier, a rake mechanism lifts the coarser sands from a slurry pool to produce a clean de-slimed product.

The hydrocyclone uses centrifugal force to accelerate settling rates and produce efficient separations of fine-sized particles. A slurry suspension is introduced at high velocity tangentially into a conical shaped vessel. Due to the swirling motion, the faster settling, larger and heavier particles move towards the outer wall, where the velocity is lowest, and settle downwards, while the lighter and smaller particles move towards the zone of low pressure along the axis, where they are carried upward.

Concentration Separation

Concentration separation requires particles to be distinguished as being either those of the valuable mineral or as gangue particles and their effective separation into a concentrate and a tailing product. The objective is to achieve maximum recovery of the valuable mineral at a grade that is acceptable for further processing or sale.

Ore sorting

The oldest and simplest method of concentration is the selection of particles visually and their removal by hand. Hand sorting has its modern equivalents in a number of electronic methods. In photometric methods, particle recognition is based on the difference in reactivity of different minerals. A blast of compressed air is then activated to remove them from a moving belt of material. The differing conductivity of different minerals may be utilized in a similar manner.

Heavy medium separation
Heavy medium or dense medium separation is a process that depends only on the density difference between minerals. It involves introducing the mixture into a liquid with a density lying between that of the two minerals to be separated, the lighter mineral then floats and the heavier sinks. In some processes it is used for the preconcentration of minerals prior to a final grind and is frequently employed as a cleaning step in coal preparation.

Heavy organic fluids such as tetrabromoethane, which has a relative density of 2.96, are used in certain applications, but on a commercial scale suspensions of finely ground solids that behave as simple Newtonian fluids are generally employed. Examples of the material used are magnetite and ferrosilicon. These form low-viscosity, inert and stable “fluids” and are easily removed from suspension magnetically.

**Gravity**

Natural separating processes such as river systems have produced placer deposits where heavier larger particles have been separated from lighter smaller ones. Gravity techniques mimic these natural processes. Separation is brought about by the movement of the particle in response to the force of gravity and the resistance exerted by the fluid in which separation takes place.

Over the years, many types of gravity separators have been developed, and their continued use testifies to the cost-effectiveness of this type of separation.

In a jig a bed of mineral particles is brought into suspension (“fluidized”) by a pulsating current of water. As the water drains back between each cycle, the denser particles fall below the less dense and during a period of draining small particles, and particularly smaller denser particles, penetrate between the spaces between the larger particles and settle lower in the bed. As the cycle is repeated, the degree of separation increases.

Shaking tables treat finer material than jigs. The table consists of a flat surface that is inclined slightly from front to back and from one end to the other. Wooden riffles divide the table longitudinally at right angles. Feed enters along the top edge, and the particles are carried downwards by the flow of water. At the same time they are subject to asymmetrical vibrations along the longitudinal or horizontal axis. Denser particles which tend to be trapped behind the riffle are shuffled across the table by the vibrations.

**Magnetic separation**

All materials are influenced by magnetic fields, although for most the effect is too slight to be detected. However, if one of the mineral components of a mixture has a reasonably strong magnetic susceptibility, this can be used to separate it from the others. Magnetic separators are classified into low- and high-intensity machines, and further into dry- and wet-feed separators.

A drum-type separator consists of a rotating non-magnetic drum containing within its shell stationary magnets of alternating polarity. Magnetic particles are attracted by the magnets, pinned to the drum and conveyed out of the magnetic field. A wet high-intensity separator (WHIMS) of the carousel type consists of a concentric rotating matrix of iron balls that passes through a strong electromagnet. Slurried residues are poured into the matrix where the electromagnet operates, and magnetic particles are attracted to the magnetized matrix while the bulk of the slurry passes through and exits via a base grid. Just past the electromagnet, the field is reversed and a stream of water is used to remove the magnetic fraction.
Electrostatic separation

Electrostatic separation, once commonly used, was displaced to a considerable extent by the advent of flotation (see below). However, it is successfully applied to a small number of minerals, such as rutile, for which other methods prove difficult and where the conductivity of the mineral makes electrostatic separation possible.

The method exploits differences in the electrical conductivity of the different minerals. Dry feed is carried into the field of an ionizing electrode where the particles are charged by ion bombardment. Conducting particles rapidly lose this charge to a grounded rotor and are thrown from the rotor by centrifugal force. Non-conductors lose their charge more slowly, remain clinging to the earth conductor by electrostatic forces, and are carried around to a collection point.

Flotation

Flotation is a process of separation that exploits differences in the physico-chemical surface properties of different minerals.

Chemical reagents called collectors are added to the pulp and react selectively with the surface of the valuable mineral particles. The reaction products formed makes the surface of the mineral hydrophobic or non-wettable, so that it readily attaches to an air bubble.

In each cell of a flotation circuit the pulp is agitated and introduced air is dispersed into the system. The hydrophobic mineral particles attach to the air bubbles and, with a suitable frothing agent present, these form a stable froth at the surface. This continuously overflows the sides of the flotation cell, carrying its mineral load with it.

A flotation plant consist of banks of interconnected cells. A first concentrate produced in rougher bank is cleaned of unwanted gangue components in a cleaner bank, and if necessary recleaned in a third bank of cells. Additional valuable mineral may be scavenged in a fourth bank and recycled to the cleaner banks before the tails are finally discarded.

Dewatering

Following most operations it is necessary to separate the water used in the separation processes from the concentrate produced or from the waste gangue material. In dry environments this is particularly important so that the water may be recycled for re-use.

A settling tank consists of a cylindrical vessel into which pulp is fed at the centre via a feed-well. This is placed below the surface to minimize disturbance of the settled solids. Clarified liquid overflows the sides of the tank into a launder. Radial arms with blades rake the settled solids towards the centre, where they are withdrawn. Flocculants may be added to the suspension to accelerate the settling rate of the solids.

Filtration is the removal of solid particles from the fluid to produce a cake of concentrate that can then be dried and transported. A common form is the continuous vacuum filter, typical of which is the drum filter. A horizontal cylindrical drum rotates in an open tank with the lower section immersed in pulp. The shell of the drum consists of a series of compartments covered by a filter medium. The inner double-walled shell is connected to a valve mechanism on the central shaft that permits either vacuum or pressure to be applied. Vacuum is applied to the section immersed in the
pulp, drawing water through the filter and forming a cake of concentrate on the cloth. The vacuum
dewaters the cake once out of the slurry. Just before the section re-enters the slurry, pressure is
applied to blow off the cake. Disc filters operate on the same principle, but consist of a series of discs
attached to the central shaft.

**Tailings Disposal**

Only a small fraction of the mined ore consists of valuable mineral. The remainder is gangue that
after processing forms the tailings that must be disposed of.

The two major considerations in tailings disposal are safety and economics. There are two aspects to
safety: the physical considerations surrounding the dump or dam in which the tailings are placed;
and pollution by the waste material that may affect human health and cause damage to the
environment. Tailings must be disposed of in the most cost-effective manner possible
commensurate with safety.

Most commonly the tailings are sized, and the coarse sand fraction is used to construct a dam at a
selected site. The fine fraction or slime is then pumped into a pond behind the dam wall.

Where toxic chemicals such as cyanide are present in the waste waters, special preparation of the
base of the dam (e.g., by the use of plastic sheeting) may be necessary to prevent the possible
contamination of ground waters.

As far as possible, the water recovered from the dam is recycled for further use. This may be of great
importance in dry regions and is increasingly becoming required by legislation aimed at preventing
the pollution of ground and surface water by chemical pollutants.

**Heap and In Situ Leaching**

Much of the concentrate produced by ore processing is processed further by hydrometallurgical
methods. The metal values are leached or dissolved from the ore, and different metals are separated
from each other. The solutions obtained are concentrated, and the metal then recovered by steps
such as precipitation and electrolytic or chemical deposition.

Many ores are of too low a grade to justify the cost of pre-concentration. Waste material may also
still contain a certain amount of metal value. In some instances, such material may be economically
processed by a version of a hydrometallurgical process known as heap or dump leaching.

Heap leaching was established at Rio Tinto in Spain more than 300 years ago. Water percolating
slowly through heaps of low-grade ore was coloured blue by dissolved copper salts arising from
oxidation of the ore. The copper was recovered from solution by precipitation onto scrap iron.

This basic process is utilized for oxide and sulphide heap leaching of low grade and waste material
around the world. Once a heap or dump of the material has been created, a suitable solubilizing
agent (e.g., an acid solution) is applied by sprinkling or flooding the top of the heap and the solution
that seeps to the bottom is recovered.

While heap leaching has long been successfully practised, it was only relatively recently that the
important role of certain bacteria in the process was recognized. These bacteria have been identified
as the iron-oxidizing species Thiobacillus ferrooxidans and the sulphur-oxidizing species Thiobacillus.
thiooxidans. The iron-oxidizing bacteria derive energy from the oxidation of ferrous ions to ferric ions and the sulphur-oxidizing species by the oxidation of sulphide to sulphate. These reactions effectively catalyze the accelerated oxidation of the metal sulphides to the soluble metal sulphates.

In situ leaching, sometimes called solution mining, is effectively a variation of heap leaching. It consists of the pumping of solution into abandoned mines, caved in workings, remote worked-out areas or even entire ore bodies where these are shown to be permeable to solution. The rock formations must lend themselves to contact with the leaching solution and to the necessary availability of oxygen.

11. COAL PREPARATION

Coal preparation is the process whereby the raw run-of-mine coal is turned into a saleable clean coal product of consistent size and quality specified by the consumer. The end use of the coal falls into the following general categories:

- **Electricity generation**: The coal is burned to supply heat to drive turbines which generate electricity.
- **Iron and steel making**: The coal is heated in ovens, in the absence of air, to drive off gases (volatile matter) to produce coke. The coke is used in the blast furnace to make iron and steel. Coal can also be added directly to the blast furnace as in the pulverized coal injection (PCI) process.
- **Industrial**: Coal is used in the metallurgical industry as a reductant, whereby its carbon content is used to remove oxygen (reducing) in a metallurgical process.
- **Heating**: Coal can be used domestically and industrially as a fuel for space heating. It is also used as a fuel in dry kilns for the manufacture of cement.

**Crushing and Breaking**

Run-of-mine (ROM) coal from the pit needs to be crushed to an acceptable top size for treatment in the preparation plant. Typical crushing and breaking devices are:

- **Feeder breakers**: A rotation drum fitted with picks that fracture the coal. The coal is delivered by a scraper conveyor and the drum rotates in the same direction as the coal flow. Feeder breakers are commonly used underground, however, there are some in use on surface in the coal preparation circuit.
- **Rotary breakers**: The breaker circuit of an outer fixed shell with an inner rotating drum fitted with perforated plates. Typical rotational speed of the drum is 12–18 rpm. Lifter plates pick up the ROM coal which then falls across the diameter of the drum. The softer coal breaks and passes through the perforations while the harder rock is transported to the exit. The rotary breaker achieves two functions, size reduction and beneficiation by removal of rock.
- **Roll crushers**: Roll crushers can consist of either a single rotating roll and a stationary anvil (plate), or two rolls rotating at the same speed towards one another. The roll faces are usually toothed or corrugated. A common form of crusher is the two stage or quad roll crusher whereby the product from the first twin roll crusher falls into the second twin roll crusher set at a smaller aperture, with the result that a large-scale reduction can be achieved in one machine. A typical application would be crushing run-of-mine material down to 50 mm.
Crushing is sometimes used following the coal cleaning process, when large size coal is crushed to meet market requirements. Roll crushers or hammer mills are usually used. The hammer mill consists of a set of free swinging hammers rotating on a shaft that strike the coal and throw it against a fixed plate.

**Sizing**

Coal is sized before and after the beneficiation (cleaning) process. Different cleaning processes are used on different sizes of coal, so that raw coal on entering the coal preparation plant will be screened (sieved) into three or four sizes which then go through to the appropriate cleaning process. The screening process is usually carried out by rectangular vibrating screens with a mesh or punched plate screen deck. At sizes below 6 mm wet screening is used to increase the efficiency of the sizing operation and at sizes below 0.5 mm a static curved screen (sieve bend) is placed before the vibrating screen to improve efficiency.

Following the beneficiation process, the clean coal is sometimes sized by screening into a variety of products for the industrial and domestic coal markets. Sizing of clean coal is rarely used for coal for electricity generating (thermal coal) or for steel making (metallurgical coal).

**Storage and Stockpiling**

Coal is typically stored and stockpiled at three points in the preparation and handling chain:

1. raw coal storage and stockpiling between the mine and the preparation plant
2. clean coal storage and stockpiling between the preparation plant and the rail or road loadout point
3. clean coal storage at ports which may or may not be controlled by the mine.

Typically raw coal storage occurs after crushing and usually takes the form of open stockpiles (conical, elongated or circular), silos (cylindrical) or bunkers. It is common for seam blending to be carried out at this stage in order to supply a homogenous product to the preparation plant. Blending may be as simple as sequentially depositing different coals onto a conical stockpile to sophisticated operations using stacker conveyors and bucket wheel reclaimers.

Clean coal can be stored in a variety of ways, such as open stockpiles or silos. The clean coal storage system is designed to allow for rapid loading of rail cars or road trucks. Clean coal silos are usually constructed over a rail track allowing unit trains of up to 100 cars to be drawn slowly under the silo and filled to a known weight. In-motion weighing is usually used to maintain a continuous operation.

There are inherent dangers in stockpiled coals. Stockpiles may be unstable. Walking on stockpiles should be forbidden because internal collapses can occur and because reclamation can start without warning. Physically cleaning blockages or hangups in bunkers or silos should be treated with the greatest care as seemingly stable coal can suddenly slip.

**Coal Cleaning (Beneficiation)**

Raw coal contains material from “pure” coal to rock with a variety of material in between, with relative densities ranging from 1.30 to 2.5. Coal is cleaned by separating the low density material...
(saleable product) from the high density material (refuse). The exact density of separation depends on the nature of the coal and the clean coal quality specification. It is impractical to separate fine coal on a density basis and as a result 0.5 mm raw coal is separated by processes using the difference in surface properties of coal and rock. The usual method employed is froth flotation.

Density separation

There are two basic methods employed, one being a system using water, where the movement of the raw coal in water results in the lighter coal having a greater acceleration than the heavier rock. The second method is to immerse the raw coal in a liquid with a density between coal and rock with the result that the coal floats and the rock sinks (dense medium separation).

The systems using water are as follows:

- **Jigs**: In this application raw coal is introduced into a pulsating bath of water. The raw coal is moved across a perforated plate with water pulsating through it. A stratified bed of material is established with the heavier rock at the bottom and the lighter coal at the top. At the discharge end, the refuse is removed from the clean coal. Typical size ranges treated in a jig are 75 mm to 12 mm. There are special application fine coal jigs which use an artificial bed of feldspar rock.

- **Concentrating tables**: A concentrating table consists of a riffled rubber deck carried on a supporting mechanism, connected to a head mechanism that imparts a rapid reciprocating motion in a direction parallel to the riffles. The slide slope of the table can be adjusted. A cross flow of water is provided by means of a launder mounted along the upper side of the deck. The feed enters just ahead of the water supply and is fanned out over the table deck by differential motion and gravitational flow. The raw coal particles are stratified into horizontal zones (or layers). The clean coal overflows the lower side of the table, and the discard is removed at the far side. Tables operate over the size range 5 × 0.5 mm.

- **Spirals**: The treatment of coal fines with spirals utilizes a principle whereby raw fine coal is carried down a spiral path in a stream of water and centrifugal forces direct the lighter coal particles to the outside of the stream and the heavier particles to the inside. A splitter device at the discharge end separates the fine coal from the fine refuse. Spirals are used as a cleaning devise on 2 mm × 0.1 mm size fractions.

- **Water-only cyclones**: The water-borne raw coal is fed tangentially under pressure into a cyclone, resulting in a whirlpool effect and centrifugal forces move the heavier material to the cyclone wall and from there they are transported to the underflow at the apex (or spigot). The lighter particles (coal) remain in the centre of the whirlpool vortex and are removed upwards via a pipe (vortex finder) and report to the overflow. The exact density of separation can be adjusted by varying pressure, vortex finder length and diameter, and apex diameter. The water-only cyclone typically treats material in the 0.5 mm × 0.1 mm size range and is operated in two stages to improve separating efficiency.

The second type of density separation is dense medium. In a heavy liquid (dense medium), particles having a density lower than the liquid (coal) will float and those having a density higher (rock) will sink. The most practical industrial application of a dense medium is a finely ground suspension of magnetite in water. This has many advantages, namely:

- The mixture is benign, as compared to inorganic or organic fluids.
- The density can be rapidly adjusted by varying the magnetite/water ratio.
The magnetite can be easily recycled by removing it from the product streams with magnetic separators.

There are two classes of dense medium separators, the bath- or vessel-type separator for coarse coal in the range 75 mm × 12 mm and the cyclone-type separator cleaning coal in the range 5 mm × 0.5 mm.

The bath-type separators can be deep or shallow baths where the float material is carried over the lip of the bath and the sink material is extracted from the bottom of the bath by scraper chain or paddle wheel.

The cyclone-type separator enhances the gravitational forces with centrifugal forces. The centrifugal acceleration is about 20 times greater than the gravity acceleration acting upon the particles in the bath separator (this acceleration approaches 200 times greater than the gravity acceleration at the cyclone apex). These large forces account for the high throughput of the cyclone and its ability to treat small coal.

The products from the dense medium separators, namely clean coal and refuse, both pass over drain and rinse screens where the magnetite medium is removed and returned to the separators. The diluted magnetite from the rinsing screens is passed through magnetic separators to recover the magnetite for re-use. The magnetic separators consist of rotating stainless steel cylinders containing fixed ceramic magnets mounted on the stationary drum shaft. The drum is immersed in a stainless steel tank containing the dilute magnetite suspension. As the drum rotates, magnetite adheres to the area near the fixed internal magnets. The magnetite is carried out of the bath and out of the magnetic field and falls from the drum surface via a scraper to a stock tank.

Both nuclear density gauges and nuclear on-stream analysers are used in coal preparation plants. Safety precautions relating to radiation source instruments must be observed.

**Froth flotation**

Froth flotation is a physio-chemical process that depends upon the selective attachment of air bubbles to coal particle surfaces and the non-attachment of refuse particles. This process involves the use of suitable reagents to establish a hydrophobic (water-repellent) surface on the solids to be floated. Air bubbles are generated within a tank (or cell) and as they rise to the surface the reagent-coated fine coal particles adhere to the bubble, the non-coal refuse remains at the bottom of the cell. The coal bearing froth is removed from the surface by paddles and is then dewatered by filtration or centrifuge. The refuse (or tailings) pass to a discharge box and are usually thickened before being pumped to a tailings impoundment pond.

The reagents used in the froth flotation of coal are generally frothers and collectors. Frothers are used to facilitate the production of a stable froth (i.e., froths that do not break up). They are chemicals that reduce the surface tension of water. The most commonly used frother in coal flotation is methyl isobutyl carbinol (MIBC). The function of a collector is to promote contact between coal particles and air bubbles by forming a thin coating over the particles to be floated, which renders the particle water-repellent. At the same time the collector must be selective, that is, it must not coat the particles that are not to be floated (i.e., the tailings). The most commonly used collector in coal flotation is fuel oil.

**Briquetting**
The briquetting of coal has a long history. In the late 1800s relatively worthless fine coal or slack was compressed to form a “patent fuel” or briquette. This product was acceptable to both the domestic and industrial markets. In order to form a stable briquette, a binder was necessary. Usually coal tars and pitches were used. The coal briquetting industry for the domestic market has been in decline for some years. However, there have been some advances in technology and applications.

High-moisture low-rank coals may be upgraded by thermal drying and subsequent removal of a portion of the inherent or “locked in” moisture. However, the product from this process is friable and prone to the re-absorption of moisture and spontaneous combustion. Briquetting of low-rank coal allows for a stable, transportable product to be made. Briquetting is also used in the anthracite industry, where large-sized products have a significantly higher selling price.

Coal briquetting has also been used in emerging economies where briquettes are used as cooking fuel in rural areas. The process of manufacture usually involves a devolatilizing step whereby excess gas or volatile matter is driven off prior to briquetting in order to produce a “smokeless” domestic fuel.

The briquetting process, therefore, usually has the following steps:

- **Coal drying:** Moisture content is critical because it has an impact on the strength of the briquette. Methods used are direct drying (a flash dryer using hot gas) and indirect drying (a disc dryer using steam heat).
- **Devolatilizing:** This is only applicable to low-rank high-volatile coals. The equipment used is a retort or a beehive type coke oven.
- **Crushing:** The coal is often crushed because a smaller particle size results in a stronger briquette.
- **Binders:** Binders are required to ensure that the briquette has adequate strength to withstand normal handling. The types of binders that have been used are coke oven pitch, petroleum asphalt, ammonium lignosulphorate and starch. The typical addition rate is 5 to 15% by weight. The fine coal and binder are mixed in a pug mill or paddle mixer at an elevated temperature.
- **Briquette manufacture:** The coal-binder mixture is fed to a double roll press with indented surfaces. A variety of briquette shapes can be made depending on the type of roller indentation. The most common form of briquette is the pillow shape. The pressure increases the apparent density of the coal-binder mix by 1.5 to 3 times.
- **Coating and baking:** With some binders (ammonium lignosulphorate and petroleum asphalt) a heat treatment in the range of 300°C is necessary to harden the briquettes. The heat treatment oven is an enclosed conveyor and heated with hot gases.
- **Cooling/quenching:** The cooling oven is an enclosed conveyor with recirculating air passing to reduce the briquette temperature to an ambient condition. Off-gases are collected, scrubbed and discharged to the atmosphere. Quenching with water is sometimes used to cool the briquettes.

