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Environmental Aspects of Selected Non-ferrous Metals (Cu, Ni, Pb, Zn, Au) Ore Mining

A Technical Guide

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This is the fifth publication in a new Technical Series that regroups the Guidelines, Overviews, Technical Reviews, and Workshop Proceedings previously published by UNEP IE/PAC. The regrouping into a single series ensures a greater cohesion among future publications, as well as having the unique advantage of incorporating into a single document a variety of elements of IE/PAC work that earlier had been presented separately.

As before, the Technical Series aims to meet the needs of a wide range of government officials, industry managers and environment protection associations, by providing information on the issues and methods of environmental management relevant to various industrial sectors.

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FOREWORD

Mining and its associated activities can be a source of considerable environmental damage. Pollution of surface and subsurface water, damage to land, and habitat destruction are some of the impacts that have been recorded in the past. Health and safety risks may also be considerable for people working in a mine, or living close by.

The deterioration of natural resources and of human health can have a negative effect on the long-term growth potential of a country, even if immediate economic benefits may be gained by individual enterprises. It is important, therefore, that mining should be carried out so as to minimize to the fullest extent possible these deleterious impacts. With careful planning, modern technologies, and sensitive management, it is in fact often possible to pursue mining at an acceptable environmental cost. This technical guide gives an overview of the methods and technologies that can be applied to achieve such a situation.

The Guide is intended for readers from several different backgrounds and areas of responsibility:

- mining industry personnel will find descriptions of procedures and technologies that minimize environmental impact, as well as policy and management guidelines for ensuring effective low-impact operation;
- government personnel and industry regulators will find indications of the level of environmental performance that can be expected of the industry, together with a description of technical, planning and management tools that foster its achievement.
- the general reader will find an overview of environmental impacts related to the mining industry, and recommended strategies for regulating these effects.

UNEP IE/PAC hopes that this report will assist decision-makers in these sectors to make technical and management decisions that are both economically and environmentally sound so as to contribute to the further development of a truly sustainable mining industry.

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ENVIRONMENTAL ASPECTS OF SELECTED NON-FERROUS METALS (Cu, Ni, Pb, Zn, Au) ORE MINING

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GLOSSARY OF KEY TERMS

Adit: An opening made horizontally into the side of a hill from which a mineral deposit will be explored and developed.

Anomaly: A deviation from the norm in rock patterns, usually discovered by geophysical methods. An anomaly suggests the possibility of a mineral deposit but only one of thousands of anomalies ever leads to a worthwhile mineral discovery.

Assay: The testing of a sample of minerals or ore to determine the contents of valuable minerals in the sample.

Backfill: Waste materials used to support the walls of a stope and provide a working platform after removal of ore.

Ball mill: A piece of milling equipment, used to grind ore into small particles, which uses steel balls as the grinding medium.

Base metal: A commercial metal such as copper, lead or zinc. The term was coined to describe a metal "inferior" to precious metals such as gold and silver.

Bedrock: The solid rock of the earth's crust, generally covered by overburden of soil or water.

Beneficiate: To treat ore so that the resulting product is richer or more concentrated with mineral. The term chiefly is applied to a preliminary mill treatment of bauxite and iron ore.

Biological leaching: A process of recovering metals from low-grade ores by dissolving them in solution, the dissolution being aided by bacterial action.

Block caving: A low cost method of mining in which large blocks of ore are undercut causing the ore left in place to break and cave under its own weight.

Concentrate: To treat ore so that the result - "concentrates" - will contain less waste and a higher amount of the valuable mineral. In many mining operations, ore is concentrated in a concentrator or mill on the surface, then shipped to a smelter, whose product is then sent on to a refinery for the recovery of the mineral content by eliminating impurities.

Cut and fill: A stoping method in which the ore is removed in slices or "lifts" after which the excavation is filled with rock (backfill) or other waste material before the next slice is mined. The backfill supports the walls of the stope as well as acting as the working floor for the next stage of mining.

Depletion: The steadily declining amount of ore in a deposit or property resulting from production. Minerals are said to be a "depleting resource" because once mined, they cannot be replaced.

Development: Bringing a mining property to the production stage. Technically, the carrying out of works to gain access to the ore body.

Dilution: A lowering of the grade of ore being mined when waste rock or low grade ore are included unavoidably in the mined ore.

Drive: A horizontal underground tunnel in such a direction that it follows the length of the ore-body.

Float: Pieces of rock that have been moved from their original location by natural forces such as frost action or glaciers.

Flotation: A common process in the concentration of minerals. When the various mineral particles have been ground sufficiently to allow separation from one to another and the gangue material, they are pumped in suspension to flotation cells. With the addition of certain chemicals and the passage of air through the suspension, the different mineral particles can be made to attach themselves selectively to the air bubbles to form a froth which is then skimmed from the remaining bulk of the suspension.

Footwall: The wall or rock on the underside of a vein or ore structure.

Gangue: The worthless minerals associated with valuable minerals in an ore deposit.

Jig: An apparatus used in milling to concentrate ore on a screen submerged in water, either by a reciprocating motion of the screen or by the pulsation of water through it.

Leaching: A chemical process used for the extraction of valuable minerals from ore. Also the natural process by which ground waters dissolve minerals.

Level