Briquetting of soft brown coal with a high moisture content of 60 to 70% is a somewhat different process than that described above. The brown coals are frequently upgraded by briquetting, which involves crushing, screening and drying the coal to approximately 15% moisture, and extrusion pressing without binder into compacts. Large quantities of coal are treated in this way in Germany, India, Poland and Australia. The dryer used is a steam-heated rotary tube dryer. Following extrusion pressing, the compacted coal is cut and cooled before being transferred to belt conveyors to railcars, road trucks or storage.
Briquetting plants handle large quantities of highly combustible material associated with potentially explosive mixtures of coal dust and air. Dust control, collection and handling as well as good housekeeping are all of considerable importance to safe operation.

Refuse and Tailings Disposal

Waste disposal is an integral part of a modern coal preparation plant. Both coarse refuse and fine tailings in the form of slurry must be transported and disposed of in an environmentally responsible way.

Coarse refuse

Coarse refuse is transported by truck, conveyor belt or aerial ropeway to the solids disposal area, which usually forms the walls of the tailings impoundment. The refuse can also be returned to the open pit.

Innovative cost-effective forms of transporting of coarse waste are now being used, namely, crushing and transportation by pumping in slurry form to an impoundment pond and also by a pneumatic system to underground storage.

It is necessary to select a disposal site which has a minimal amount of exposed surface while at the same time provides for good stability. A structure that is exposed on all sides permits more surface drainage, with a greater tendency for silt formation in nearby water courses, and also a greater probability of spontaneous combustion. To minimize both these effects, greater quantities of cover material, compacting and sealing, are required. The ideal disposal construction is the valley-fill type of operation.

Preparation-plant waste embankments may fail for several reasons:

- weak foundations
- excessively steep slopes of excessive heights
- poor control of water and fine material seepage through the dump
- inadequate water control during extreme rainfall events.

The principal categories of design and construction techniques which can greatly reduce environmental hazards associated with coal-refuse disposal are:

- drainage from within the refuse pile
- diversion of surface drainage
- waste compaction to minimize spontaneous combustion
- waste pile stability.

Tailings

Tailings (fine solid waste in water) are usually transported by pipe line to an impoundment area. However, in some instances tailings impoundment is not environmentally acceptable and alternative treatment is necessary, namely, dewatering of tailings by belt press or high speed centrifuge and then disposal of the dewatered product by belt or truck in the coarse refuse area.
Tailings impoundments (ponds) operate on the principle that the tailings settle out to the bottom and the resulting clarified water is pumped back to the plant for reuse. The pool elevation in the pond is maintained such that storm in-flows are stored and then drawn off by pumping or small decant systems. It may be necessary periodically to remove sediment from smaller impoundments to extend their life. The retaining embankment of the impoundment is usually constructed of coarse refuse. Poor design of the retaining wall and liquefaction of the tailings due to poor drainage can lead to dangerous situations. Stabilizing agents, usually calcium-based chemicals, have been used to produce a cementation effect.

Tailings impoundments normally develop over an extended period of the mine’s life, with continually changing conditions. Therefore the stability of the impoundment structure should be carefully and continuously monitored.

12. MINE AIR POLLUTION, DUST, AND RELATED OCCUPATIONAL DISEASES - NUISANCE TO BE CHECKED FOR IMPROVEMENT OF GENERAL SAFETY AND HEALTH STANDARD IN MINES

Mine Air pollution is the presence of high concentration of contaminations, dust, smokes etc., in the general body of Mine-air man breaths. Dust is defined as particulate matter as "any airborne finely divided solid or liquid material with a diameter smaller than 100 micrometers." Dust and smoke are the two major components of particulate matter. These materials come from various sources, including, but not limited to, various industrial processes including coal handling plants, paved and unpaved Mine roadways, construction and demolition sites, parking lots, storage piles, handling and transfer of materials, and open areas.

Dust when inhaled can increase breathing problems, damage lung tissue, and aggravate existing health problems. In addition to health concerns, dust generated from various activities can reduce visibility, resulting in accidents. Therefore, every federal Govt. has stringent regulations which require prevention, reduction and/or mitigation of dust emissions.

Thus, prime sources of air pollution are the industrial activities or processes releasing large quantity of pollutants in the atmosphere. These pollutants are mainly:

(a) Smoke comes out from various industries like, power plants, chemical plants, other manufacturing facilities, motor vehicles etc.;

(b) Burning of wood, coal in furnaces and incinerators;

(c) Gaseous pollutants from Oil refining industries;
(d) Dust generated and thrown to general atmosphere by various industries such as Coal handling plants, ore / stone crushing units, mining industries due to rock drilling & movements of mining machineries & blasting etc.;

(e) Waste deposition for landfills which generate methane;

(f) Toxic / germ / noxious gasses and fumes generated from military activities and explosives blasting in mines.

**Mechanism of Adverse Impact of Smoke Pollutant**

The main sources of smoke pollutants in Mining Areas are Petrol / Diesel driven Heavy-motor vehicles, coal-burning power plants etc.

Petrol / Diesel driven Heavy-motor vehicles produce high levels of Carbon Dioxide (CO2) / Carbon Monoxide (CO), major source of Hydrocarbon (HC) and Nitrogen oxides (NOx). Fuel combustion in stationary sources is the dominant source of Carbon Dioxide (CO2) and Sulfur Dioxide (SO2).

**Carbon Dioxide (CO2)** – This is one of the major gas pollutants in the atmosphere. Major sources of CO2 are due to burning of fossil fuels and deforestation. Industrially developed countries like USA, Russia etc., account for more than 65% of CO2 emission. Less developed countries with 80% of world’s population responsible for about 35% of CO2 emission. Due to high growth reported from less developed countries in last decade, it is estimated that, the Carbon dioxide emissions may rise from these areas and by 2020 their contribution may become 50%. It has also been seen that, Carbon dioxide emissions are rising by 4% annually.

As ocean water contain about 60 times more CO2 than atmosphere; CO2 released by the industry leads to disturbance of equilibrium of concentration of CO2 in the system. In such a scenario, the oceans would absorb more and more CO2 and atmosphere would also remain excess of CO2. As water warms, ocean’s ability to absorb CO2 is reduced. CO2 is a good transmitter of sunlight, but
partially restricts infrared radiation going back from the earth into space. This produces the so-called “Greenhouse Effect” that prevents a drastic cooling of the Earth during the night. This so-called “Greenhouse Effect” is responsible for GLOBAL WARMING. Currently Carbon Dioxide is responsible for major portion of the global warming trend.

**Nitrogen oxides (NOx)** - They come mainly from blasting in mines, Heavy vehicles, deforestation, and biomass burning. Nitrogen oxides contribute mostly as atmospheric contaminants. These gases are responsible in the formation of both acid precipitation and photochemical smog and causes nitrogen loading. These gases have a role in reducing stratospheric ozone.

**Sulfur Dioxide (SO2)** - Sulfur dioxide is produced by combustion of sulfur-containing fuels, such as coal and fuel oils. SO2 also produced in the process of producing Sulfuric Acid and in metallurgical process involving ores that contain sulfur. Sulfur oxides can injure man, plants and materials. As emissions of sulfur dioxide and nitric oxide from stationary sources are transported long distances by winds, they form secondary pollutants such as nitrogen dioxide, nitric acid vapor, and droplets containing solutions of sulfuric acid, sulfate, and nitrate salts. These chemicals descend to the earth’s surface in wet form as rain or snow and in dry form as a gases fog, dew, or solid particles. This is known as acid deposition or acid rain.

Smog – Smog is the result from the irradiation by sunlight of hydrocarbons caused primarily by unburned gasoline emitted by automobiles and other combustion sources. Smog is created by burning coal and heavy oil that contain mostly sulfur impurities.

**Mechanism of air pollution by particulate matters (Fine and Coarse Dust particles)**

‘Fine particles’ are less than 2.5 micron in size and require electron microscope for detection, however, they are much larger than the molecules of Ozone etc., and other gaseous pollutants, which are thousands times smaller and cannot be seen through even electron microscope.

Fine particles are formed by the condensation of molecules into solid or liquid droplets, whereas larger particles are mostly formed by mechanical breakdown of material or crushing of minerals. ‘Coarse particles’ are between 2.5 to 10 micron size, and cannot penetrate as readily as of Fine particle; however, it has been seen these are responsible for serious health hazards. The severity of the health hazards vary with the chemical nature of the particles.

The inhalation of particles has been linked with illness and deaths from heart and lung disease as a result of both short- and long-term exposures. People with heart and lung disease may experience chest pain, shortness of breath, fatigue etc., when exposed to particulate-matter pollutants.

Inhalation of particulate matter can increase susceptibility to respiratory infections such as Asthma, Chronic Bronchitis. The general medical term given for such lung diseases is ‘Pneumoconiosis’.

Emissions from diesel-fuel combustion in vehicles / engines / equipments; Dusts from cement plants, power plants, chemical plants, mines are a special problem, specially for those individuals breathing in close proximity to such atmosphere. Cars, trucks and off-road engines emit more than half a million tones of diesel particulate matter per year.
**Controlling Airborne Particulate Matters** - Airborne particulate matters (PM) emissions can be minimized by pollution prevention and emission control measures. Prevention, which is frequently more cost-effective than control, should be emphasized. Special attention should be given to mitigate the effects, where toxics associated with particulate emissions may pose a significant environmental risk.

Measures such as improved process design, operation, maintenance, housekeeping and other management practices can reduce emissions. By improving combustion efficiency in Diesel engines, generation of particulate matters can be significantly reduced. Proper fuel-firing practices and combustion zone configuration, along with an adequate amount of excess air, can achieve lower PICs (products of incomplete combustion). Few following steps should be adhered to control PM:

a. Choosing cleaner fuels - Natural gas used as fuel emits negligible amounts of particulate matter.

b. Low-ash fossil fuels contain less non-combustible, ash-forming mineral matter and thus generate lower levels of particulate emissions.

c. Reduction of ash by coal cleaning reduces the generation of ash and Particulate Matter (PM) emissions by up to 40%.

d. The use of more efficient technologies or process changes can reduce PIC emissions.

e. Advanced coal combustion technologies such as coal gasification and fluidized-bed combustion are examples of cleaner processes that may lower PICs by approximately 10%.

f. A variety of particulate removal technologies, are available – these are (a) Inertial or impingement separators, (b) Electrostatic precipitators (ESPs) , (c) Filters and dust collectors (baghouses), (d) Wet scrubbers that rely on a liquid spray to remove dust particles from a gas stream.

**Mechanical systems for controlling dust:** Several mechanical equipments are used in cement manufacturing plant to control / collect dust. These are:

(i) **Dust collector** - A dust collector (bag house) is a typically low strength enclosure that separates dust from a gas stream by passing the gas through a media filter. The dust is collected on either the inside or the outside of the filter. A pulse of air or mechanical vibration removes the layer of dust from the filter. This type of filter is typically efficient when particle sizes are in the 0.01 to 20 micron range.
(ii) **Cyclone** - Dust laden gas enters the chamber from a tangential direction at the outer wall of the device, forming a vortex as it swirls within the chamber. The larger articulates, because of their greater inertia, move outward and are forced against the chamber wall. Slowed by friction with the wall surface, they then slide down the wall into a conical dust hopper at the bottom of the cyclone. The cleaned air swirls upward in a narrower spiral through an inner cylinder and emerges from an outlet at the top. Accumulated particulate dust is deposited into a hopper, dust bin or screw conveyor at the base of the collector. Cyclones are typically used as pre-cleaners and are followed by more efficient air-cleaning equipment such as electrostatic precipitators and bag houses.
(iii) Electrostatic Precipitator - In an electrostatic precipitator, particles suspended in the air stream are given an electric charge as they enter the unit and are then removed by the influence of an electric field. A high DC voltage (as much as 100,000 volts) is applied to the discharge electrodes to charge the particles, which then are attracted to oppositely charged collection electrodes, on which they become trapped. An electrostatic precipitator can remove particulates as small as 1 μm (0.00004 inch) with an efficiency exceeding 99 percent.
Dust control systems in Coal Handling Plant:

Thermal power plants (coal-fired power plants) use coal as their fuel. To handle the coal, each power station is equipped with a coal handling plant. The coal has to be sized, processed, and handled which should be done effectively and efficiently. The major factor which reduces the staff efficiency in operation of coal handling plant is the working environment i.e. a dusty atmosphere and condition. Lots of care is always needed to reduce dust emission. In developing countries, all most all systems used in power station coal handling plants are wet dust suppression systems.

* After dust is formed, control systems are used to reduce dust emissions. Although installing a dust control system does not assure total prevention of dust emissions, a well-designed dust control system can protect workers and often provide other benefits, such as (a) Preventing or reducing risk of dust explosion or fire; (b) Increasing visibility and reducing probability of accidents; (c) Preventing unpleasant odors; (d) Reducing cleanup and maintenance costs; (e) Reducing equipment wear, especially for components such as bearings and pulleys on which fine dust can cause a "grinding" effect and increase wear or abrasion rates; (f) Increasing worker morale and productivity; (f) Assuring continuous compliance with existing health regulations. In addition, proper planning, design, installation, operation, and maintenance are essential for an efficient, cost-effective, and reliable dust control system.

* There are two basic types of dust control systems currently used in minerals processing operations are:

(a) Dust collection system - Dust collection systems use ventilation principles to capture the dust-filled air-stream and carry it away from the source through ductwork to the collector. A typical dust collection system consists of four major components, such as (1) An exhaust hood to capture dust emissions at the source; (2) Ductwork to transport the captured dust to a dust collector; (3) A dust collector to remove the dust from the air; (4) A fan and motor to provide the necessary exhaust volume and energy.

(b) Wet dust suppression system - Wet dust suppression techniques use water sprays to wet the material so that it generates less dust. There are two different types of wet dust suppressions:

(i) Wets the dust before it is airborne (surface wetting) and

(ii) Wets the dust after it becomes airborne. In many cases surfactants or chemical foams are often added to the water into these systems in order to improve performance.

A water spray with surfactant means that a surfactant has been added to the water in order to lower the surface tension of the water droplets and allow these droplets to spread further over the material and also to allow deeper penetration into the material.

• Surface wetting system: The principle behind surface wetting is the idea that dust will not even be given a chance to form and become airborne. With this method, effective wetting of the material can take place by static spreading (wetting material while it is stationary) and dynamic spreading (wetting material while it is moving). For static wetting, more effective dust suppression arises by increasing the surface coverage by either reducing the droplet
diameter or its contact angle. For dynamic spreading, more factors come into play such as the surface tension of the liquid, the droplet diameter, the size of the material being suppressed, and the droplet impact velocity.

- **Airborne dust capture system** - Airborne dust capture systems may also use a water-spray technique; however, airborne dust particles are sprayed with atomized water. When the dust particles collide with the water droplets, agglomerates are formed. These agglomerates become too heavy to remain airborne and settle. Airborne dust wet suppression systems work on the principle of spraying very small water droplets into airborne dust. When the small droplets collide with the airborne dust particles, they stick to each other and fall out of the air to the ground. Research showed that, if a sufficient number of water droplets of approximately the same size as the dust particles could be produced, the possibility of collision between the two would be extremely high. It was also determined that if the droplet exceeded the size of the dust particle, there was little probability of impact and the desired precipitation. Instead, the dust particle would move around the droplet.

![Diagram of airflow around large water droplet and dust particle](image)

*System Efficiency*: Over the years, water sprays has established the following facts:

(a) For a given spray nozzle, the collection efficiency for small dust particles increases as the pressure increases;

(b) At a given pressure, the efficiency increases as the nozzle design is changed so as to produce smaller droplets. The efficiency of spray dust capture increases by increasing the number of smaller sized spray droplets per unit volume of water utilized and by optimizing the energy transfer of spray droplets with the dust-laden air.

* Sophisticated system like ‘Ultrasonic Dust Suppression’ systems uses water and compressed air to produce micron sized droplets that are able to suppress respirable dust without adding any detectable moisture to the process. Ideal for spray curtains to contain dust within hoppers. The advantages of using Ultrasonic Atomizing Systems for dust suppression can therefore be summarized as: (a) reduced health hazards; (b) decrease in atmospheric pollution; (c) improved working conditions; (d) efficient operation with minimum use of water.
Air pollution control devices / equipments for industries, in general

The commonly used equipments / process for control of dust in various industries are (a) Mechanical dust collectors in the form of dust cyclones; (b) Electrostatic precipitators – both dry and wet system; (c) particulate scrubbers; (d) Water sprayer at dust generation points; (e) proper ventilation system and (f) various monitoring devices to know the concentration of dust in general body of air.

The common equipments / process used for control of toxic / flue gases are the (a) process of desulphurisation; (b) process of denitrification; (c) Gas conditioning etc. and (d) various monitoring devices to know the efficacy of the systems used.

Occupational Hazards / diseases due to expose in dusty and polluted air

There are certain diseases which are related to one’s occupation. These are caused by constant use of certain substances that sneak into air and then enter our body.

(i) Silicosis (Silico-tuberculosis) occurs due to inhalation of free silica, or SiO2 (Silicon dioxide), while mining or working in industries related to pottery, ceramic, glass, building and construction work. The workers get chronic cough and pain in the chest. Silicosis treatment is extremely limited considering a lack of cure for the disease. However, like all occupational respiratory ailments, it is 100% preventable if exposure is minimized.

(ii) Asbestosis is caused by asbestos, which is used in making ceilings. It is also considered as cancer causing agent. Pathogenesis of the disease is characterized as progressive and irreversible, leading to subsequent respiratory disability. In severe cases, asbestosis results in death from pulmonary hypertension and cardiac failure.

(iii) Byssinosis, also referred to as brown lung disease, is an occupational respiratory disorder characterized by the narrowing of pulmonary airways. It is a disabling lung disease, which is marked by chronic cough and chronic bronchitis due to inhalation of cotton fibers over a long period of time.

(iv) Coal worker’s Pneumoconiosis occurs due to inhalation of coal dust from coal mining industry. Also referred to as black lung disease. The workers suffer from lung problems. Apart from asbestosis, black lung disease is the most frequently occurring type of pneumoconiosis. In terms of disease pathogenesis, a time delay of nearly a decade or more occurs between exposure and disease onset.

Preventive Measures :

The most successful tool of prevention of respiratory diseases from industrial dust is to minimize exposure. However, this is not a practical approach from the perspective of industries such as mining, construction/demolition, refining/manufacturing/processing, where industrial dust is an unavoidable byproduct. In such cases, industries must implement a stringent safety protocol that effectively curtails exposure to potentially hazardous dust sources. NIOSH recommended precautionary measures to reduce exposure to a variety of industrial dust types.

1. Recognize when industrial dust may be generated and plan ahead to eliminate or control the dust at the source. Awareness and planning are keys to prevention of silicosis.
2. Do not use silica sand or other substances containing more than 1% crystalline silica as abrasive blasting materials. Substitute less hazardous materials.

3. Use engineering controls and containment methods such as blast-cleaning machines and cabinets, wet drilling, or wet sawing of silica-containing materials to control the hazard and protect adjacent workers from exposure.

4. Routinely maintain dust control systems to keep them in good working order.

5. Practice good personal hygiene to avoid unnecessary exposure to other worksite contaminants such as lead.

6. Wear disposable or washable protective clothes at the worksite.

7. Shower (if possible) and change into clean clothes before leaving the worksite to prevent contamination of cars, homes, and other work areas.

8. Conduct air monitoring to measure worker exposures and ensure that controls are providing adequate protection for workers.

9. Use adequate respiratory protection when source controls cannot keep silica exposures below the designated limit.

10. Provide periodic medical examinations for all workers who may be exposed to respirable crystalline silica.

11. Post warning signs to mark the boundaries of work areas contaminated with respirable crystalline silica.

12. Provide workers with training that includes information about health effects, work practices, and protective equipment for respirable crystalline silica.

13. Report all cases of silicosis to Federal / State health departments.

13. GROUND CONTROL IN UNDERGROUND MINES

The principal objective of ground control is to maintain safe excavations in rock and soil (the terms strata control and slope management are also used in underground mines and surface mines, respectively). Ground control also finds many applications in civil engineering projects such as tunnels, hydro-electric power plants and nuclear waste repositories. It has been defined as the practical application of rock mechanics to everyday mining. The US National Committee on Rock Mechanics has proposed the following definition: “Rock mechanics is the theoretical and applied science of the mechanical behaviour of rock and rock masses; it is that branch of mechanics concerned with the response of rock and rock masses to the force fields of their physical environment”.

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Rock masses exhibit extremely complex behaviour, and rock mechanics and ground control have been the subject of considerable fundamental and applied research throughout the world since the 1950s. In many ways ground control is a craft more than a science. Ground control requires an understanding of structural geology, rock properties, groundwater and ground stress regimes and of how these factors interact. Tools include the methods of site investigation and rock testing, measures to minimize damage to the rock mass caused by blasting, the application of design techniques, monitoring and ground support. Several important developments have taken place in rock mechanics and ground control in recent years, including the development of empirical design and computer analysis techniques for mine design, the introduction and wide use of a variety of ground monitoring instruments and the development of specialized ground support tools and techniques. Many mining operations have ground control departments staffed by specialist engineers and technicians.

Underground openings are more difficult to create and maintain than rock or soil slopes, therefore underground mines generally must devote more resources and design efforts to ground control than surface mines and quarries. In traditional underground mining methods, such as shrinkage and cut-and-fill, workers are directly exposed to potentially unstable ground in the ore zone. In bulk mining methods, such as blasthole stoping, workers do not enter the ore zone. There has been a trend away from selective methods to bulk methods in the past decades.

**Ground Failure Types**

Rock structure and rock stress are important causes of instability in mines.

A particular rock mass consists of intact rock and any number of rock structures or structural discontinuities. Major types of rock structures include bedding planes (division planes which separate the individual strata), folds (bends in rock strata), faults (fractures on which movement has occurred), dykes (tabular intrusions of igneous rock) and joints (breaks of geological origin along which there has been no visible displacement). The following properties of structural discontinuities affect the engineering behaviour of rock masses: orientation, spacing, persistence, roughness, aperture and presence of infilling material. The collection of pertinent structural information by engineers and geologists is an important component of the ground control programme at a mining operation. Sophisticated computer programmes to analyse structural data and the geometry and stability of wedges in surface or underground mines are now available.

Stresses in rock also can cause instability in mines; knowledge of the stress-strain behaviour of rock masses is essential to sound engineering design. Laboratory tests on cylindrical specimens of rock from drill core can provide useful strength and deformability information concerning the intact rock; different rock types behave differently, from the plastic behaviour of salt to the elastic, brittle behaviour of many hard rocks. Jointing will greatly influence the strength and deformability of the entire rock mass.

There are some common types of rock slope failures in surface mines and quarries. The sliding block failure mode occurs where movement takes places along one or more rock structures (plane shear, step path, wedge, step wedge or slab failures); a rotational shear failure can occur in a soil or weak rock mass slope; additional failure modes include toppling of blocks formed by steeply dipping structures and ravelling (e.g., dislodging of blocks by freeze-thaw or rain).

Major slope failures can be catastrophic, although slope instability does not necessarily mean slope failure from an operational standpoint. The stability of individual benches is usually of more
immediate concern to the operation, as failure can occur with little warning, with potential loss of life and equipment damage.

In underground mines, instability can result from movement and collapse of rock blocks as a result of structural instability, failure of rock around the opening as a result of high rock stress conditions, a combination of stress-induced rock failure and structural instability and instability caused by rockbursts. Rock structure can influence the choice of an underground mining method and the design of mining layouts because it can control stable excavation spans, support requirements capability and subsidence. Rock at depth is subjected to stresses resulting from the weight of the overlying strata and from stresses of tectonic origin, and horizontal stresses are often greater than the vertical stress. Instruments are available to determine the level of stress in the ground before mining has begun. When a mine opening is excavated, the stress field around this opening changes and possibly exceeds the strength of the rock mass, resulting in instability.

There are also various types of failure which are commonly observed in underground hard rock mines. Under low stress levels, failures are largely structurally controlled, with wedges or blocks falling from the roof or sliding out of the walls of the openings. These wedges or blocks are formed by intersecting structural discontinuities. Unless loose wedges or blocks are supported, failure can continue until natural arching of the opening takes place. In stratified deposits, bed separation and failure can occur along bedding planes. Under high stress levels, failure consists of brittle spalling and slabbing in the case of a massive rock mass with few joints, to a more ductile type of failure for heavily jointed rock masses.

A rockburst may be defined as damage to an excavation that occurs in a sudden or violent manner and is associated with a seismic event. Various rockburst damage mechanisms have been identified, namely expansion or buckling of the rock due to fracturing around the opening, rockfalls induced by seismic shaking and ejection of rock due to energy transfer from a remote seismic source. Outbursts of rock and gas occur catastrophically in some coal, salt and other mines as a result of high rock stresses and large volumes of compressed methane or carbon dioxide. In quarries and surface mines, sudden buckling and heaving of rock floors has also been experienced. Considerable research has taken place in several countries into the causes and possible alleviation of rockbursts. Techniques for minimizing rockbursts include altering the shape, orientation and sequence of extraction, the use of a technique known as destress blasting, stiff mine backfills and the use of specialized support systems. Sophisticated local or mine-wide seismic monitoring systems can assist in the identification and analysis of source mechanisms, although the prediction of rockbursts remains unreliable at the present time.

In the Canadian province of Ontario, nearly one-third of all underground fatal injuries in the highly mechanized mining industry result from rockfalls and rockbursts. In less mechanized underground mining industries, or where ground support is not widely used, considerably higher injury and fatality frequencies due to falls of ground and rockbursts can be expected. The ground control related safety record for surface mines and quarries is generally better than for underground mines.

Design Methods

The design of underground excavations is the process of making engineering decisions on such matters as the locations, sizes and shapes of excavations and rock pillars, the mining sequence and the application of support systems. In surface mines, an optimum slope angle must be chosen for each section of the pit, along with other design aspects and slope support. Designing a mine is a dynamic process which is updated and refined as more information becomes available through
observation and monitoring during the mining. The empirical, observational and analytical design methods are commonly used.

Empirical methods often use a rock mass classification system (several such schemes have been developed, such as the Rock Mass System and the Rock Tunnelling Quality Index), complemented by design recommendations based on a knowledge of accepted practice. Several empirical design techniques have been successfully applied, such as the Stability Graph Method for open stope design.

Observational methods rely on the actual monitoring of ground movement during excavation to detect measurable instability and on the analysis of ground-support interaction. Examples of this approach include the New Austrian Tunnelling Method and the Convergence-Confinement method.

Analytical methods utilize the analysis of stresses and deformations around openings. Some of the earliest stress analysis techniques utilized closed form mathematical solutions or photo elastic models, but their application was limited due to the complex three-dimensional shape of most underground excavations. A number of computer-based numerical methods have been developed recently. These methods provide the means for obtaining approximate solutions to the problems of stresses, displacements and failure in rock surrounding mine openings.

Recent refinements have included the introduction of three-dimensional models, the ability to model structural discontinuities and rock-support interaction and the availability of user-friendly graphical interfaces. In spite of their limitations, numerical models can provide real insights into complex rock behaviour.

The three methodologies described above should be considered as essential parts of a unified approach to the design of underground excavations rather than independent techniques. The design engineer should be prepared to use a range of tools and to re-evaluate the design strategy when required by the quantity and quality of information available.

Drilling and Blasting Controls

A particular concern with rock blasting is its effect on the rock in the immediate vicinity of an excavation. Intense local fracturing and disruption of the integrity of the interlocked, jointed assembly can be produced in the near-field rock by poor blast design or drilling procedures. More extensive damage can be induced by the transmission of blasting energy to the far field, which may trigger instability in mine structures.

Blast results are affected by the rock type, stress regime, structural geology and presence of water. Measures for minimizing blast damage include the proper choice of explosive, the use of perimeter blasting techniques such as pre-split blasting (parallel, closely spaced holes, which will define the excavation perimeter), decoupling charges (the diameter of the explosive is smaller than that of the blasthole), delay timing and buffer holes. The geometry of the drilled holes affects the success of a wall control blast; hole pattern and alignment must be carefully controlled.

Monitoring of blast vibrations is often performed to optimize blasting patterns and to avoid damage to the rock mass. Empirical damage blast damage criteria have been developed. Blast monitoring equipment consists of surface-mounted or down-the-hole transducers, cables leading to an amplifying system and a digital recorder. Blast design has been improved by the development of computer models for the prediction of blast performance, including the fragmentation, muck profile
and crack penetration behind blastholes. Input data for these models include the geometry of the excavation and of the drilled and loaded pattern, detonation characteristics of the explosives and dynamic properties of the rock.

Scaling of Roof and Walls of Excavations

Scaling is the removal of loose slabs of rock from roofs and walls of excavations. It can be performed manually with a steel or aluminium scaling bar or by using a mechanical scaling machine. When scaling manually, the miner checks the soundness of the rock by striking the roof; a drum-like sound usually indicates that the ground is loose and should be barred down. The miner must follow strict rules in order to avoid injury while scaling (e.g., scaling from good ground to unchecked ground, maintaining good footing and a clear area to retreat and ensuring that scaled rock has a proper place on which to fall). Manual scaling requires considerable physical effort, and it can be a high-risk activity. For example, in Ontario, Canada, one third of all injuries caused by falls of rock occur while scaling.

The use of baskets on extendable booms so that miners can manually scale high backs introduces additional safety hazards, such as possible overturning of the scaling platform by falling rocks. Mechanical scaling rigs are now commonplace in many large mining operations. The scaling unit consists of a heavy hydraulic breaker, scraper or impact hammer, mounted on a pivoting arm, which is in turn attached to a mobile chassis.

Ground Support

The main objective of ground support is to help the rock mass support itself. In rock reinforcement, rockbolts are installed within the rock mass. In rock support, such as that provided by steel or timber sets, external support is provided to the rock mass. Ground support techniques have not found wide application in surface mining and quarrying, partly because of the uncertainty of the ultimate pit geometry and partly because of concerns with corrosion. A wide variety of rockbolting systems is available worldwide. Factors to consider when selecting a particular system include ground conditions, planned service life of the excavation, ease of installation, availability and cost.

The mechanically anchored rockbolt consists of an expansion shell (various designs are available to suit different rock types), steel bolt (threaded or with a forged head) and face plate. The expansion shell generally consists of toothed blades of malleable cast iron with a conical wedge threaded at one end of the bolt. When the bolt is rotated inside the hole, the cone is forced into the blades and presses them against the walls of the drillhole. The expansion shell increases its grip on the rock as tension on the bolt increases. Bolts of various lengths are available, along with a range of accessories. Mechanically anchored rockbolts are relatively inexpensive and, therefore, most widely used for short-term support in underground mines.

The grouted dowel consists of a ribbed reinforcing bar that is inserted in a drillhole and bonded to the rock over its full length, providing long-term reinforcement to the rock mass. Several types of cement and polyester resin-grouts are used. The grout can be placed in the drillhole by pumping or by using cartridges, which is quick and convenient. Steel and fibreglass dowels of various diameters are available, and bolts can be untensioned or tensioned.

The friction stabilizer commonly consists of a steel tube slotted along its entire length, which, when driven into a slightly undersized drillhole, compresses and develops friction between the steel tube
and the rock. The drillhole diameter must be controlled within close tolerances for this bolt to be effective.

The Swellex rockbolt consists of an involute steel tube which is inserted in a drillhole and expanded by hydraulic pressure using a portable pump. Various types and lengths of Swellex tubes are available.

The grouted cable bolt is frequently installed to control caving and stabilize underground stope roofs and walls. A Portland cement-based grout is generally used, while cable geometries and installation procedures vary. High-capacity reinforcing bars and rock anchors are also found in mines, along with other bolt types, such as tubular groutable mechanically anchored bolts.

Steel straps or mesh, made from either woven or welded wire, is often installed in the roof or walls of the opening to support the rock between bolts.

Mining operations should develop a quality control programme, which can include a variety of field tests, to ensure that ground support is effective. Poor ground support installations can be the result of inadequate design (failure to choose the correct ground support type, length or pattern for the ground conditions), sub-standard ground support materials (as supplied by manufacturer or damaged during handling or because of storage conditions at the mine site), installation deficiencies (defective equipment, poor timing of installation, inadequate preparation of the rock surface, poor training of crews or not following specified procedures), mining-induced effects that were unforeseen at the design stage (stress changes, stress or blast-induced fracturing/spalling, joint relaxation or rockbursting) or mine design changes (changes in excavation geometry or service life longer than originally anticipated).

The behaviour of reinforced or supported rock masses remains incompletely understood. Rules of thumb, empirical design guidelines based on rock mass classification systems and computer programs have been developed. However, the success of a particular design relies heavily on the knowledge and experience of the ground control engineer. A good quality rock mass, with few structural discontinuities and small openings of limited service life, may require little or no support. However, in this case rockbolts may be required at selected locations to stabilize blocks that have been identified as potentially unstable. At many mines, pattern bolting, the systematic installation of rockbolts on a regular grid to stabilize the roof or walls, is often specified for all excavations. In all cases, miners and supervisors must have sufficient experience to recognize areas where additional support may be required.

The oldest and simplest form of support is the timber post; timber props and cribs are sometimes installed when mining through unstable ground. Steel arches and steel sets are high load-carrying capacity elements used to support tunnels or roadways. In underground mines, additional and important ground support is provided by mine backfill, which can consist of waste rock, sand or mill tailings and a cementing agent. Backfill is used to fill voids created by underground mining. Among its many functions, backfill helps prevent large-scale failures, confines and thus provides residual strength to rock pillars, allows transfer of rock stresses, helps reduce surface subsidence, allows for maximum ore recovery and provides a work platform in some mining methods.

A relatively recent innovation in many mines has been the use of shotcrete, which is concrete sprayed on a rock face. It can be applied directly to rock with no other form of support, or it can be sprayed over mesh and rockbolts, forming part of an integrated support system. Steel fibres can be added, along with other admixtures and mix designs to impart specific properties. Two different...
Shotcreting processes exist, termed dry mix and wet mix. Shotcrete has found a number of applications in mines, including stabilizing rock faces that would otherwise ravel because of their close jointing. In surface mines, shotcrete has also been used successfully to stabilize progressive raveling failures. Other recent innovations include the use of polyurethane spray-on liners in underground mines.

In order to function effectively during a rockburst, support systems must possess certain important characteristics, including deformation and energy absorption. Support selection under rockburst conditions is the subject of ongoing research in several countries, and new design recommendations have been developed.

In small underground openings, manual ground support installation is commonly done using a stoper drill. In larger excavations, semi-mechanized equipment (mechanized drilling and manual equipment for rockbolt installation) and fully mechanized equipment (mechanized drilling and rockbolt installation controlled from an operator’s panel located under bolted roof) are available. Manual ground support installation is a high-risk activity.

Other hazards include possible splashes of cement grout or resin in the eyes, allergic reactions from chemical spillage and fatigue. The installation of large numbers of rockbolts is made safer and more efficient by the use of mechanized bolting machines.

Monitoring of Ground Conditions

Monitoring of ground conditions in mines may be carried out for a variety of reasons, including obtaining data needed for mine design, such as rock mass deformability or rock stresses; verifying design data and assumptions, thereby allowing calibration of computer models and adjustment of mining methods to improve stability; assessing the effectiveness of existing ground support and possibly directing the installation of additional support; and warning of potential ground failures.

Monitoring of ground conditions can be done either visually or with the help of specialized instruments. Surface and underground inspections must be done carefully and with the assistance of high-intensity inspection lights if necessary; miners, supervisors, engineers and geologists all have an important role to play in carrying out regular inspections.

Visual or audible signs of changing ground conditions in mines include but are not limited to the condition of diamond drill core, contacts between rock types, drum-like ground, the presence of structural features, obvious loading of ground support, floor heaving, new cracks on walls or roof, groundwater and pillar failures. Miners often rely on simple instruments (e.g., wooden wedge in crack) to provide a visual warning that roof movement has occurred.

Planning and implementing a monitoring system involves defining the purpose of the programme and the variables to be monitored, determining the required measurement accuracy, selecting and installing equipment and establishing the frequency of observations and means of data presentation. Monitoring equipment should be installed by experienced personnel. Instrument simplicity, redundancy and reliability are important considerations. The designer should determine what constitutes a threat to safety or stability. This should include the preparation of contingency plans in the event that these warning levels are exceeded.

The components of a monitoring system include a sensor, which responds to changes in the variable being monitored; a transmitting system, which transmits the sensor output to the read-out location,
using rods, electrical cables, hydraulic lines or radiotelemetry lines; a read-out unit (e.g., dial gauge, pressure gauge, multimeter or digital display); and a recording/processing unit (e.g., tape recorder, datalogger or microcomputer).

Various modes of instrument operation exist, namely:

- **Mechanical**: often provide the simplest, cheapest and most reliable methods of detection, transmission and readout. Mechanical movement detectors use a steel rod or tape, fixed to the rock at one end, and in contact with a dial gauge or electrical system at the other. The main disadvantage of mechanical systems is that they do not lend themselves to remote reading or to continuous recording.
- **Optical**: used in conventional, precise and photogrammetric surveying methods of establishing excavation profiles, measuring movements of excavation boundaries and monitoring surface subsidence.
- **Hydraulic and Pneumatic**: diaphragm transducers that are used for measuring water pressures, support loads and so forth. The quantity measured is a fluid pressure which acts on one side of a flexible diaphragm made of a metal, rubber or plastic.
- **Electrical**: the most common instrument mode used in mines, although mechanical systems still find widespread use in displacement monitoring. Electrical systems operate on one of three principles, electric resistance strain gauge, vibrating wire and self-inductance.

Most commonly monitored variables include movement (using surveying methods, surface devices such as crack gauges and tape extensometers, borehole devices such as rod extensometers or inclinometers); rock stresses (absolute stress or stress change from borehole devices); pressure, load and strain on ground support devices (e.g., load cells); seismic events and blast vibrations.

### 14. VENTILATION AND COOLING IN UNDERGROUND MINES

The main objective of mine ventilation is the provision of sufficient quantities of air to all the working places and travel ways in an underground mine to dilute to an acceptable level those contaminants which cannot be controlled by any other means. Where depth and rock temperatures are such that air temperatures are excessive, mechanical refrigeration systems may be used to supplement the beneficial effects of ventilation.

#### The Mine Atmosphere

The composition of the gaseous envelope encircling the earth varies by less than 0.01% from place to place and the constitution of “dry” air is usually taken as 78.09% nitrogen, 20.95% oxygen, 0.93% argon and 0.03% carbon dioxide. Water vapour is also present in varying amounts depending on the air temperature and pressure and the availability of free water surfaces. As ventilation air flows through a mine, the concentration of water vapour may change significantly and this variation is the subject of the separate study of psychrometry. To define the state of a water vapour and dry air mixture at a particular point requires the three measurable independent properties of barometric pressure, dry bulb and wet bulb temperatures.

#### Ventilation Requirements

The contaminants to be controlled by dilution ventilation are primarily gases and dust, although ionizing radiations associated with naturally occurring radon may present problems, especially in
uranium mines and where the background uranium concentrations of the host or adjacent rocks are elevated. The amount of air required for dilution control will depend on both the strength of the contaminant source and the effectiveness of other control measures such as water for dust suppression or methane drainage systems in coal mines. The minimum dilution air flow rate is determined by the contaminant requiring the greatest dilution quantity with due cognizance of the possible additive effects of mixtures and synergism where one contaminant can increase the effect of another. Overriding this value could be a minimum air velocity requirement which is typically 0.25 m/s and increasing as air temperatures also increase.

**Diesel-powered equipment ventilation**

In mechanized mines using diesel-powered mobile equipment and in the absence of continuous gas monitoring, exhaust gas dilution is used to determine the minimum ventilation air requirements where they operate. The amount of air required normally ranges between 0.03 and 0.06 m$^3$/s per kW of rated power at the point of operation depending on the type of the engine and whether any exhaust gas conditioning is being used. Continuing developments in both fuel and engine technology are providing lower engine emissions while catalytic converters, wet scrubbers and ceramic filters may further reduce the leaving concentrations of carbon monoxide/aldehydes, oxides of nitrogen and diesel particulates respectively. This helps in meeting increasingly stringent contaminant limits without significantly increasing exhaust dilution rates. The minimum possible dilution limit of 0.02 m$^3$/s per kW is determined by the carbon dioxide emissions which are proportional to engine power and unaffected by exhaust gas conditioning.

Diesel engines are about one-third efficient at converting the energy available in the fuel to useful power and most of this is then used to overcome friction resulting in a heat output which is about three times the power output. Even when hauling rock up a decline in a truck, the useful work done is only about 10% of energy available in the fuel. Higher diesel engine powers are used in larger mobile equipment which require bigger excavations to operate safely. Allowing for normal vehicle clearances and a typical diesel exhaust gas dilution rate of 0.04 m$^3$/s per kW, the minimum air velocities where diesels operate average about 0.5 m/s.

**Ventilation of different mining methods**

Although the setting of general air quantity requirements is not appropriate where detailed mine and ventilation planning information is available or possible, they are supportive of the criteria being used for design. Deviations from normal values generally can be explained and justified, for instance, in mines with heat or radon problems. The general relationship is:

\[
\text{Mine quantity} = \alpha t + \beta
\]

where ‘t’ is the annual production rate in million tonnes per annum (Mtpa), ‘\(\alpha\)’ is a variable air quantity factor which is directly related to production rate and ‘\(\beta\)’ is the constant air quantity required to ventilate the mine infrastructure such as the ore handling system. Typical values of \(\alpha\) are given in Table - A below.
Table – A: Design air quantity factors

<table>
<thead>
<tr>
<th>Mining method</th>
<th>$\alpha$ (air quantity factor $m^3/s/Mtpa$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Block-caving</td>
<td>50</td>
</tr>
<tr>
<td>Room-and-pillar (Potash)</td>
<td>75</td>
</tr>
<tr>
<td>Sub-level caving</td>
<td>120</td>
</tr>
<tr>
<td>Open stoping</td>
<td></td>
</tr>
<tr>
<td>large &gt;.5 Mtpa</td>
<td>160</td>
</tr>
<tr>
<td>small &lt;.5 Mtpa</td>
<td>240</td>
</tr>
<tr>
<td>Mechanized cut-and-fill</td>
<td>320</td>
</tr>
<tr>
<td>Non-mechanized mining</td>
<td>400</td>
</tr>
</tbody>
</table>

The constant air quantity $\beta$ is mainly dependent on the ore handling system and, to a certain extent, on the overall mine production rate. For mines where rock is transported through a decline using diesel powered truck haulage or there is no crushing of the mined rock, a suitable value of $\beta$ is 50 $m^3/s$. This typically increases to 100 $m^3/s$ when using underground crushers and skip hoisting with underground maintenance areas. As the ore handling system become more extensive (i.e., using conveyors or other ore transfer systems), $\beta$ can further increase by up to 50%. On very large mines where multiple shaft systems are used, the constant air quantity $\beta$ is also a multiple of the number of shaft systems required.

**Cooling Requirements**

**Design thermal conditions** - The provision of suitable thermal conditions to minimize the dangers and adverse effects of heat stress may require mechanical cooling in addition to the ventilation necessary to control contaminants. Although the applied heat stress is a complex function of climatic variables and physiological responses to them, in practical mining terms it is the air velocity and wet bulb temperature that have the greatest influence. This is illustrated by the clothing-corrected air cooling powers ($W/m^2$) given in Table - B. Underground the radiant temperature is taken to be equal to the dry bulb temperature and 10 °C higher than the wet bulb temperature. The barometric pressure and the clothing regime are typical for underground work (i.e., 110 kPa and 0.52 clothing units).

Table – B: Clothing-corrected air cooling powers ($W/m^2$)

<table>
<thead>
<tr>
<th>Air velocity (m/s)</th>
<th>Wet bulb temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>20.0</td>
</tr>
<tr>
<td>0.1</td>
<td>176</td>
</tr>
<tr>
<td>0.25</td>
<td>238</td>
</tr>
<tr>
<td>0.5</td>
<td>284</td>
</tr>
<tr>
<td>1.0</td>
<td>321</td>
</tr>
</tbody>
</table>
An air velocity of 0.1 m/s reflects the effect of natural convection (i.e., no perceivable airflow at all). An air velocity of 0.25 m/s is the minimum normally allowed in mining and 0.5 m/s would be required where the wet bulb temperature exceeds 25 °C. With respect to achieving thermal equilibrium, the metabolic heat resulting from typical work rates are: rest, 50 W/m$^2$; light work, 115 to 125 W/m$^2$; medium work, 150 to 175 W/m$^2$; and hard work, 200 to 300 W/m$^2$. Design conditions for a specific mine application would be determined from a detailed optimization study. Generally, optimum wet bulb temperatures are between 27.5 °C and 28.5 °C with the lower temperatures applicable to less mechanized operations. Work performance decreases and the risk of heat-related illness increases significantly when the wet bulb temperature exceeds 30.0 °C, and work should not normally continue when the wet bulb temperature is greater than 32.5 °C.

Mine heat loads

The mine refrigeration load is the mine heat load less the cooling capacity of the ventilation air. The mine heat load includes the effects of auto-compression of the air in the intake airways (the conversion of potential energy to enthalpy as the air flows down into the mine), heat flow into the mine from the surrounding rock, heat removed from the rock broken or any fissure water before they are removed from the intakes or working sections of the mine, and the heat resulting from the operation of any equipment used in the ore breaking and transportation processes. The cooling capacity of the ventilation air depends on both the design thermal environmental conditions in the working places and the actual climatic conditions on surface.

Although the relative contributions of each heat source to the total is site specific, auto-compression is usually the main contributor at between 35 and 50% of the total. As the depth of mining increases, auto-compression can cause the cooling capacity of the air to become negative and the effect of supplying more air is to increase the mine refrigeration load. In this case, the amount of ventilation supplied should be the minimum consistent with meeting contaminant control and increasing amounts of refrigeration are required to provide productive and safe working conditions. The depth of mining at which refrigeration becomes necessary will depend primarily on the surface climatic conditions, the distance the air travels through the intake airways before it is used and the extent to which large equipment (diesel or electric powered) is used.

Primary Ventilation Systems

Networks

Primary ventilation systems or networks are concerned with ensuring the flow of air through interconnected mine openings. The overall ventilation network has junctions where three or more airways meet, branches that are airways between junctions and meshes which are closed paths traversed through the network. Although most mine ventilation networks are ramified with hundreds or even thousands of branches, the number of main intake (branch between surface and the mine workings) and return or exhaust (branch between the workings and surface) airways is usually limited to less than ten.

With large numbers of branches in a network, determining a flow pattern and establishing the overall pressure loss is not straightforward. Although many are in simple series or parallel arrangement which can be solved algebraically and precisely, there will be some compound sections requiring iterative methods with convergence to an acceptable tolerance. Analogue computers have been successfully used for network analysis; however, these have been superseded by less time-
Airway resistance and shock losses

The resistance to airflow of a tunnel or mine opening is a function of its size and surface roughness and the resultant pressure loss depends on this resistance and the square of the air velocity. By adding energy to the system, a pressure can be generated which then overcomes the pressure loss. This may occur naturally where the energy is provided by heat from the rock and other sources (natural ventilation). Although this used to be the main method of providing ventilation, only 2 to 3% of the energy is converted and, during hot summers, the rock may actually cool the intake air resulting in flow reversals. In modern mines a fan is normally used to provide energy to the air stream which then overcomes the pressure loss although the effects of natural ventilation can either assist or retard it depending on the time of year.

When air flows over a surface, the air molecules immediately next to the surface are at a standstill and those adjacent slip over those at rest with a resistance which is dependent on the viscosity of the air. A velocity gradient is formed where the velocity increases with increasing distance from the surface. The boundary layer created as a result of this phenomenon and the laminar sub-layer also formed as the boundary layer develops have a profound effect on the energy required to promote flow. Generally, the roughness of the surface of mine airways is large enough for the “bumps” to extend through the boundary sub-layer. The airway is then hydraulically rough and the resistance is a function of the relative roughness, i.e., the ratio of the roughness height to the diameter of the airway.

Most airways mined by conventional drill and blast techniques have roughness heights between 100 and 200 mm and even in very “blocky” ground, the average roughness height would not exceed 300 mm. Where airways are driven using boring machines, the roughness height is between 5 and 10 mm and still considered to be hydraulically rough. The roughness of airways can be reduced by lining them, although the justification is more usually ground support rather than a reduction in power required to circulate the ventilation air. For example, a large concrete-lined shaft with a roughness of 1 mm would be transitionally rough and the Reynolds number, which is the ratio of inertial to viscous forces, would also affect the resistance to airflow.

In practice, the difficulties in smooth concrete lining such a large shaft from the top down as it is being sunk results in increased roughness and resistances about 50% higher than the smooth values.

With a limited number of intake and return airways between the workings and surface, a large proportion (70 to 90%) of the total mine pressure loss occurs in them. Airway pressure losses also depend on whether there are any discontinuities causing shock losses such as bends, contractions, expansions or any obstructions in the airway. The losses resulting from these discontinuities such as bends into and out of airways, when expressed in terms of the losses which would be produced in an equivalent length of straight airway, can be a significant proportion of the total and need to be assessed carefully, particularly when considering the main intakes and exhausts. The losses in discontinuities depend on the amount of boundary layer separation; this is minimized by avoiding sudden changes in area.

Resistance of airways with obstructions
The effect of an obstruction on pressure losses depends on its drag coefficient and the fill coefficient, which is the ratio of the blockage area of the object and the cross-sectional area of the airway. The losses caused by obstructions can be reduced by minimizing boundary-layer separation and the extent of any turbulent wake by streamlining the object. Drag coefficients are affected by their shape and arrangement in the shaft; comparative values would be: I beam, 2.7; square, 2.0; cylinder, 1.2; elongated hexagon, 0.6; and fully streamlined, 0.4.

Even with small fill coefficients and low drag coefficients, if the obstruction is repeated regularly, such as with the beams separating hoisting compartments in a shaft, the cumulative effect on pressure losses is significant. For example, the resistance of a shaft equipped with semi-streamlined elongated hexagon beams and a fill coefficient of 0.08 would be about four times that of the concrete lined shaft alone. Although the material costs of the more readily available rectangular hollow structural steel sections are more than I beams, the drag coefficients are about one-third and easily justify their application.

**Main and booster fans**

Both axial and centrifugal fans are used to provide air circulation in mine ventilation systems, with fan efficiencies of over 80% being achievable. The selection between axial flow or centrifugal for main mine fans depends on cost, size, pressure, robustness, efficiency and any performance variation. In mines where a fan failure may result in dangerous methane accumulations, additional fan capacity is installed to ensure continuity of ventilation. Where this is not so critical and with a twin fan installation, about two-thirds of the mine airflow will continue if one fan stops. Vertical axial flow fans installed over the airways have low costs but are limited to about 300 m$^3$/s. For larger air quantities, multiple fans are required and they are connected to the exhaust with ducting and a bend.

To obtain the highest efficiencies at reasonable cost, axial flow fans are used for low pressure (less than 1.0 kPa) applications and centrifugal fans for high pressure (greater than 3.0 kPa) systems. Either selection is suitable for the intermediate pressures. Where robustness is required, such as with exhausts with air velocities above the critical range, and water droplets are carried up and out of the system, a centrifugal fan will provide a more reliable selection. The critical air velocity range is between 7.5 m/s and 12.5 m/s where the water droplets may stay in suspension depending on their size. Within this range, the amount of suspended water can build up and increase the system pressure until the fan stalls. This is the region where some of the air recirculates around the blades and fan operation becomes unstable. Although not desirable for any type of fan, the possibility of a centrifugal fan blade failure is significantly less than an axial blade failure in this region of flow fluctuation.

It is rare that a main fan is required to operate at the same duty point over the life of the mine, and effective methods of varying fan performance are desirable. Although variable speed results in the most efficient operation for both axial and centrifugal fans, the costs, particularly for large fans, is high. The performance of an axial flow fan can be varied by adjusting the blade angle and this can be carried out either when the fan is stopped or, at a significantly higher cost, when it is rotating. By imparting a swirl to the air entering a fan using variable inlet vanes, the performance of a centrifugal fan can be varied while it is running.

The efficiency of the centrifugal fan away from its design point falls off more rapidly than that of an axial flow fan and, if a high performance is required over a wide range of operating points and the pressures are suitable, the axial flow fan is selected.
Ventilation systems

The position of the main fan in the overall system is normally on surface at the exhaust airway. The main reasons for this are simplicity where the intake is often a hoisting shaft and the exhaust is a separate single purpose airway and minimization of the heat load by excluding fans from intake airways. Fans can be installed at hoisting shafts either in forcing or exhausting mode by providing a sealed headframe. However, where workers, materials or rock also enter or leave the shaft, there is a potential for air leakage.

Push-pull systems where both intake and exhaust fans are installed are used either to reduce the maximum pressure in the system by sharing or to provide a very small pressure difference between the workings and surface. This is pertinent in mines using caving methods where leakage through the caved area may be undesirable. With large pressure differences, although air leakage through a caved zone is normally small, it may introduce heat, radiation or oxidation problems into the working places.

Underground booster fans, because of space limitations, are almost always axial flow and they are used to boost flow in the deeper or more distant sections of a mine. Their main drawback is the possibility of recirculation between the booster fan exhaust and the intake airways. By only providing a boost to the smaller airflows where they are required, they can result in a lower main fan pressure for the full mine airflow and a consequent reduction in total fan power required.

Secondary Ventilation

Auxiliary systems

Secondary ventilation systems are required where through ventilation is not possible, such as in development headings. Four arrangements are possible, each having its own advantages and disadvantages.

The forcing system results in the coolest and freshest air reaching the face and allows cheaper flexible duct to be used. The high velocity of the air issuing from the end of the supply duct creates a jet which entrains additional air and helps sweep the face of contaminants and provide an acceptable face velocity. Its main drawback is that the rest of the heading is ventilated with air that is contaminated with the gases and dust produced by mining operations in the face. This is particularly a problem after blasting, where safe re-entry times are increased.

An exhausting system allows all the face contaminants to be removed and maintains the rest of the heading in intake air. The drawbacks are that heat flow from the surrounding rock and moisture evaporation will result in higher face delivery air temperatures; operations in the heading back from the face, such as rock removal using diesel-powered equipment, will contaminate the intake air; there is no air jet produced to sweep the face; and more costly duct which is capable of sustaining a negative pressure is required.

In an exhaust-overlap system the problem of clearing the face with an air jet is overcome by installing a smaller fan and duct (the overlap). In addition to the extra cost, a disadvantage is that the overlap needs to be advanced with the face.

In a reversing system, the forcing ventilation mode is used, except during blasting and the re-entry period after blasting, when the airflow is reversed. Its main application is in shaft sinking, where re-
entry times for deep shafts can be prohibitive if a forcing only system was used. The air reversal can be obtained by either using dampers at the fan inlet and outlet or, by taking advantage of a feature of axial flow fans, where changing the direction of blade rotation results in a flow reversal with about 60% of the normal flow being delivered.

Fans and ducts

The fans used for secondary ventilation are almost exclusively axial flow. To achieve the high pressures necessary to cause the air to flow through long lengths of duct, multiple fans with either contra-rotating or co-rotating impeller arrangements may be used. Air leakage is the greatest problem in auxiliary fan and duct systems, particularly over long distances. Rigid ducts fabricated from galvanized steel or fibreglass, when installed with gaskets, have suitably low leakage and may be used to develop headings up to several kilometres in length.

Flexible ducts are considerably cheaper to purchase and easier to install; however, leakage at the couplings and the ease with which they are ripped by contact with mobile equipment results in much higher air losses. Practical development limits using flexible duct rarely exceed 1.0 km, although they can be extended by using longer duct lengths and ensuring ample clearances between the duct and mobile equipment.

Ventilation Controls

Both through ventilation and auxiliary fan and duct systems are used to provide ventilation air to locations where personnel may work. Ventilation controls are used to direct the air to the working place and to minimize the short circuiting or loss of air between intake and exhaust airways.

A bulkhead is used to stop air flowing through a connecting tunnel. The materials of construction will depend on the pressure difference and whether it will be subject to shock waves from blasting. Flexible curtains attached to the surrounding rock surfaces are suitable for low pressure applications such as separating the intake and return airways in a room-and-pillar panel mined with a continuous miner. Timber and concrete bulkheads are suitable for higher pressure applications and may incorporate a heavy rubber flap which can open to minimize any blast damage.

A ventilation door is needed where pedestrian or vehicular passage is required. The materials of construction, opening mechanism and degree of automation are influenced by the pressure difference and the frequency of opening and closing. For high pressure applications, two or even three doors may be installed to create air locks and reduce leakage and the loss of intake air. To assist in opening air lock doors, they usually contain a small sliding section which is opened first to allow equalization of the pressure on both sides of the door to be opened.

A regulator is used where the amount of air flowing through a tunnel is to be reduced rather than stopped completely and also where access is not required. The regulator is a variable orifice and by changing the area, the air quantity flowing through it can also be changed. A drop board is one of the simplest types where a concrete frame supports channels into which timber boards can be placed (dropped) and the open area varied. Other types, such as butterfly louvres, can be automated and remotely controlled. On the upper levels in some open stoping systems, infrequent access through the regulators may be required and horizontally stiffened, flexible panels can be simply raised or lowered to provide access while minimizing blast damage. Even piles of broken rock have been used to increase the resistance in sections of a level where there is temporarily no mining activity.
Refrigeration and Cooling Systems

The first mine refrigeration system was installed at Morro Velho, Brazil, in 1919. Since that date, the growth in worldwide capacity has been linear at about 3 megawatts of refrigeration (MWR) per year until 1965, when the total capacity reached about 100 MWR. Since 1965 the growth in capacity has been exponential, with a doubling every six or seven years. The development of mine refrigeration has been influenced both by the air conditioning industry and the difficulties of dealing with a dynamic mining system in which the fouling of heat exchanger surfaces may have profound effects on the amount of cooling provided.

Initially, the refrigeration plants were installed on surface and the mine intake air was cooled. As the distance underground from the surface plant increased, the cooling effect was reduced and the refrigeration plants were moved underground closer to the workings.

Limitations in underground heat rejection capacity and the simplicity of surface plants have resulted in a move back to the surface location. However, in addition to the intake air being cooled, chilled water is now also supplied underground. This may be used in air-cooling devices adjacent to the working areas or as the service water used in drills and for dust suppression.

Refrigeration plant equipment

Vapour compression refrigeration systems are exclusively used for mines, and the central element of the surface plant is the compressor. Individual plant capacities may vary between 5 MWR and over 100 MWR and generally require multiple compressor systems which are either of the centrifugal or positive displacement screw design. Ammonia is normally the refrigerant selected for a surface plant and a suitable halocarbon is used underground.

The heat required to condense the refrigerant after compression is rejected to the atmosphere and, to minimize the power required to provide the mine cooling, this is kept as low as practical. The wet bulb temperature is always less than or equal to the dry bulb temperature and consequently wet-heat rejection systems are invariably selected. The refrigerant may be condensed in a shell and tube or plate and frame heat exchanger using water and the heat extracted and then rejected to the atmosphere in a cooling tower. Alternatively, the two processes can be combined by using an evaporative condenser where the refrigerant circulates in tubes over which air is drawn and water is sprayed. If the refrigeration plant is installed underground, mine exhaust air is used for heat rejection unless the condenser water is pumped to surface. Operation of the underground plant is limited by the amount of air available and higher underground wet bulb temperatures relative to those on surface.

After passing the condensed refrigerant through an expansion valve, the evaporation of the low temperature liquid and gas mixture is completed in another heat exchanger that cools and provides the chilled water. In turn, this is used both to cool the intake air and as cold service water supplied to the mine. The contact between water, ventilation air and the mine reduces water quality and increases heat exchanger fouling. This increases the resistance to heat flow. Where possible, this effect is minimized by selecting equipment having large water side surface areas that are easy to clean. On surface and underground, spray chambers and cooling towers are used to provide the more effective direct contact heat exchange between the air being cooled and the chilled water. Cooling coils which separate the air and water streams become clogged with dust and diesel particulate and their effectiveness rapidly declines.
Energy recovery systems can be used to offset the costs of pumping the water back out of the mine and pelton wheels are well suited to this application. The use of cold water as service water has helped to ensure that cooling is available wherever there is mining activity; its use has significantly improved the effectiveness of mine cooling systems.

**Ice systems and spot coolers**

The cooling capacity of 1.0 l/s of chilled water supplied underground is 100 to 120 kWR. On mines where large amounts of refrigeration are required underground at depths greater than 2,500 m, the costs of circulating the chilled water can justify replacing it with ice. When the latent heat of fusion of the ice is taken into account, the cooling capacity of each 1.0 l/s is increased approximately fourfold, thus reducing the mass of water that needs to be pumped from the mine back to surface. The reduction in pump power resulting from the use of ice to transport the coolness offsets the increased refrigeration plant power required to produce the ice and the impracticability of energy recovery.

Development is usually the mining activity with the highest heat loads relative to the amount of air available for ventilation. This often results in worksite temperatures significantly higher than those found with other mining activities in the same mine. Where the application of refrigeration is a borderline issue for a mine, spot coolers specifically targeted at development ventilation can defer its general application. A spot cooler is essentially a miniature underground refrigeration plant where the heat is rejected into the return air from the development and typically provides 250 to 500 kWR of cooling.

**Monitoring and Emergencies**

Ventilation surveys which include airflow, contaminant and temperature measurements are undertaken on a routine basis to meet both statutory requirements and to provide a continuing measure of the effectiveness of the ventilation control methods used. Where practical, important parameters such as main fan operation are monitored continuously. Some degree of automatic control is possible where a critical contaminant is monitored continuously and, if a pre-set limit is exceeded, corrective action can be prompted.

More detailed surveys of barometric pressure and temperatures are undertaken less frequently and are used to confirm airway resistances and to assist in planning extensions of existing operations. This information can be used to adjust the network simulation resistances and reflect the actual airflow distribution. Refrigeration systems can also be modelled and flow and temperature measurements analysed to determine actual equipment performance and to monitor any changes.

The emergencies that may affect or be affected by the ventilation system are mine fires, sudden gas outbursts and power failures. Fires and outbursts are dealt with elsewhere in this chapter and power failures are only a problem in deep mines where the air temperatures may increase to dangerous levels. It is common to provide a diesel-powered backup fan to ensure a small airflow through the mine under these conditions. Generally, when an emergency such as a fire occurs underground, it is better not to interfere with the ventilation while personnel who are familiar with the normal flow patterns are still underground.

### 15. LIGHTING IN UNDERGROUND MINES

**Light Sources in Mining**

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In 1879 a practical incandescent filament lamp was patented. As a result light no longer depended on a fuel source. Many startling breakthroughs have been made in lighting knowledge since Edison’s discovery, including some with applications in underground mines. Each has inherent advantages and disadvantages. Table - C lists the light source types and compares some parameters.

**Table – C: Comparison of mine light sources**

<table>
<thead>
<tr>
<th>Type of light source</th>
<th>Approximate luminance cd/m² (clear bulb)</th>
<th>Average rated life (h)</th>
<th>DC source</th>
<th>Approximate initial efficacy lm·W⁻¹</th>
<th>Colour rendition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tungsten filament</td>
<td>10⁵ to 10⁷</td>
<td>750 to 1,000</td>
<td>Yes</td>
<td>5 to 30</td>
<td>Excellent</td>
</tr>
<tr>
<td>Incandescent</td>
<td>2 × 10⁷</td>
<td>5 to 2,000</td>
<td>Yes</td>
<td>28</td>
<td>Excellent</td>
</tr>
<tr>
<td>Fluorescent</td>
<td>5 × 10⁴ to 2 × 10⁵</td>
<td>500 to 30,000</td>
<td>Yes</td>
<td>100</td>
<td>Excellent</td>
</tr>
<tr>
<td>Mercury vapour</td>
<td>10⁵ to 10⁷</td>
<td>16,000 to 24,000</td>
<td>Yes with limitations</td>
<td>63</td>
<td>Average</td>
</tr>
<tr>
<td>Metal halide</td>
<td>5 × 10⁶</td>
<td>10,000 to 20,000</td>
<td>Yes with limitations</td>
<td>125</td>
<td>Good</td>
</tr>
<tr>
<td>High-pressure sodium</td>
<td>10⁷</td>
<td>12,000 to 24,000</td>
<td>Not advised</td>
<td>140</td>
<td>Fair</td>
</tr>
<tr>
<td>Low-pressure sodium</td>
<td>10⁵</td>
<td>10,000 to 18,000</td>
<td>Not advised</td>
<td>183</td>
<td>Poor</td>
</tr>
</tbody>
</table>

cd = candela, DC = direct current; lm = lumens.

Current to energize the light sources may be either alternating (AC) or direct (DC). Fixed light sources almost always use alternating current whereas portable sources such as cap lamps and underground vehicle headlights use a DC battery. Not all light source types are suitable for direct current.

**Fixed light sources**

Tungsten filament lamps are most common, often with a frosted bulb and a shield to reduce glare. The fluorescent lamp is the second most common light source and is easily distinguishable by its tubular design. Circular and U-shaped designs are compact and have mining applications as mining areas are often in cramped spaces. Tungsten filament and fluorescent sources are used to light such diverse underground openings as shaft stations, conveyors, travelways, lunchrooms, charging stations, fuel bays, repair depots, warehouses, tool rooms and crusher stations.

The trend in mine lighting is to use more efficient light sources. These are the four high-intensity discharge (HID) sources called mercury vapour, metal halide, high-pressure sodium and low-pressure sodium. Each requires a few minutes (one to seven) to come up to full light output. Also, if power to the lamp is lost or turned off, the arc tube must be cooled before the arc can be struck and the lamp relit. (However, in the case of low-pressure sodium (Sox) lamps, restrike is almost instantaneous.) Their spectral energy distributions differ from that of natural light. Mercury vapour lamps produce a bluish white light whereas high-pressure sodium lamps produce a yellowish light. If colour differentiation is important in underground work (e.g., for using colour-coded gas bottles for welding, reading colour-coded signs, electrical wiring hook-ups or sorting ore by colour), care must be taken in the colour rendition properties of the source. Objects will have their surface colours distorted when lit by a low-pressure sodium lamp. Table - C gives colour rendition comparisons.

**Mobile light sources**
With working places spread out often both laterally and vertically, and with continual blasting in these working places, permanent installations are often deemed impractical because of the costs of installation and upkeep. In many mines the battery-operated cap lamp is the most important single source of light. Although fluorescent cap lamps are in use, by far the majority of cap lamps use tungsten filament battery-operated cap lamps. Batteries are lead acid or nickel cadmium. A miniature tungsten-halogen lamp bulb is often used for the miner’s cap lamp. The small bulb allows the beam to be easily focused. The halogen gas surrounding the filament prevents the tungsten filament material from boiling off, which keeps lamp walls from blackening. The bulb can also be burned hotter and hence brighter.

For mobile vehicle lighting, incandescent lamps are most commonly used. They require no special equipment, are inexpensive and are easy to replace. Parabolic aluminized reflector (PAR) lamps are used as headlights on vehicles.

**Standards for Mine Lighting**

Countries with a well-established underground mining industry are usually quite specific in their requirements regarding what constitutes a safe mine lighting system. This is particularly true for mines which have methane gas given off from the workings, usually coal mines. Methane gas can ignite and cause an underground explosion with devastating results. Consequently any lights must be designed to be either “intrinsically safe” or “explosion proof”. An intrinsically safe light source is one in which the current feeding the light has very little energy so that any short in the circuit would not produce a spark which could ignite the methane gas. For a lamp to be explosion proof, any explosion triggered by the lamp’s electrical activity is contained within the device. In addition, the device itself will not become hot enough to cause an explosion. The lamp is more expensive, heavier, with metal parts usually made of castings. Governments usually have test facilities to certify whether lamps can be classified for use in a gassy mine. A low-pressure sodium lamp could not be so certified as the sodium in the lamp could ignite if the lamp were to break and the sodium came in contact with water.

Countries also legislate standards for the amount of light required for various tasks but legislation varies greatly in the amount of light that should be placed in the various working places.

Guidelines for mine lighting are also provided by international bodies concerned with lighting, such as the Illumination Engineering Society (IES) and the Commission internationale de l’éclairage (CIE). The CIE stresses that the quality of light being received by the eye is as important as the quantity and provides formulas to ascertain whether glare may be a factor in visual performance.

**Effects of Lighting on Accidents, Production and Health**

One would expect that better lighting would reduce accidents, increase production and reduce health hazards, but it is not easy to substantiate this. The direct effect of lighting on underground efficiency and safety is hard to measure because lighting is only one of many variables that affect production and safety. There is well-documented evidence that shows highway accidents decrease with improved illumination. A similar correlation has been noted in factories. The very nature of mining, however, dictates that the work area is constantly changing, so that very few reports relating mine accidents to lighting can be found in the literature and it remains an area of research that has been largely unexplored. Accident investigations show that poor lighting is rarely the primary cause of underground accidents but is often a contributing factor. While lighting conditions play some role
in many mine accidents, they have special significance in accidents involving falls of ground, since poor lighting makes it easy to miss dangerous conditions that could otherwise be corrected.

Until the beginning of the twentieth century, miners commonly suffered from the eye disease nystagmus, for which there was no known cure. Nystagmus produced uncontrollable oscillation of the eyeballs, headaches, dizziness and loss of night vision. It was caused by working under very low light levels over long periods of time. Coal miners were particularly susceptible, since very little of the light that strikes the coal is reflected. These miners often had to lie on their sides when working in low coal and this may also have contributed to the disease. With the introduction of the electric cap lamp in mines, miner’s nystagmus has disappeared, eliminating the most important health hazard associated with underground lighting.

With recent technological advances in new light sources, the interest in lighting and health has been revived. It is now possible to have lighting levels in mines that would have been extremely difficult to achieve previously. The main concern is glare, but concern has also been expressed about the radiometric energy given off by the lights. Radiometric energy can affect workers either by acting directly on cells on or near the surface of the skin or by triggering certain responses, such as biological rhythms on which physical and mental health depends. An HID light source can still operate even though the glass envelope containing the source is cracked or broken. Workers can then be in danger of receiving doses beyond threshold limit values, particularly since these light sources often cannot be mounted very high.

16. PERSONAL PROTECTIVE EQUIPMENT IN MINING

Head Protection

In most countries miners must be provided with, and must wear, safety caps or hats which are approved in the jurisdiction in which the mine operates. Hats differ from caps in that they have a full brim rather than just a front peak. This has the advantage of shedding water in mines which are very wet. It does, however, preclude the incorporation of side slots for mounting of hearing protection, flashlights and face shields for welding, cutting, grinding, chipping and scaling or other accessories. Hats represent a very small percentage of the head protection worn in mines.

The cap or hat would in most cases be equipped with a lamp bracket and cord holder to permit mounting of a miner’s cap lamp.

The traditional miner’s cap has a very low profile which significantly reduces the propensity for the miner to bump his or her head in low seam coal mines. However, in mines where head room is adequate the low profile serves no useful purpose. Furthermore, it is achieved by reducing the clearance between the crown of the cap and the wearer’s skull so that these types of cap rarely meet the top impact standards for industrial head protection. In jurisdictions where the standards are enforced, the traditional miner’s cap is giving way to conventional industrial head protection.

Standards for industrial head protection have changed very little since the 1960s. However, in the 1990s, the boom in recreational head protection, such as hockey helmets, cycle helmets and so on, has highlighted what are perceived to be inadequacies in industrial head protection, most notably lack of lateral impact protection and lack of retention capabilities in the event of an impact. Thus, there has been pressure to upgrade the standards for industrial head protection and in some jurisdictions this has already happened. Safety caps with foam liners and, possibly, ratchet suspensions and/or chin straps are now appearing in the industrial marketplace. They have not been
widely accepted by users because of the higher cost and weight and their lesser comfort. However, as the new standards become more widely entrenched in labour legislation the new style of cap is likely to appear in the mining industry.

Cap Lamps

In areas of the mine where permanent lighting is not installed, the miner’s cap lamp is essential to permit the miner to move and work effectively and safely. The key requirements for a cap lamp are that it be rugged, easy to operate with gloved hands, provide sufficient light output for the full duration of a work shift (to illumination levels required by local regulation) and that it be as light as possible without sacrificing any of the above performance parameters.

Halogen bulbs have largely replaced the incandescent tungsten filament bulb in recent years. This has resulted in three- or fourfold improvement in illumination levels, making it feasible to meet the minimum standards of illumination required by legislation even at the end of an extended work-shift. Battery technology also plays a major part in lamp performance. The lead acid battery still predominates in most mining applications, although some manufacturers have successfully introduced nickel-cadmium (nicad) batteries, which can achieve the same performance with a lower weight. Reliability, longevity and maintenance issues, however, still favour the lead acid battery and probably account for its continued dominance.

In addition to its primary function of providing lighting, the cap lamp and battery have recently been integrated into mine safety communications systems. Radio receivers and circuitry embedded in the battery cover permit the miners to receive messages, warnings or evacuation instructions through very low frequency (VLF) radio transmission and enable them to be made aware of an incoming message by means of an on/off flashing of the cap lamp.

Such systems are still in their infancy but they do have the potential to provide an advance in early warning capability over traditional stench gas systems in those mines where a VLF radio communication system can be engineered and installed.

Eye and Face Protection

Most mining operations around the world have compulsory eye protection programmes which require the miner to wear safety spectacles, goggles, faceshields or a full facepiece respirator, depending on the operations being performed and the combination of hazards to which the miner is exposed. For the majority of mining operations, safety spectacles with side shields provide suitable protection. The dust and dirt in many mining environments, most notably hard-rock mining, can be highly abrasive. This causes scratching and rapid wear of safety glasses with plastic (polycarbonate) lenses. For this reason, many mines still permit the use of glass lenses, even though they do not provide the resistance to impact and shattering offered by polycarbonates, and even though they may not meet the prevailing standard for protective eye wear in the particular jurisdiction. Progress continues to be made in both anti-fog treatments and surface hardening treatments for plastic lenses. Those treatments which change the molecular structure of the lens surface rather than simply applying a film or coating are typically more effective and longer lasting and have the potential to replace glass as the lens material of choice for abrasive mining environments.

Goggles are not worn frequently below ground unless the particular operation poses a danger of chemical splash.
A faceshield may be worn where the miner requires full-face protection from weld spatter, grinding residues or other large flying particles which could be produced by cutting, chipping or scaling. The faceshield may be of a specialized nature, as in welding, or may be clear acrylic or polycarbonate. Although faceshields can be equipped with their own head harness, in mining they will normally be mounted in the accessory slots in the miner’s safety cap. Faceshields are designed so that they can be quickly and easily hinged upwards for observation of the work and down over the face for protection when performing the work.

A full facepiece respirator may be worn for face protection when there is also a requirement for respiratory protection against a substance which is irritating to the eyes. Such operations are more often encountered in the above ground mine processing than in the below ground mining operation itself.

**Respiratory Protection**

The most commonly needed respiratory protection in mining operations is dust protection. Coal dust as well as most other ambient dusts can be effectively filtered using an inexpensive quarter facepiece dust mask. The type which uses an elastomer nose/mouth cover and replaceable filters is effective. The moulded throw-away fibre-cup type respirator is not effective.

Welding, flame cutting, use of solvents, handling of fuels, blasting and other operations can produce air-borne contaminants that require the use of twin cartridge respirators to remove combinations of dust, mists, fumes, organic vapours and acid gases. In these cases, the need for protection for the miner will be indicated by measurement of the contaminants, usually performed locally, using detector tubes or portable instruments. The appropriate respirator is worn until the mine ventilation system has cleared the contaminant or reduced it to levels that are acceptable.

Certain types of particulates encountered in mines, such as asbestos fibres found in asbestos mines, coal fines produced in longwall mining and radionuclides found in uranium mining, may require the use of a positive pressure respirator equipped with a high-efficiency particulate absolute (HEPA) filter. Powered air-purifying respirators (PAPRs) which supply the filtered air to a hood, tight-fitting facepiece or integrated helmet facepiece assembly meet this requirement.

**Hearing Protection**

Underground vehicles, machinery and power tools generate high ambient noise levels which can create long-term damage to human hearing. Protection is normally provided by ear muff type protectors which are slot-mounted on the miner’s cap. Supplementary protection can be provided by wearing closed cell foam ear plugs in conjunction with the ear muffs. Ear plugs, either of the disposable foam cell variety or the reusable elastomeric variety, may be used on their own, either because of preference or because the accessory slot is being used to carry a face shield or other accessory.

**Skin Protection**

Certain mining operations may cause skin irritation. Work gloves are worn whenever possible in such operations and barrier creams are provided for additional protection, particularly when the gloves cannot be worn.

**Foot Protection**

Partha Das Sharma, B.Tech(Hons.) in Mining Engineering; E.mail: sharmapd1@gmail.com; Website: http://miningandblasting.wordpress.com/
The mining work boot may be of either leather or rubber construction, depending on whether the mine is dry or wet. Minimum protective requirements for the boot include a full puncture-proof sole with a composite outer layer to prevent slipping, a steel toe-cap and a metatarsal guard. Although these fundamental requirements have not changed in many years, advances have been made towards meeting them in a boot that is far less cumbersome and far more comfortable than the boots of several years ago. For example, metatarsal guards are now available in moulded fibre, replacing the steel hoops and saddles that were once common. They provide equivalent protection with less weight and less risk of tripping. The lasts (foot forms) have become more anatomically correct and energy absorbing mid-soles, full moisture barriers and modern insulating materials have made their way from the sports/recreation footwear market into the mining boot.

**Clothing**

Ordinary cotton coveralls or treated flame-resistant cotton coveralls are the normal workwear in mines. Strips of reflective material are usually added to make the miner more visible to drivers of moving underground vehicles. Miners working with jumbo drills or other heavy equipment may also wear rain suits over their coveralls to protect against cutting fluid, hydraulic oil and lubricating oils, which can spray or leak from the equipment.

Work gloves are worn for hand protection. A general purpose work glove would be constructed of cotton canvas reinforced with leather. Other types and styles of glove would be used for special job functions.

**Belts and Harnesses**

In most jurisdictions, the miners belt is no longer considered suitable or approved for fall protection. A webbing or leather belt is still used, however, with or without suspenders and with or without a lumbar support to carry the lamp battery as well as a filter self-rescuer or self-contained (oxygen generating) self-rescuer, if required.

A full body harness with D-ring attachment between the shoulder blades is now the only recommended device for protecting miners against falls. The harness should be worn with a suitable lanyard and shock absorbing device by miners working in shafts, over crushers or near open sump or pits. Additional D-rings may be added to a harness or a miner’s belt for work positioning or to restrict movement within safe limits.

**Protection from Heat and Cold**

In open-pit mines in cold climates, miners will have winter clothing including thermal socks, underwear and gloves, wind resistant pants or over-pants, a lined parka with hood and a winter liner to wear with the safety cap.

In underground mines, heat is more of a problem than cold. Ambient temperatures may be high because of the depth of the mine below ground or because it is located in a hot climate. Protection from heat stress and potential heat stroke can be provided by special garments or undergarments which can accommodate frozen gel packs or which are constructed with a network of cooling tubes to circulate cooling fluids over the surface of the body and then through an external heat exchanger. In situations where the rock itself is hot, heat resistant gloves, socks and boots are worn. Drinking water or, preferably, drinking water with added electrolytes must be available and must be consumed to replace lost body fluids.
Other Protective Equipment

Depending on local regulations and the type of mine, miners may be required to carry a self-rescue device. This is a respiratory protection device which will help the miner to escape from the mine in the event of a mine fire or explosion that renders the atmosphere unbreathable because of carbon monoxide, smoke and other toxic contaminants. The self-rescuer may be a filtration type device with a catalyst for carbon monoxide conversion or it may be a self-contained self-rescuer, i.e., a closed-cycle breathing apparatus which chemically regenerates oxygen from exhaled breath.

Portable instruments (including detector tubes and detector tube pumps) for the detection and measurement of toxic and combustible gases are not carried routinely by all miners, but are used by mine safety officers or other designated personnel in accordance with standard operating procedures to test mine atmospheres periodically or before entry.

Improving the ability to communicate with personnel in underground mining operations is proving to have enormous safety benefits and two-way communication systems, personal pagers and personnel locating devices are finding their way into modern mining operations.

17. FIRES AND EXPLOSIONS IN MINES

Fires and explosions pose a constant threat to the safety of miners and to the productive capacity of mines. Mine fires and explosions traditionally have ranked among the most devastating industrial disasters.

At the end of the nineteenth century, fires and explosions in mines resulted in loss of life and property damage on a scale unmatched in other industrial sectors. However, clear progress has been achieved in controlling these hazards, as evidenced by the decline in mine fires and explosions reported in recent decades.

This article describes the basic fire and explosion hazards of underground mining and the safeguards needed to minimize them. Fire protection information on surface mines can be found in standards such as those promulgated by organizations such as the National Fire Protection Association in the United States.

Permanent Service Areas

By their nature, permanent service areas involve certain hazardous activities, and thus special precautions should be taken. Underground maintenance shops and related facilities are a special hazard in an underground mine.

Mobile equipment in maintenance shops is regularly found to be a frequent source of fires. Fires on diesel-powered mining equipment typically arise from leaking high-pressure hydraulic lines which can spray a heated mist of highly combustible liquid onto an ignition source, such as a hot exhaust manifold or turbocharger. Fires on this type of equipment can grow quickly.

Much of the mobile equipment used in underground mines contains not only fuel sources (e.g., diesel fuel and hydraulics) but they also contain ignition sources (e.g., diesel engines and electrical equipment). Thus, this equipment presents an appreciable risk for fires. In addition to this
equipment, maintenance shops generally contain a variety of other tools, materials and equipment (e.g., degreasing equipment) that are a hazard in any mechanical shop environment.

Welding and cutting operations are a leading cause of fires in mines. This activity can be expected to occur regularly in a maintenance area. Special precautions need to be taken to ensure that these activities do not create a possible ignition source for a fire or explosion. Fire and explosion protection information relating to safe welding practices can be found in other documents such as the National Fire Protection Association (NFPA) in the United States.

Consideration should be given to making the entire shop area a completely enclosed structure of fire resistant construction. This is particularly important for shops intended for use longer than 6 months. If such an arrangement is not possible, then the area should be protected throughout by an automatic fire suppression system. This is especially important for coal mines, where it is critical to minimize any potential fire source.

Another important consideration for all shop areas is that they be vented directly to the air return, thus limiting the spread of products of combustion from any fire. Requirements for these types of facilities are clearly outlined in documents such as NFPA 122, Standard for Fire Prevention and Control in Underground Metal and Nonmetal Mines, and NFPA 123, Standard for Fire Prevention and Control in Underground Bituminous Coal Mines (NFPA 1995a, 1995b).

**Fuel Bays and Fuel Storage Areas**

The storage, handling and use of flammable and combustible liquids pose a special fire hazard for all sectors of the mining industry.

In many underground mines, mobile equipment is typically diesel-powered, and a large percentage of the fires involve the fuel used by these machines. In coal mines, these fire hazards are compounded by the presence of coal, coal dust and methane.

The storage of flammable and combustible liquids is an especially important concern because these materials ignite more easily and propagate fire more rapidly than ordinary combustibles. Both flammable and combustible liquids are often stored underground in most non-coal mines in limited quantities. In some mines, the main storage facility for diesel fuel, lubricating oil and grease, and hydraulic fluid is underground. The potential seriousness of a fire in an underground flammable and combustible liquid storage area requires extreme care in the design of the storage areas, plus the implementation and strict enforcement of safe operating procedures.

All aspects of using flammable and combustible liquids present challenging fire protection concerns, including the transfer to underground, storage, dispensing and ultimate use in equipment. The hazards and protection methods for flammable and combustible liquids in underground mines can be found in NFPA standards (e.g., NFPA 1995a, 1995b, 1996b).

**Fire Prevention**

Safety for fires and explosions in underground mines is based on the general principles of preventing fire and explosion. Normally, this involves using common-sense fire safety techniques, such as preventing smoking, as well as providing built-in fire protection measures to prevent fires from growing, such as portable extinguishers or early fire detection systems.
Fire and explosion prevention practices in mines generally fall into three categories: limiting ignition sources, limiting fuel sources and limiting fuel and ignition source contact.

Limiting ignition sources is perhaps the most basic way of preventing a fire or explosion. Ignition sources that are not essential to the mining process should be banned altogether. For example, smoking and any open fires, especially in underground coal mines, should be prohibited. All automated and mechanized equipment that may be subject to unwanted build-up of heat, such as conveyors, should have slippage and sequence switches and thermal cut-outs on electric motors. Explosives present an obvious hazard, but they could also be an ignition source for suspended dust of hazardous gas and should be used in strict conformance with special blasting regulations.

Eliminating electrical ignition sources is essential for preventing explosions. Electrical equipment operating where methane, sulphide dust or other fire hazards may be present should be designed, constructed, tested and installed so that its operation will not cause a mine fire or explosion. Explosion proof enclosures, such as plugs, receptacles and circuit interrupting devices, should be used in hazardous areas. The use of intrinsically safe electrical equipment is described in further detail in documents such as NFPA 70, National Electrical Code (NFPA 1996c).

Limiting fuel sources starts with good housekeeping to prevent unsafe accumulations of trash, oily rags, coal dust and other combustible materials.

When available, less hazardous substitutes should be used for certain combustible materials such as hydraulic fluids, conveyor belting, hydraulic hoses and ventilation tubing (Bureau of Mines 1978). The highly toxic products of combustion that may result from the burning of certain materials often necessitates less hazardous materials. As an example, polyurethane foam had previously been widely used in underground mines for ventilation seals, but more recently has been banned in many countries.

For underground coal mine explosions, coal dust and methane are typically the primary fuels involved. Methane may also be present in non-coal mines and is most commonly handled by dilution with ventilation air and exhaustion from the mine. For coal dust, every attempt is made to minimize the generation of dust in the mining processes, but the tiny amount needed for a coal dust explosion is almost unavoidable. A layer of dust on the floor that is only 0.012 mm thick will cause an explosion if suspended in air. Thus, rock dusting using an inert material such as pulverized limestone, dolomite or gypsum (rock dust) will help to prevent coal dust explosions.

Limiting fuel and ignition source contact depends upon preventing contact between the ignition source and the fuel source. For example, when welding and cutting operations cannot be performed in fire-safe enclosures, it is important that areas be wet down and nearby combustibles covered with fire resistant materials or relocated. Fire extinguishers should be readily available and a fire watch posted for as long as necessary to guard against smouldering fires.

Areas with a high loading of combustible materials, such as timber storage areas, explosives magazines, flammable and combustible liquid storage areas and shops, should be designed to minimize possible ignition sources. Mobile equipment should have hydraulic fluid, fuel and lubricant lines re-routed away from hot surfaces, electrical equipment and other possible ignition sources. Spray shields should be installed to deflect sprays of combustible liquid from broken fluid lines away from potential ignition sources.
Fire and explosion prevention requirements for mines are clearly outlined in NFPA documents (e.g., NFPA 1992a, 1995a, 1995b).

**Fire Detection and Warning Systems**

The elapsed time between the onset of a fire and its detection is critical since fires may grow rapidly in size and intensity. The most rapid and reliable indication of fire is through advanced fire detection and warning systems using sensitive heat, flame, smoke and gas analysers.

The detection of gas or smoke is the most cost-effective approach to providing fire detection coverage over a large area or throughout the entire mine. Thermal fire detection systems are commonly installed for unattended equipment, such as over conveyor belts. Faster-acting fire detection devices are considered appropriate for certain high-hazard areas, such as flammable and combustible liquids storage areas, refuelling areas and shops. Optical flame detectors that sense either ultraviolet or infrared radiation emitted by a fire are often used in these areas.

All miners should be warned once a fire has been detected. Telephones and messengers are sometimes used, but miners are often remote from telephones and they are often widely scattered. In coal mines, the most common means of fire warning are shutdown of electric power and subsequent notification by telephone and messengers. Special wireless radio frequency communication systems have also been used successfully in both coal and non-coal mines (Bureau of Mines 1988).

The primary concern during an underground fire is the safety of underground personnel. Early fire detection and warning permit the initiation of an emergency plan in the mine. Such a plan assures that the necessary activities, such as evacuation and fire-fighting will occur. To assure smooth implementation of the emergency plan, miners should be provided with comprehensive training and periodic retraining in emergency procedures. Fire drills, complete with the activation of the mine warning system, should be performed frequently to reinforce the training and to identify weaknesses in the emergency plan.

Further information on fire detection and warning systems can be found elsewhere in this Encyclopaedia and in NFPA documents (e.g., NFPA 1995a, 1995b, 1996d).

**Fire Suppression**

The most common types of fire suppression equipment used in underground mines are portable hand extinguishers, water hoselines, sprinkler systems, rock dust (applied manually or from a rock dusting machine) and foam generators. The most common type of portable hand extinguishers are typically those using multi-purpose dry chemicals.

Fire suppression systems, either manual or automatic, are becoming more common for mobile equipment, combustible liquids storage areas, conveyor belt drives and electrical installations. Automatic fire suppression is especially important for unattended, automated or remote control equipment where personnel are not present to detect a fire, to activate a fire suppression system or to initiate fire-fighting operations.

Explosion suppression is a variation of fire suppression. Some European coal mines use this technology in the form of passive or triggered barriers on a limited basis. Passive barriers consist of rows of large tubs containing water or rock dust that are suspended from the roof of a mine entry.
an explosion, the pressure front that precedes the arrival of the flame front triggers the dumping of the contents of the tubs. The dispersed suppressants quench the flame as it passes through the entry protected by the barrier system. Triggered barriers utilize an electrically or pneumatically operated actuation device that is triggered by the heat, flame or pressure of the explosion to release suppressant agents that are stored in pressurized containers.

Fires that grow to an advanced stage should be fought only by highly trained and specially equipped fire-fighting teams. Where large areas of coal or timber are burning in an underground mine and fire-fighting is complicated by extensive roof falls, ventilation uncertainties and accumulations of explosive gas, special action should be taken. The only practical alternatives may be inerting with nitrogen, carbon dioxide, the combustion products of an inert gas generator, or by flooding with water or sealing part or all of the mine.

Further information on fire suppression can be found in various NFPA documents (e.g., NFPA 1994b, 1994c, 1994d, 1995a, 1995b, 1996e, 1996f, 1996g).

**Fire Containment**

Fire containment is a fundamental control mechanism for any type of industrial facility. Means for confining or limiting an underground mine fire can help ensure a safer mine evacuation and lessen the hazards of fire fighting.

For underground coal mines, oil and grease should be stored in closed, fire-resistant containers, and the storage areas should be of fire-resistant construction. Transformer stations, battery charging stations, air compressors, substations, shops and other installations should be housed in fire-resistant areas or in fireproof structures. Unattended electrical equipment should be mounted on non-combustible surfaces and separated from coal and other combustibles or protected by a fire-suppression system.

Materials for building bulkheads and seals, including wood, cloth, saws, nails, hammers, plaster or cement and rock dust, should be readily available to each working section. In underground non-coal mines, oil, grease and diesel fuel should be stored in tightly sealed containers in fire-resistive areas at safe distances from explosives magazines, electrical installations and shaft stations. Ventilation-control barriers and fire doors are required in certain areas to prevent the spread of fire, smoke and toxic gas.

**Surface Fire (Mills and coal processing units)**

Operations that are used to process the ore produced in a mining operations may result in certain hazardous conditions. Among the concerns are certain types of dust explosions and fires involving conveyor operations.

The heat generated by friction between a conveyor belt and a drive roller or idler is a concern and can be addressed by the use of sequence and slippage switches. These switches can be effectively used along with thermal cut-outs on electric motors.

Possible explosions can be prevented by eliminating electrical ignition sources. Electrical equipment operating where methane, sulphide dust or other hazardous environments may be present should be designed, constructed, tested and installed such that its operation will not cause a fire or explosion.
Exothermic oxidation reactions can occur in both coal and metal sulphide ores. When the heat generated by these reactions is not dissipated the temperature of the rock mass or pile increases. If temperatures become high enough, rapid combustion of coal, sulphide minerals and other combustibles may result. Although spontaneous ignition fires occur relatively infrequently, they are generally quite disruptive to operations and difficult to extinguish.

The processing of coal presents special concerns because by its nature it is a fuel source. Fire and explosion protection information relating to the safe handling of coal can be found in NFPA documents (e.g., NFPA 1992b, 1994e, 1996h).

18. DETECTION OF GASES

All who work in underground mines should have a sound knowledge of mine gases and be aware of the dangers they may present. A general knowledge of gas detection instruments and systems is also necessary. For those assigned to use these instruments, detailed knowledge of their limitations and the gases they measure is essential.

Even without instruments, the human senses may be able to detect the progressive appearance of the chemical and physical phenomena associated with spontaneous combustion. The heating warms the ventilating air and saturates it with both surface and integral moisture driven off by the heating. When this air meets colder air at the ventilation split, condensation occurs resulting in a haze and the appearance of sweating on surfaces in the returns. A characteristic oily or petrol smell is the next indication, followed eventually by smoke and, finally, visible flames.

Carbon monoxide (CO), which is odourless, appears in measurable concentrations some 50 to 60 °C before the characteristic smell of a spontaneous combustion appears. Consequently, most fire detection systems rely on the detection of a rise in carbon monoxide concentration above the normal background for the particular part of the mine.

Sometimes, a heating is first detected by an individual who notices a faint smell for a fleeting instant. Thorough examination of the area may have to be repeated a number of times before a measurable sustained increase in the concentration of carbon monoxide can be detected. Accordingly, vigilance by all those in the mine should never be relaxed and a prearranged intervention process should be implemented as soon as the presence of an indicator has been suspected or detected and reported. Fortunately, thanks to considerable progress in the technology of fire detection and monitoring made since the 1970s (e.g., detector tubes, pocket-sized electronic detectors, and computerized fixed systems), it is no longer necessary to rely on the human senses alone.

Portable Instruments for Gas Detection

The gas detection instrument is designed to detect and monitor the presence of a wide range of gas types and concentrations that could result in a fire, an explosion and a toxic or oxygen-deficient atmosphere as well as to provide early warning of an outbreak of spontaneous combustion. Gases for which they are used include CO, carbon dioxide (CO₂), nitrogen dioxide (NO₂), hydrogen sulphide (H₂S) and sulphur dioxide (SO₂). Different types of instrument are available, but before deciding which to use in a particular situation, the following questions must be answered:

- Why is the detection of a particular gas or gases required?
- What are the properties of these gases?
Where and in what circumstances do they occur?
Which gas detecting instrument or device is most suitable for those circumstances?
How does this instrument work?
What are its limitations?
How should the results it provides be interpreted?

Workers must be trained in the correct use of portable gas detectors. Instruments must be maintained according to the manufacturer’s specifications.

Universal detector kits

A detector kit consists of a spring-loaded piston- or bellows-type of pump and a range of replaceable glass indicating tubes that contain chemicals specific for a particular gas. The pump has a capacity of 100 cc and can be operated with one hand. This allows a sample of that size to be drawn through the indicator tube before passing to the bellows. The warning indicator on the graduated scale corresponds to the lowest level of general discolouration, not the deepest point of colour penetration.

The device is easy to use and does not require calibration. However, certain precautions are applicable:

- Indicator tubes (which should be dated) generally have a shelf-life of two years.
- An indicator tube may be re-used ten times provided there has been no discolouration.
- The general accuracy of each determination is usually within ± 20%.
- Hydrogen tubes are not approved for use underground because of the intense heat developed.
- A “pre-tube” filled with activated charcoal is required when estimating low levels of carbon monoxide in the presence of diesel exhausts or the higher hydrocarbons that may be present in afterdamp.
- Exhaust gas should be passed through a cooling device to make sure the temperature is below 40 °C before passing though the indicator tube.
- Oxygen and methane tubes are not approved for use underground because of their inaccuracy.

Catalytic-type methanometers

The catalytic-type methanometer is used in underground mines to measure the concentration of methane in the air. It has a sensor based on the principle of a network of four resistance-matched spiral wires, usually catalytic filaments, arranged in a symmetrical form known as a Wheatstone-bridge. Normally, two filaments are active and the other two are passive. The active filaments or beads are usually coated with a palladium oxide catalyst to cause oxidation of the flammable gas at a lower temperature.

Methane in the atmosphere reaches the sample chamber either by diffusion through a sintered disc or by being drawn in by an aspirator or internal pump. Pressing the operating button of the methanometer closes the circuit and the current flowing through the Wheatstone-bridge oxidizes the methane on the catalytic (active) filaments in the sample chamber. The heat of this reaction raises the temperature of the catalytic filaments, increasing their electrical resistance and electrically unbalancing the bridge. The electric current that flows is proportional to the resistance of the element and, hence, the amount of methane present. This is shown on an output indicator.
graduated in percentages of methane. The reference elements in the Wheatstone-bridge circuit serve to compensate for variations in environmental conditions such as ambient temperature and barometric pressure.

This instrument has a number of significant limitations:

- Both methane and oxygen must be present to get a response. If the oxygen level in the sample chamber is below 10%, not all the methane reaching the detector will be oxidized and a false low reading will be obtained. For this reason, this instrument should not be used to measure methane levels in afterdamp or in sealed off areas where the oxygen concentration is low. If the chamber contains pure methane, there will be no reading at all. Accordingly, the operating button must be depressed before moving the instrument into a suspected methane layer in order to draw some oxygen-containing air into the chamber. The presence of a layer will be confirmed by a greater than full scale reading followed by a return to scale when the oxygen in consumed.
- The catalytic type of methanometer will respond to flammable gases other than methane, for example, hydrogen and carbon monoxide. Ambiguous reading, therefore, may be obtained in post-fire or explosion gases (afterdamp).
- Instruments with diffusion heads should be sheltered from high air velocities to avoid false readings. This may be accomplished by shielding it with a hand or some other object.
- Instruments with catalytic filaments may fail to respond to methane if the filament comes in contact with the vapours of known poisons when being calibrated or used (e.g., silicones in furniture polish, floor polish and paints, phosphate esters present in hydraulic fluids, and fluorocarbons used as the propellant in aerosol sprays).
- Methanometers based on the Wheatstone-bridge principle may give erroneous readings at variable angles of inclination. Such inaccuracies will be minimized if the instrument is held at an angle of 45° when it is calibrated or used.
- Methanometers may give inaccurate readings at variable ambient temperatures. These inaccuracies will be minimized by calibrating the instrument under temperature conditions similar to those found underground.

Electrochemical cells

Instruments using electrochemical cells are used in underground mines to measure oxygen and carbon monoxide concentrations. Two types are available: the composition cell, which responds only to changes in oxygen concentration, and the partial pressure cell, which responds to changes in the partial pressure of oxygen in the atmosphere and, hence, the number of oxygen molecules per unit of volume.

The composition cell employs a capillary diffusion barrier which slows the diffusion of oxygen through the fuel cell so that the speed at which the oxygen can reach the electrode depends solely on the oxygen content of the sample. This cell is unaffected by variations in altitude (i.e., barometric pressure), temperature and relative humidity. The presence of CO₂ in the mixture, however, upsets the rate of oxygen diffusion and leads to false high readings. For example, the presence of 1% of CO₂ increases the oxygen reading by as much as 0.1%. Although small, this increase may still be significant and not fail-safe. It is particularly important to be aware of this limitation if this instrument is to be used in afterdamp or other atmospheres known to contain CO₂.

The partial pressure cell is based on the same electrochemical principle as the concentration cell but lacks the diffusion barrier. It responds only to the number of oxygen molecules per unit volume,
making it pressure dependent. CO$_2$ in concentrations below 10% have no short-term effect on the reading, but over the long term, the carbon dioxide will destroy the electrolyte and shorten the life of the cell.

The following conditions affect the reliability of oxygen readings produced by partial pressure cells:

- **Altitude and barometric pressure:** The trip from the surface to the bottom of the shaft would increase the oxygen reading by 0.1% for every 40 m travelled. This would also apply to dips, encountered in the underground workings. In addition, the 5 millibar normal daily variations in barometric pressure could alter the oxygen reading by as much as 0.1%. Thunderstorm activity could be accompanied by a 30 millibar drop in pressure that would cause a 0.4% drop in the oxygen reading.

- **Ventilation:** The maximum ventilation change at the fan would be 6-8 inches water gauge or 10 millibar. This would cause a drop of 0.4% in the oxygen reading going from the intake to the return at the fan and a drop of 0.2% in travelling from the furthest face from the pit bottom.

- **Temperature:** Most detectors have an electronic circuit that senses cell temperature and corrects for the temperature effect on the sensor output.

- **Relative humidity:** An increase in relative humidity from dry to saturated at 20 °C would cause approximately a 0.3% decrease in the oxygen reading.

**Other electrochemical cells**

Electrochemical cells have been developed which are capable of measuring concentrations of CO from 1 ppm to an upper limit of 4,000 ppm. They operate by measuring the electric current between electrodes immersed in an acidic electrolyte. CO is oxidized on the anode to form CO$_2$ and the reaction releases electrons in direct proportion to the CO concentration.

Electrochemical cells for hydrogen, hydrogen sulphide, nitric oxide, nitrogen dioxide and sulphur dioxide are also available but suffer from cross-sensitivity.

There are no commercially available electrochemical cells for CO$_2$. The deficiency has been overcome with the development of a portable instrument containing a miniaturized infrared cell that is sensitive to carbon dioxide in concentrations up to 5%.

**Non-dispersive infrared detectors**

Non-dispersive infrared detectors (NDIRs) can measure all gases that contain such chemical groups as -CO, -CO$_2$ and –CH$_4$, which absorb infrared frequencies that are specific to their molecular configuration. These sensors are expensive but they can provide accurate readings for gases such as CO, CO$_2$ and methane in a changing background of other gases and low oxygen levels and are therefore ideal for monitoring gases behind seals. O$_2$, N$_2$ and H$_2$ do not absorb infrared radiation and cannot be detected by this method.

Other portable systems with detectors based on thermal conduction and refractive index have found limited use in the coal mining industry.

**Limitations of portable gas detection instruments**

The effectiveness of portable gas detection instruments is limited by a number of factors:
• Calibration is required. This normally involves a daily check on zero and voltage, a weekly span check and a calibration test by an authorized external authority every 6 months.
• Sensors have a finite life. If not dated by the manufacturer, the date of acquisition should be inscribed.
• Sensors can be poisoned.
• Sensors may suffer from cross-sensitivity.
• Overexposure may saturate the sensor causing its slow recovery.
• Inclination may affect the reading.
• Batteries require charging and regular discharging.

Centralized Monitoring Systems

Inspections, ventilation and surveys with hand-held instruments often succeed in detecting and locating a small heating with limited makes of CO before the gas is dispersed by the ventilation system or its level exceeds the statutory limits. These do not suffice, however, where a significant risk of combustion is known to occur, methane levels in the returns exceed 1%, or a potential hazard is suspected. Under these circumstances, continuous monitoring at strategic locations is required. A number of different types of centralized continuous monitoring systems are in use.

Tube bundle systems

The tube bundle system was developed in Germany in the 1960s to detect and monitor the progress of spontaneous combustion. It involves a series of as many as 20 plastic tubes made of nylon or polyethylene 1/4 or 3/8 of an inch in diameter that extend from a bank of analysers on the surface to selected locations underground. The tubes are equipped with filters, drains and flame traps; the analysers are usually infrared for CO, CO$_2$ and methane and paramagnetic for oxygen. A scavenger pump pulls a sample through each tube simultaneously and a sequential timer directs the sample from each tube through the analysers in turn. The data logger records the concentration of each gas at each location and automatically triggers an alarm when predetermined levels are exceeded.

This system has a number of advantages:

• No explosion-proof instruments are required.
• Maintenance is relatively easy.
• Underground power is not required.
• It covers a wide range of gases.
• Infrared analysers are usually quite stable and reliable; they maintain their specificity in a changing background of fire gases and low oxygen atmospheres (high concentrations of methane and/or carbon dioxide may be cross-sensitive to the carbon monoxide reading in the low ppm range).
• Instruments can be calibrated on the surface, although calibration samples of gases should be sent through the tubes to test the integrity of the collection system and the system for identifying the locations where particular samples originated.

There are also some disadvantages:

• The results are not in real time.
• Leaks are not immediately apparent.
• Condensation may collect in the tubes.
• Defects in the system are not always immediately apparent and may be difficult to identify.
The tubes may be damaged by blasting or in a fire or an explosion.

**Telemetric (electronic) system**

The telemetric automatic gas monitoring system has a control module on the surface and intrinsically safe sensor heads strategically located underground which are connected by phone lines or fibre-optic cables. Sensors are available for methane, CO and air velocity. The sensor for CO is similar to the electrochemical sensor used in portable instruments and is subject to the same limitations. The methane sensor works through the catalytic combustion of methane on the active elements of a Wheatstone-bridge circuit which can be poisoned by sulphur compounds, phosphate esters or silicon compounds and will not work when the oxygen concentration is low.

The unique advantages of this system include:

- The results are available in real time (i.e., there is rapid indication of fire or a build-up of methane).
- Long distances between the sensor heads and the control unit are possible without compromising the system.
- Sensor failure is recognized immediately.

There are also some disadvantages:

- A high level of maintenance is required.
- The sensor range for CO is limited (0.4%).
- The variety of sensors is limited; there are none for CO₂ or hydrogen.
- The methane sensor is subject to poisoning.
- In situ calibration is required.
- Cross-sensitivity may be a problem.
- There may be a loss of power (e.g., >1.25% for methane).
- Sensor life is limited to 1 to 2 years.
- The system is not suitable for low oxygen atmospheres (e.g., behind seals).

**Gas chromatograph**

The gas chromatograph is a sophisticated piece of equipment that analyses samples with high degrees of accuracy and that, until recently, could only be fully utilized by chemists or specially qualified and trained personnel.

Gas samples from a tube bundle-type of system are injected into the gas chromatograph automatically or they can be manually introduced from bag samples brought out of the mine. A specially packed column is used to separate different gases and a suitable detector, usually thermal conductivity or flame ionization, is used to measure each gas as it elutes from the column. The separation process provides a high degree of specificity.

The gas chromatograph has particular advantages:

- No cross-sensitivity from other gases occurs.
- It is capable of measuring hydrogen.
- It is capable of measuring ethylene and higher hydrocarbons.
• It can accurately measure from very low to very high concentrations of most of the gases that occur or are produced underground by a heating or a fire.
• It is well recognized that modern methods of combating fires and heating in coal mines may be most effectively implemented on the basis of interpretation of gas analyses from strategic locations in the mine. Accurate, reliable and complete results require a gas chromatograph and interpretation by qualified, experienced and fully trained personnel.

Its disadvantages include:

• The analyses are relatively slow.
• A high level of maintenance is required.
• The hardware and the controls are complex.
• Expert attention is required periodically.
• Calibration must be scheduled frequently.
• High methane concentrations interfere with low level CO measurements.

Choice of system

Tube-bundle systems are preferred for monitoring locations that are not expected to have rapid changes in gas concentrations or, like sealed areas, may have low oxygen environments.

Telemetric systems are preferred in locations such as belt roads or on the face where rapid changes in gas concentrations may have significance.

Gas chromatography does not replace existing monitoring systems but it enhances the range, accuracy and reliability of the analyses. This is particularly important when determination of the risk of explosion is involved or when a heating is reaching an advanced stage.

Sampling considerations

• The sitting of sampling points at strategic locations is of major importance. The information from a single sampling point some distance from the source is only suggestive; without confirmation from other locations it may lead to over- or underestimation of the seriousness of the situation. Consequently, sampling points to detect an outbreak of spontaneous combustion must be sited where heating are most likely to occur. There must be little dilution of flows between the heating and the detectors. Consideration must be given to the possibility of the layering of methane and warm combustion gases which may rise up the dip in a sealed area. Ideally, the sampling sites should be located in panel returns, behind stoppings and seals, and in the main stream of the ventilation circuit. The following considerations are applicable:
  • The sampling site should be set at least 5 m inbye (i.e., toward the face of) a seal because seals “breathe in” when the atmospheric pressure rises.
  • Samples should be taken from boreholes only when they breathe out and when it can be ensured that the borehole is leak free.
  • Samples should be taken more than 50 m downwind from a fire to ensure mixing.
  • Samples should be taken up the gradient from a fire near the roof because hot gases rise.
  • Samples should be taken inbye a ventilation door to avoid leakage.
  • All sampling points should be clearly shown on maps of schematics of the mine ventilation system. Taking gas samples underground or from surface boreholes for analysis at another
location is difficult and error prone. The sample in the bag or container must truly represent
the atmosphere at the sampling point.

Plastic bags are now widely used in the industry for taking samples. The plastic minimizes leakage
and can keep a sample for 5 days. Hydrogen, if present in the bag, will degrade with a daily loss of
about 1.5% of its original concentration. A sample in a football bladder will change concentration in
half an hour. Bags are easy to fill and the sample can be squeezed into an analysing instrument or it
can be drawn out with a pump.

Metal tubes that are filled under pressure by a pump can store samples for a long time but the size
of the sample is limited and leakage is common. Glass is inert to gases but glass containers are
fragile and it is difficult to get the sample out without dilution.

In collecting samples, the container should be pre-flushed at least three times to ensure that the
previous sample is completely flushed out. Each container should have a tag carrying such
information as the date and time of sampling, the exact location, the name of the person collecting
the sample and other useful information.

**Interpretation of Sampling Data**

Interpretation of the results of gas sampling and analysis is a demanding science and should be
attempted only by individuals with special training and experience. These data are vital in many
emergencies because they provide information on what is happening underground that is needed to
plan and implement corrective and preventive actions. During or immediately after an underground
heating, fire or explosion, all possible environmental parameters should be monitored in real time to
enable those in charge to accurately determine the status of the situation and measure its progress
so that they lose no time in initiating any needed rescue activities.

Gas analysis results must meet the following criteria:

- **Accuracy.** Instruments must be correctly calibrated.
- **Reliability.** Cross-sensitivities must be known.
- **Completeness.** All gases, including hydrogen and nitrogen, should be measured.
- **Timeliness.** If real time is not possible, trending should be carried out.
- **Validity.** Sample points must be in and around the site of the incident.

The following rules should be followed in interpreting gas analysis results:

- A few sampling points should be carefully selected and marked on the plan. This is better for
trending than taking sample from many points.
- If a result deviates from a trend, it should be confirmed by resampling or the calibration of
the instrument should be checked before taking action. Variations in outside influences,
such as ventilation, barometric pressure and temperature or a diesel engine running in the
area, are often the reason for the changing result.
- The gas make or mixture under non-mining conditions should be known and allowed for in
the calculations.
- No analysis result should be accepted on faith; results must be valid and verifiable.
- It should be borne in mind that isolated figures do not indicate the progress—trends give a
more accurate picture.
Spontaneous Combustion

Spontaneous combustion is a process whereby a substance can ignite as a result of internal heat which arises spontaneously due to reactions liberating heat faster than it can be lost to the environment. The spontaneous heating of coal is usually slow until the temperature reaches about 70 °C, referred to as the “cross over” temperature. Above this temperature, the reaction usually accelerates. At over 300 °C, the volatiles, also called “coal gas” or “cracked gas”, are given off. These gases (hydrogen, methane and carbon monoxide) will ignite spontaneously at temperatures of approximately 650 °C (it has been reported that the presence of free radicals can result in the appearance of flame in the coal at about 400 °C). The processes involved in a classic case of spontaneous combustion are presented in Table - D (different coals will produce varying pictures).

**Table – D: Heating of coal - hierarchy of temperatures**

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Event Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>30 °C</td>
<td>Complex breaks down to produce CO/CO₂</td>
</tr>
<tr>
<td>45 °C</td>
<td>True oxidation of coal to produce CO and CO₂</td>
</tr>
<tr>
<td>70 °C</td>
<td>Cross-over temperature, heating accelerates</td>
</tr>
<tr>
<td>110 °C</td>
<td>Moisture, H₂ and characteristic smell released</td>
</tr>
<tr>
<td>150 °C</td>
<td>Desorbed CH₄, unsaturated hydrocarbons released</td>
</tr>
<tr>
<td>300 °C</td>
<td>Cracked gases (e.g., H₂, CO, CH₄) released</td>
</tr>
<tr>
<td>400 °C</td>
<td>Open flame</td>
</tr>
</tbody>
</table>

Source: Chamberlain et al. 1970.

Carbon monoxide

CO is actually released some 50 °C before the characteristic smell of combustion is noticed. Most systems designed to detect the onset of spontaneous combustion are based on the detection of carbon monoxide in concentrations above the normal background for a particular area of the mine.

Once a heating has been detected, it must be monitored in order to determine the state of the heating (i.e., its temperature and extent), the rate of accelerations, toxic emissions and explosibility of the atmosphere.

**Monitoring a heating**

There are a number of indices and parameters available to assist planners to determine the extent, temperature and rate of progression of a heating. These are usually based on changes in the composition of the air passing through a suspected area. Many indicators have been described in the literature over the years and most offer a very limited window of usage and are of minimal value. All are site specific and differ with different coals and conditions. Some of the more popular ones include: carbon monoxide trending; carbon monoxide make (Funkemeyer and Kock 1989); Graham’s ratio (Graham 1921) tracer gases (Chamberlain 1970); Morris ratio (Morris 1988); and the carbon monoxide/carbon dioxide ratio. After sealing, indicators may be difficult to use because of the absence of a defined air flow.
Explosions

Explosions are the greatest single hazard in coal mining. It has the potential to kill the entire underground workforce, destroy all the equipment and services and prevent any further working of the mine. And, all this can happen in 2 to 3 seconds.

The explosibility of the atmosphere in the mine must be monitored at all times. It is especially urgent when workers are engaged in a rescue operation in a gassy mine.

As in the case of indicators for evaluating a heating, there are a number of techniques for calculating the explosibility of the atmosphere in an underground mine. They include: Coward’s triangle (Greuer 1974); Hughes and Raybold’s triangle (Hughes and Raybold 1960); Elicott’s diagram (Elicott 1981); and Trickett’s ratio (Jones and Trickett 1955). Because of the complexity and variability of the conditions and circumstances, there is no single formula that can be relied on as a guarantee that an explosion will not occur at a particular time in a particular mine. One must rely on a high and unremitting level of vigilance, a high index of suspicion and an unhesitating initiation of appropriate action at the slightest indication that an explosion might be imminent. A temporary halt in production is a relatively small premium to pay for assurance that an explosion will not occur.

Conclusion

This article has summarized the detection of gases that might be involved in fires and explosions in underground mines. The other health and safety implications of the gaseous environment in mines (e.g., dust diseases, asphyxia, toxic effects, etc.) are discussed in other articles.

19. EMERGENCY PREPAREDNESS

Mine emergencies often occur as the result of a lack of systems, or failures in existing systems, to limit, control or prevent circumstances that trigger incidents which, when ineffectively managed, lead to disasters. An emergency may then be defined as an unplanned event that impacts upon the safety or welfare of personnel, or the continuity of operations, which requires an effective and timely response in order to contain, control or mitigate the situation.

All forms of mining operations have particular hazards and risks that may lead to an emergency situation. Hazards in underground coal mining include methane liberation and coal dust generation, high-energy mining systems and coal’s propensity to spontaneous combustion. Emergencies can occur in underground metalliferous mining due to strata failure (rock bursts, rock falls, hangingwall and pillar failures), unplanned initiation of explosives and sulphide ore dusts. Surface mining operations involve risks relating to, large-scale high-speed mobile equipment, unplanned initiation of explosives, and slope stability. Hazardous chemical exposure, spill or leak, and tailing dam failure can take place in minerals processing.

Good mining and operational practices have evolved that incorporate relevant measures to control or mitigate these risks. However, mine disasters continue to occur regularly throughout the world, even though formal risk management techniques have been adopted in some countries as a pro-
active strategy to improve mine safety and reduce the likelihood and consequence of mine emergencies.

Accident investigations and inquiries continue to identify failures to apply the lessons of the past and failures to apply effective barriers and control measures to known hazards and risks. These failures are often compounded by a lack of adequate measures to intervene, control and manage the emergency situation.

This article outlines an approach to emergency preparedness that can be utilized as a framework to both control and mitigate mining hazards and risks and to develop effective measures to ensure control of the emergency and the continuity of mine operations.

Emergency Preparedness Management System

The emergency preparedness management system proposed comprises an integrated systems approach to the prevention and management of emergencies. It includes:

- Organizational intent and commitment (corporate policy, management commitment and leadership)
- Risk management (identification, assessment and control of hazards and risks)
- Definition of measures to manage an unplanned event, incident or emergency
- Definition of emergency organization (strategies, structure, staffing, skills, systems and procedures)
- Provision of facilities, equipment, supplies and materials
- Training of personnel in the identification, containment and notification of incidents and their roles in the mobilization, deployment and post-incident activities
- Evaluation and enhancement of the overall system through regular auditing procedures and trials
- Periodic risk and capability reassessment
- Critique and evaluation of the response in the event of an emergency, coupled with necessary system enhancement.

Incorporation of emergency preparedness within the ISO 9000 quality management system framework provides a structured approach to contain and control emergency situations in a timely, effective and safe manner.

Organizational Intent and Commitment

Few people will be convinced of the need for emergency preparedness unless a potential danger is recognized and it is seen as directly threatening, highly possible if not probable and likely to occur in a relatively short time span. However, the nature of emergencies is that this recognition generally does not occur prior to the event or is rationalized as non-threatening. The lack of adequate systems, or failures in existing systems, results in an incident or emergency situation.

Commitment to and investment in effective emergency preparedness planning provides an organization with the capability, expertise and systems to provide a safe work environment, meet moral and legal obligations and enhance prospects for business continuity in an emergency. In coal mine fires and explosions, including non-fatal incidents, business continuity losses are often significant due to the extent of damage, the type and nature of control measures employed or even
loss of the mine. Investigative processes also impact considerably. Failure to have effective measures in place to manage and control an incident will further compound overall losses.

Development and implementation of an effective emergency preparedness system requires management leadership, commitment and support. Consequently it will be necessary to:

- provide and ensure continuing management leadership, commitment and support
- establish long-term goals and purpose
- guarantee financial support
- guarantee availability of personnel and their access to and involvement in training
- provide appropriate organizational resources to develop, implement and maintain the system.

The necessary leadership and commitment can be demonstrated through the appointment of an experienced, capable and highly respected officer as Emergency Preparedness Coordinator, with the authority to ensure participation and cooperation at all levels and within all units of the organization. Formation of an Emergency Preparedness Planning Committee, under the Coordinator’s leadership, will provide the necessary resources to plan, organize and implement an integrated and effective emergency preparedness capability throughout the organization.

Risk Assessment

The risk management process enables the type of risks facing the organization to be identified and analysed to determine the likelihood and the consequence of their occurrence. This framework then enables the risks to be assessed against established criteria to determine if the risks are acceptable or what form of treatment must be applied to reduce those risks (e.g., reducing likelihood of occurrence, reducing consequence of occurrence, transferring all or part of the risks or avoiding the risks). Targeted implementation plans are then developed, implemented and managed to control the identified risks.

This framework can be similarly applied to develop emergency plans that enable effective controls to be implemented, should a contingent situation arise. Identification and analysis of risks enables likely scenarios to be predicted with a high degree of accuracy. Control measures can then be identified to address each of the recognized emergency scenarios, which then form the basis of emergency preparedness strategies.

Emergency Control Measures and Strategies

Three levels of response measures should be identified, evaluated and developed within the emergency preparedness system. Individual or primary response comprises the actions of individuals upon the identification of hazardous situations or an incident, including:

- Notifying appropriate supervisors, controllers or management personnel of the situation, circumstances or incident
- Containment (basic fire-fighting, life support or extrication)
- Evacuation, escape or refuge.

Secondary response comprises the actions of trained responders upon notification of the incident, including fire teams, search and rescue teams and special casualty access teams (SCAT), all utilizing advanced skills, competencies and equipment.
Tertiary response comprises the deployment of specialized systems, equipment and technologies in situations where primary and secondary response cannot be safely or effectively utilized, including:

- Personnel locating devices and seismic event detectors
- Large diameter borehole rescue
- Inertization, remote sealing or flooding
- Surveillance/exploration vehicles and systems (e.g., borehole cameras and atmospheric sampling).

**Defining the Emergency Organization**

Emergency conditions grow more serious the longer the situation is allowed to proceed. Onsite personnel must be prepared to respond appropriately to emergencies. A multitude of activities must be coordinated and managed to ensure that the situation is rapidly and effectively controlled.

Emergency organization provides a structured framework that defines and integrates the emergency strategies, management structure (or chain of command), personnel resources, roles and responsibilities, equipment and facilities, systems and procedures. It encompasses all phases of an emergency, from the initial identification and containment activities, to notification, mobilization, deployment and recovery (re-establishment of normal operations).

The emergency organization should address a number of key elements, including:

- Capability for primary and secondary response to an emergency
- Capability to manage and control an emergency
- Co-ordination and communications, including gathering, assessing and evaluating data, decision making and implementation
- The breadth of procedures necessary for effective control, including identification and containment, notification and early reporting, declaration of an emergency, specific operational procedures, fire-fighting, evacuation, extrication and life support, monitoring and review
- Identification and assignment of key functional responsibilities
- Control, advisory, technical, administration and support services
- Transitional arrangements from normal to emergency operations in terms of lines of communication, authority levels, accountability, compliance, liaison and policy
- Capability and capacity to maintain emergency operations for an extended period and provide for shift changes
- Impact of organizational changes in an emergency situation, including supervision and control of personnel; re-allocation or re-assignment of personnel; motivation, commitment and discipline; role of experts and specialists, external agencies and corporate officers
- Contingency provisions to address situations such as those arising after hours or where key organizational members are unavailable or affected by the emergency
- Integration and deployment of tertiary response systems, equipment and technologies.

**Emergency Facilities, Equipment and Materials**

The nature, extent and scope of facilities, equipment and materials required to control and mitigate emergencies will be identified through application and extension of the risk management process and determination of the emergency control strategies. For example, a high-level risk of fire will necessitate the provision of adequate fire-fighting facilities and equipment. These would be
deployed consistently with the risk profile. Similarly, the facilities, equipment and materials necessary to address effectively life support and first aid or evacuation, escape and rescue can be identified as illustrated in Table - E.

Table – E: Emergency facilities, equipment and materials

<table>
<thead>
<tr>
<th>Emergency</th>
<th>Response level</th>
<th>Primary</th>
<th>Secondary</th>
<th>Tertiary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fire</td>
<td>Primary</td>
<td>Fire extinguishers, hydrants and hoses installed adjacent to high risk areas, such as conveyors, fuelling stations, electrical transformers and sub-stations, and on mobile equipment</td>
<td>Breathing apparatus and protective clothing provided in central areas to enable a “fire team” response with advanced apparatus such as foam generators and multiple hoses</td>
<td>Provision for remote sealing or inertization.</td>
</tr>
<tr>
<td>Life support and first aid</td>
<td>Life support, respiration and circulation</td>
<td>First aid, triage, stabilization and extrication</td>
<td>Paramedical, forensic, legal</td>
<td></td>
</tr>
<tr>
<td>Evacuation, escape and rescue</td>
<td>Provision of warning or notification systems, secure escapeways, oxygen-based self rescuers, lifelines and communication systems, availability of transportation vehicles</td>
<td>Provision of suitably equipped refuge chambers, trained and equipped mines rescue teams, personnel locating devices</td>
<td>Large diameter borehole rescue systems, inertization, purpose-designed rescue vehicles</td>
<td></td>
</tr>
</tbody>
</table>

Other facilities and equipment that may be necessary in an emergency include incident management and control facilities, employee and rescue muster areas, site security and access controls, facilities for next of kin and the media, materials and consumables, transport and logistics. These facilities and equipment are provided for prior to an incident. Recent mine emergencies have reinforced the necessity to focus on three specific infrastructure issues, refuge chambers, communications, and atmospheric monitoring.

**Refuge chambers**

Refuge chambers are being increasingly utilized as a means of enhancing escape and rescue of underground personnel. Some are designed to permit persons to be self-rescuers and communicate with the surface in safety; others have been designed to effect refuge for an extended period so as to permit assisted rescue.

The decision to install refuge chambers is dependent upon the overall escape and rescue system for the mine. The following factors need to be evaluated when considering the need for and design of refuges:

- The likelihood of entrapment
• The time taken for people underground to evacuate through the normal means of egress, which may be excessive in mines with extensive workings or difficult conditions such as low heights or steep grades
• The capability of persons underground to escape unassisted (e.g., pre-existing medical conditions or fitness levels and injuries sustained in the incident)
• The discipline required to maintain and utilize refuge chambers
• The means to assist personnel to locate the refuge chambers in conditions of extremely low visibility and duress
• The required resistance to explosions and fire
• The necessary size and capacity
• The services provided (e.g., ventilation/air purification, cooling, communications, sanitation, and sustenance)
• The potential application of inertization as a control strategy
• The options for final recovery of personnel (e.g., mine rescue teams and large diameter boreholes).

Communications

Communications infrastructure is generally in place in all mines to facilitate management and control of operations as well as contribute to the safety of the mine through calls for support. Unfortunately, the infrastructure is usually not robust enough to survive a significant fire or explosion, disrupting communication when it would be most beneficial. Furthermore conventional systems incorporate handsets which cannot be safely used with most breathing apparatus and are usually deployed in main intake airways adjacent to fixed plant, rather than in escapeways.

The need for post-incident communications should be closely evaluated. While it is preferable that a post-incident communications system is part of the pre-incident system, to enhance maintainability, cost and reliability, a stand-alone emergency communications system may be warranted. Regardless, the communications system should be integrated within the overall escape, rescue and emergency management strategies.

Post-Incident Atmospheric Monitoring

Knowledge of conditions in a mine following an incident is essential to enable the most appropriate measures to control a situation to be identified and implemented and to assist escaping workers and protect rescuers. The need for post-incident atmospheric monitoring should be closely evaluated and systems should be provided that meet mine-specific needs, possibly incorporating:

• The location and design of fixed station atmospheric and ventilation sampling points for normal and potentially abnormal atmospheric conditions
• The maintenance of capabilities to analyse, trend and interpret the mine atmosphere, particularly where explosive mixtures may be present post-incident
• Modularization of tube-bundle systems around boreholes to minimize sampling delays and improve the system’s robustness
• Provision of systems to verify integrity of tube-bundle systems post-incident
• Utilization of gas chromatography where explosive mixtures are possible after the incident and rescuers may be required to enter the mine.

Emergency Preparedness Skills, Competencies and Training
The skills and competencies required to cope effectively with an emergency can be readily determined by identification of core risks and emergency control measures, development of emergency organization and procedures and identification of necessary facilities and equipment.

Emergency preparedness skills and competencies include not only planning and management of an emergency, but a diverse range of basic skills associated with the primary and secondary response initiatives that should be incorporated in a comprehensive training strategy, including:

- Identification and containment of the incident (e.g., fire-fighting, life support, evacuation and extrication)
- Notification (e.g., radio and telephone procedures)
- Mobilization and deployment activities (e.g., search and rescue, fire-fighting, casualty management and recovering bodies).

The emergency preparedness system provides a framework for the development of an effective training strategy by identifying the necessity, extent and scope of specific, predictable and reliable workplace outcomes in an emergency situation and the underpinning competencies. The system includes:

- A statement of intent that details why the necessary expertise, skills and competencies are to be developed and provides the organizational commitment and leadership to succeed
- Risk management and measures to manage emergencies that identify key content elements (e.g., fires, explosions, hazardous materials, unplanned movements and discharges, sabotage, bomb threats, security breaches, etc.)
- A definition of the emergency organization (strategies, structure, staffing, skills, systems and procedures) that identifies who is to be trained, their role in an emergency and the necessary skills and competencies
- Identification of training resources that determines what aids, equipment, facilities and personnel are necessary
- Training of personnel in identification and containment, notification, mobilization, deployment and post-incident activities that develops the necessary skills and competency base
- Routine testing, evaluation and enhancement of the overall system, coupled with periodic risk and capability reassessment, that completes the learning process and ensures that an effective emergency preparedness system exists.

Emergency preparedness training can be structured into a number of categories as illustrated in Table - F.

Table – F: Emergency preparedness training matrix

<table>
<thead>
<tr>
<th>Training response level</th>
<th>Educational primary</th>
<th>Procedural/secondary</th>
<th>Functional/tertiary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Designed to ensure employees understand the nature of mine emergencies and how specific aspects of the overall emergency plan may involve or affect the individual, including primary response measures.</td>
<td>Skills and competencies to successfully complete specific procedures defined under the emergency response plans and the secondary response measures associated with specific emergency scenarios.</td>
<td>Development of skills and competencies necessary for the management and control of emergencies.</td>
<td></td>
</tr>
</tbody>
</table>
## Knowledge and competence elements

<table>
<thead>
<tr>
<th>Knowledge of key indicators of mine incidents</th>
<th>Knowledge of key indicators of mine incidents</th>
<th>Knowledge of key indicators of mine emergencies and detailed knowledge of trigger events to initiate emergency response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Environmental conditions following an incident (e.g., temperature, visibility and gases)</td>
<td>Ability to detect, monitor and evaluate environmental conditions following an incident (e.g., mine gases, ventilation, smoke)</td>
<td>Detailed knowledge of mine design, mine ventilation and monitoring systems</td>
</tr>
<tr>
<td>Ability to respond to adverse changes in environmental conditions (e.g., smoke, ventilation disruption)</td>
<td>Ability to assess and interpret changes to mine ventilation systems (e.g., destruction of stoppings, seals and air crossings, damage to main fans)</td>
<td>Ability to assess and interpret current information systems at the mine (e.g., ventilation and environmental monitoring data)</td>
</tr>
<tr>
<td>Ability to perform notification and communications required post-incident</td>
<td>Knowledge of response measures that can be used to manage and mitigate an emergency (e.g., fire-fighting, search and rescue, restoration of ventilation, first aid, triage and extrication)</td>
<td>Awareness of control measures that can be used to manage and mitigate an emergency</td>
</tr>
<tr>
<td>Knowledge of appropriate emergency response options to environmental conditions</td>
<td>Knowledge of roles and responsibilities of all mine personnel under the emergency response plans and the capability to perform their nominated role</td>
<td>Ability to operate and manage emergency response plans and procedures, conducting simulated emergencies</td>
</tr>
<tr>
<td>Awareness of use and limitations of escape apparatus, routes and systems</td>
<td>Awareness of use and limitations of escape apparatus, routes and systems (e.g., self-rescuers, refuge chambers, breathing apparatus)</td>
<td>Ability to implement emergency communications and protocols, both internally and externally</td>
</tr>
<tr>
<td>Knowledge of roles and responsibilities of all mine personnel under emergency response plans including specific roles and responsibilities</td>
<td>Ability to implement internal emergency communications and protocols</td>
<td>Capability of mine rescue and other emergency services and access support from these services</td>
</tr>
<tr>
<td>Possession of primary response skills and competencies associated with specific emergency scenarios (e.g., basic fire-fighting, life support, escape and refuge)</td>
<td>Awareness of use and limitations of escape and rescue apparatus and systems (e.g., self-rescuers, refuge chambers, breathing apparatus)</td>
<td>Ability to establish and support critical incident team</td>
</tr>
<tr>
<td>Knowledge about mine rescue and other emergency services</td>
<td>Capability of mine rescue and other emergency services</td>
<td>Knowledge of the capability and deployment of tertiary response systems (e.g., locating systems, inertization, remote sealing, large diameter borehole rescue, mobile laboratories)</td>
</tr>
<tr>
<td>Participation in simulated emergencies</td>
<td>Initiation of call out and mutual assistance schemes</td>
<td>Ability to use specialist resources (e.g., paramedical, forensic, legal, critical incident stress debriefing, technologists)</td>
</tr>
<tr>
<td>Participating in simulated exercises and emergencies</td>
<td></td>
<td>Crisis management and leadership</td>
</tr>
</tbody>
</table>
Audit, Review and Evaluation

Audit and review processes need to be adopted to assess and evaluate the effectiveness of the overall emergency systems, procedures, facilities, maintenance programmes, equipment, training and individual competencies. The conduct of an audit or simulation provides, without exception, opportunities for improvement, constructive criticism and verification of satisfactory performance levels of key activities.

Every organization should test its overall emergency plan at least once per year for each operating shift. Critical elements of the plan, such as emergency power or remote alarm systems, should be tested separately and more frequently.

Two basic forms of auditing are available. Horizontal auditing involves the testing of small, specific elements of the overall emergency plan to identify deficiencies. Seemingly minor deficiencies could become critical in the event of an actual emergency. Examples of such elements and related deficiencies are listed in Table - G. Vertical auditing tests multiple elements of a plan simultaneously through simulation of an emergency event. Activities such as activation of the plan, search and rescue procedures, life support, fire-fighting and the logistics related to an emergency response at a remote mine or facility can be audited in this manner.

Table – G: Examples of horizontal auditing of emergency plans

<table>
<thead>
<tr>
<th>Element</th>
<th>Deficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indicators of incipient incident or event</td>
<td>Failure to recognize, notify, record and action</td>
</tr>
<tr>
<td>Alert/evacuation procedures</td>
<td>Employees unfamiliar with evacuation procedures</td>
</tr>
<tr>
<td>Donning of emergency respirators</td>
<td>Employees unfamiliar with respirators</td>
</tr>
<tr>
<td>Fire-fighting equipment</td>
<td>Fire extinguishers discharged, sprinkler heads painted over, fire hydrants concealed or buried</td>
</tr>
<tr>
<td>Emergency alarms</td>
<td>Alarms ignored</td>
</tr>
<tr>
<td>Gas testing instruments</td>
<td>Not regularly maintained, serviced or calibrated</td>
</tr>
</tbody>
</table>

Simulations may involve personnel from more than one department and perhaps personnel from other companies, mutual aid organizations, or even emergency services such as police and fire departments. Involvement of external emergency service organizations provides all parties with an invaluable opportunity to enhance and integrate emergency preparedness operations, procedures and equipment and tailor response capabilities to major risks and hazards at specific sites.

A formal critique should be conducted as soon as possible, preferably immediately following the audit or simulation. Recognition should be extended to those individuals or teams that performed well. Weaknesses must be described as specifically as possible and procedures reviewed to incorporate systemic improvements where necessary. Necessary changes must be implemented and performance must be monitored for improvements.

A sustained programme emphasizing planning, practice, discipline and teamwork are necessary elements of well-balanced simulations and training drills. Experience has proven repeatedly that
every drill is a good drill; every drill is beneficial and presents opportunities to demonstrate strengths and expose areas that require improvement.

**Periodic Risk and Capability Reassessment**

Few risks remain static. Consequently, risks and the capability of control and emergency preparedness measures needs to be monitored and evaluated to ensure that changing circumstances (e.g., people, systems, processes, facilities or equipment) do not alter risk priorities or diminish system capabilities.

**20. HEALTH HAZARDS OF MINING AND QUARRYING**

The principal airborne hazards in the mining industry include several types of particulates, naturally occurring gases, engine exhaust and some chemical vapours; the principal physical hazards are noise, segmental vibration, heat, changes in barometric pressure and ionizing radiation. These occur in varying combinations depending on the mine or quarry, its depth, the composition of the ore and surrounding rock, and the method(s) of mining. Among some groups of miners who live together in isolated locations, there is also risk of transmitting some infectious diseases such as tuberculosis, hepatitis (B and E), and the human-immunodeficiency virus (HIV). Miners’ exposure varies with the job, its proximity to the source of hazards and the effectiveness of hazard control methods.

**Airborne Particulate Hazards**

Free crystalline silica is the most abundant compound in the earth’s crust and, consequently, is the most common airborne dust that miners and quarry-workers face. Free silica is silicon dioxide that is not chemically bonded with any other compound as a silicate. The most common form of silica is quartz although it can also appear as trydimite or christobalite. Respirable particles are formed whenever silica-bearing rock is drilled, blasted, crushed or otherwise pulverized into fine particles. The amount of silica in different species of rock varies but is not a reliable indicator of how much respirable silica dust may be found in an air sample. It is not uncommon, for example, to find 30% free silica in a rock but 10% in an air sample, and vice versa. Sandstone can be up to 100% silica, granite up to 40%, slate, 30%, with lesser proportions in other minerals. Exposure can occur in any mining operation, surface or underground, where silica is found in the overburden of a surface mine or the ceiling, floor or ore deposit of an underground mine. Silica can be dispersed by the wind, by vehicular traffic or by earth-moving machinery.

With sufficient exposure, silica can cause silicosis, a typical pneumoconiosis that develops insidiously after years of exposure. Exceptionally high exposure can cause acute or accelerated silicosis within months with significant impairment or death occurring within a few years. Exposure to silica is also associated with an increased risk of tuberculosis, lung cancer and of some autoimmune diseases, including scleroderma, systemic lupus erythematosus and rheumatoid arthritis. Freshly fractured silica dust appears to be more reactive and more hazardous than old or stale dust. This may be a consequence of a relatively higher surface charge on freshly formed particles.

The most common processes that produce respirable silica dust in mining and quarrying are drilling, blasting and cutting silica-containing rock. Most holes drilled for blasting are done with an air powered percussion drill mounted on a tractor crawler. The hole is made with a combination of rotation, impact and thrust of the drill bit. As the hole deepens, steel drill rods are added to connect the drill bit to the power source. Air not only powers the drilling, it also blows the chips and dust out of the hole which, if uncontrolled, injects large amounts of dust into the environment. The hand-
held jack-hammer or sinker drill operates on the same principle but on a smaller scale. This device conveys a significant amount of vibration to the operator and with it, the risk of vibration white finger. Vibration white finger has been found among miners in India, Japan, Canada and elsewhere. The track drill and the jack-hammer are also used in construction projects where rock must be drilled or broken to make a highway, to break rock for a foundation, for road repair work and other purposes.

Dust controls for these drills have been developed and are effective. A water mist, sometimes with a detergent, is injected into the blow air which helps the dust particles to coalesce and drop out. Too much water results in a bridge or collar forming between the drill steel and the side of the hole. These often have to be broken in order to remove the bit; too little water is ineffective. Problems with this type of control include reduction in the drilling rate, lack of reliable water supply and displacement of oil resulting in increased wear on lubricated parts.

The other type of dust control on drills is a type of local exhaust ventilation. Reverse air-flow through the drill steel withdraws some of the dust and a collar around the drill bit with ductwork and a fan to remove the dust. These perform better than the wet systems described above: drill bits last longer and the drilling rate is higher. However, these methods are more expensive and require more maintenance.

Other controls that provide protection are cabs with filtered and possibly air-conditioned air supply for drill operators, bulldozer operators and vehicle drivers. The appropriate respirator, correctly fitted, may be used for worker protection as a temporary solution or if all others prove to be ineffective.

Silica exposure also occurs at stone quarries that must cut the stone to specified dimensions. The most common contemporary method of cutting stone is with the use of a channel burner fuelled by diesel fuel and compressed air. This results in some silica particulate. The most significant problem with channel burners is the noise: when the burner is first ignited and when it emerges from a cut, sound level can exceed 120 dBA. Even when it is immersed in a cut, noise is around 115 dBA. An alternative method of cutting stone is to use very high-pressure water.

Often attached to or nearby a stone quarry is a mill where pieces are sculpted into a more finished product. Unless there is very good local exhaust ventilation, exposure to silica can be high because vibrating and rotating hand tools are used to shape the stone into the desired form.

Respirable coal mine dust is a hazard in underground and surface coal mines and in coal-processing facilities. It is a mixed dust, consisting mostly of coal, but can also include silica, clay, limestone and other mineral dusts. The composition of coal mine dust varies with the coal seam, the composition of the surrounding strata and mining methods. Coal mine dust is generated by blasting, drilling, cutting and transporting coal.

More dust is generated with mechanized mining than with manual methods, and some methods of mechanized mining produce more dust than others. Cutting machines that remove coal with rotating drums studded with picks are the principal sources of dust in mechanized mining operations. These include so-called continuous miners and longwall mining machines. Longwall mining machines usually produce larger amounts of dust than do other methods of mining. Dust dispersion can also occur with the movement of shields in longwall mining and with the transfer of coal from a vehicle or conveyor belt to some other means of transport.
Coal mine dust causes coal workers’ pneumoconiosis (CWP) and contributes to the occurrence of chronic airways disease such as chronic bronchitis and emphysema. Coal of high rank (e.g., high carbon content such as anthracite) is associated with a higher risk of CWP. There are some rheumatoid-like reactions to coal mine dust as well.

The generation of coal mine dust can be reduced by changes in coal cutting techniques and its dispersion can be controlled with the use of adequate ventilation and water sprays. If the speed of rotation of cutting drums is reduced and the tram speed (the speed with which the drum advances into the coal seam) is increased, dust generation can be reduced without losses in productivity. In longwall mining, dust generation can be reduced by cutting coal in one pass (rather than two) across the face and tramming back without cutting or by a clean-up cut. Dust dispersion on longwall sections can be reduced with homotropal mining (i.e., the chain-conveyor at the face, the cutter head and the air all travelling in the same direction). A novel method of cutting coal, using an eccentric cutter head that continuously cuts perpendicular to the grain of a deposit, seems to generate less dust than the conventional circular cutting head.

Adequate mechanical ventilation flowing first over a mining crew and then to and across the mining face can reduce exposure. Auxiliary local ventilation at the working face, using a fan with ductwork and scrubber, can also reduce exposure by providing local exhaust ventilation.

Water sprays, strategically placed close to the cutterhead and forcing dust away from the miner and towards the face, also assist in reducing exposure. Surfactants provide some benefit in reducing the concentration of coal dust.

Asbestos exposure occurs among asbestos miners and in other mines where asbestos is found in the ore. Among miners throughout the world, exposure to asbestos has elevated the risk of lung cancer and of mesothelioma. It has also elevated the risk of asbestosis (another pneumoconiosis) and of airways disease.

Diesel engine exhaust is a complex mixture of gases, vapours and particulate matter. The most hazardous gases are carbon monoxide, nitrogen oxide, nitrogen dioxide and sulphur dioxide. There are many volatile organic compounds (VOCs), such as aldehydes and unburned hydrocarbons, polycyclic aromatic hydrocarbons (PAHs) and nitro-PAH compounds (N-PAHs). PAH and N-PAH compounds are also adsorbed onto diesel particulate matter. Nitrogen oxides, sulphur dioxide and aldehydes are all acute respiratory irritants. Many of the PAH and N-PAH compounds are carcinogenic.

Diesel particulate matter consists of small diameter (<1 µm in diameter) carbon particles that are condensed from the exhaust fume and often aggregate in air in clumps or strings. These particles are all respirable. Diesel particulate matter and other particles of similar size are carcinogenic in laboratory animals and appear to increase the risk of lung cancer in exposed workers at concentrations above about 0.1 mg/m$^3$. Miners in underground mines experience exposure to diesel particulate matter at significantly higher levels. The International Agency for Research on Cancer (IARC) considers diesel particulate matter to be a probable carcinogen.

The generation of diesel exhaust can be reduced by engine design and with high-quality, clean and low-sulphur fuel. De-rated engines and fuel with a low cetane number and low sulphur content produce less particulate matter. Use of low sulphur fuel reduces the generation of SO$_2$ and of particulate matter. Filters are effective and feasible and can remove more than 90% of diesel particulate matter from the exhaust stream. Filters are available for engines without scrubbers and
for engines with either water or dry scrubbers. Carbon monoxide can be significantly reduced with a catalytic converter. Nitrogen oxides form whenever nitrogen and oxygen are under conditions of high pressure and temperature (i.e., inside the diesel cylinder) and, consequently, they are more difficult to eliminate.

The concentration of dispersed diesel particulate matter can be reduced in an underground mine by adequate mechanical ventilation and restrictions on the use of diesel equipment. Any diesel powered vehicle or other machine will require a minimum amount of ventilation to dilute and remove the exhaust products. The amount of ventilation depends on the size of the engine and its uses. If more than one diesel powered piece of equipment is operating in one air course, ventilation will have to be increased to dilute and remove the exhaust.

Diesel powered equipment may increase the risk of fire or explosion since it emits a hot exhaust, with flame and sparks, and its high surface temperatures may ignite any accumulated coal dust or other combustible material. Surface temperature of diesel engines have to be kept below 305 °F (150 °C) in coal mines in order to prevent the combustion of coal. Flame and sparks from the exhaust can be controlled by a scrubber to prevent ignition of coal dust and of methane.

Gases and Vapours

Table - H lists gases commonly found in mines. The most important naturally occurring gases are methane and hydrogen sulphide in coal mines and radon in uranium and other mines. Oxygen deficiency is possible in either. Methane is combustible. Most coal mine explosions result from ignitions of methane and are often followed by more violent explosions caused by coal dust that has been suspended by the shock of the original explosion. Throughout the history of coal mining, fires and explosions have been the principal cause of death of thousands of miners. Risk of explosion can be reduced by diluting methane to below its lower explosive limit and by prohibiting potential ignition sources in the face areas, where the concentration is usually the highest. Dusting the mine ribs (wall), floor and ceiling with incombustible limestone (or other silica-free incombustible rock dust) helps to prevent dust explosions; if dust suspended by the shock of a methane explosion is not combustible, a secondary explosion will not occur.

**Table – H: Common names and health effects of hazardous gases occurring in coal mines**

<table>
<thead>
<tr>
<th>Gas</th>
<th>Common name</th>
<th>Health effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methane (CH₄)</td>
<td>Fire damp</td>
<td>Flammable, explosive; simple asphyxiati</td>
</tr>
<tr>
<td>Carbon monoxide (CO)</td>
<td>White damp</td>
<td>Chemical asphyxiati</td>
</tr>
<tr>
<td>Hydrogen sulphide (H₂S)</td>
<td>Stink damp</td>
<td>Eye, nose, throat irritation; acute respiratory depression</td>
</tr>
<tr>
<td>Oxygen deficiency</td>
<td>Black damp</td>
<td>Anoxia</td>
</tr>
<tr>
<td>Blasting by-products</td>
<td>After damp</td>
<td>Respiratory irritants</td>
</tr>
<tr>
<td>Diesel engine exhaust</td>
<td>Same</td>
<td>Respiratory irritant; lung cancer</td>
</tr>
</tbody>
</table>

Radon is a naturally occurring radioactive gas that has been found in uranium mines, tin mines and some other mines. It has not been found in coal mines. The primary hazard associated with radon is its being a source of ionizing radiation, which is discussed below.
Other gaseous hazards include respiratory irritants found in diesel engine exhaust and blasting by-products. Carbon monoxide is found not only in engine exhaust but also as a result of mine fires. During mine fires, CO can reach not only lethal concentrations but also can become an explosion hazard.

Nitrogen oxides (NO\textsubscript{x}), primarily NO and NO\textsubscript{2}, are formed by diesel engines and as a by-product of blasting. In engines, NO\textsubscript{x} are formed as an inherent by-product of putting air, 79% of which is nitrogen and 20% of which is oxygen, under conditions of high temperature and pressure, the very conditions necessary to the functioning of a diesel engine. The production of NO\textsubscript{x} can be reduced to some extent by keeping the engine as cool as possible and by increasing ventilation to dilute and remove the exhaust.

NO\textsubscript{x} is also a blasting by-product. During blasting, miners are removed from an area where blasting will occur. The conventional practice to avoid excessive exposure to nitrogen oxides, dust and other results of blasting is to wait until mine ventilation removes a sufficient amount of blasting by-products from the mine before re-entering the area in an intake airway.

Oxygen deficiency can occur in many ways. Oxygen can be displaced by some other gas, such as methane, or it may be consumed either by combustion or by microbes in an air space with no ventilation.

There is a variety of other airborne hazards to which particular groups of miners are exposed. Exposure to mercury vapour, and thus risk of mercury poisoning, is a hazard among gold miners and millers and among mercury miners. Exposure to arsenic, and risk of lung cancer, occurs among gold miners and lead miners. Exposure to nickel, and thus to risk of lung cancer and skin allergies, occurs among nickel miners.

Some plastics are finding use in mines also. These include urea-formaldehyde and polyurethane foams, both of which are plastics made in-place. They are used to plug up holes and improve ventilation and to provide a better anchor for roof supports. Formaldehyde and isocyanates, two starting materials for these two foams, are respiratory irritants and both can cause allergic sensitization making it nearly impossible for sensitized miners to work around either ingredient. Formaldehyde is a human carcinogen (IARC Group 1).

**Physical Hazards**

Noise is ubiquitous in mining. It is generated by powerful machines, fans, blasting and transportation of the ore. The underground mine usually has limited space and thus creates a reverberant field. Noise exposure is greater than if the same sources were in a more open environment.

Exposure to noise can be reduced by using conventional means of noise control on mining machinery. Transmissions can be quieted, engines can be muffled better, and hydraulic machinery can be quieted as well. Chutes can be insulated or lined with sound-absorbing materials. Hearing protectors combined with regular audiometric testing is often necessary to preserve miners’ hearing.

Ionizing radiation is a hazard in the mining industry. Radon can be liberated from stone while it is loosened by blasting, but it may also enter a mine through underground streams. It is a gas and therefore it is airborne. Radon and its decay products emit ionizing radiation, some of which have
enough energy to produce cancer cells in the lung. As a result, death rates from lung cancer among uranium miners are elevated. For miners who smoke, the death rate is very much higher.

Heat is a hazard for both underground and surface miners. In underground mines, the principal source of heat is from the rock itself. The temperature of the rock goes up about 1 °C for every 100 m in depth. Other sources of heat stress include the amount of physical activity workers are doing, the amount of air circulated, the ambient air temperature and humidity and the heat generated by mining equipment, principally diesel powered equipment. Very deep mines (deeper than 1,000 m) can pose significant heat problems, with the temperature of mine ribs about 40 °C. For surface workers, physical activity, the proximity to hot engines, air temperature, humidity and sunlight are the principal sources of heat.

Reduction of heat stress can be accomplished by cooling high temperature machinery, limiting physical activity and providing adequate amounts of potable water, shelter from the sun and adequate ventilation. For surface machinery, air-conditioned cabs can protect the equipment operator. At deep mines in South Africa, for example, underground air-conditioning units are used to provide some relief, and first aid supplies are available to deal with heat stress.

Many mines operate at high altitudes (e.g., greater than 4,600 m), and because of this, miners may experience altitude sickness. This can be aggravated if they travel back and forth between a mine at a high altitude and a more normal atmospheric pressure.

21. ROBOTICS AND INTELLIGENT SYSTEMS IN MINING - NEW WAVE OF TECHNOLOGICAL ADVANCES IS KNOCKING DOWN THE DOORS

Now in mining, this new wave of technological advances is knocking down the doors of conventional mining methods with improved systems.

It is reported that, Korean mining fields are likely to see a new army of remote-controlled robotic coal-miners in four years time. Australians are also working hard to put Robotics and advanced Intelligent systems for mining operation. It is all about getting people out of hazardous
environments and making system safer and productive. Safety, efficiency and better productivity are the key factors driving the trend to automation.

It is expected that, the robots will increase productivity by working around the clock and going deeper, which will reduce the risk of human losses from conventional mining. The robots will not only drill in mines but will up- and offload coal onto conveyors for transportation, with operators outside to control them remotely using a three-dimensional scanner attached at the back of the robots.

Currently, miners often go 2 to 7 kilometers underground to collect coal. Necessity for a mechanized intelligent robotic-miner has been raised as miners can only work four or five hours a day.

Robots will also be doing jobs like laying explosives, going underground after blasting to stabilize a mine roof or mining in areas where it is impossible for humans to work or even survive. Examples of the trend to mining advanced automation include:

a) Tele-operated and automated load-haul-dump trucks that self-navigate through tunnels, clearing the walls by centimeters.

b) The world's largest "robot", a 3500 tonne coal dragline featuring automated loading and unloading.

c) A robot device for drilling and bolting mine roofs to stabilize them after blasting.

d) A pilotless burrowing machine for mining in flooded gravels and sands underground, where human operators cannot go.

e) A robotic drilling and blasting device for inducing controlled caving.

Robotic and advanced automation can be helpful in reducing the huge operational costs that exist largely because people are put into hazardous mining environments. These operational costs include making a mine safe and habitable for humans to work. For example, in an underground mine a lot of expenses go into providing good mining environment, cooled air etc. Whereas, machines can
operate with lower requirements, reducing the need for expensive infrastructure. Robots must demonstrate efficiency gains or cost savings.

The mining robots and advanced intelligent systems are expected to change the concept of mines and working conditions as well as improving productivity.

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Author’s Published Books:


Currently, author has following useful blogs on Web:

- http://miningandblasting.wordpress.com/
- http://saferenvironment.wordpress.com
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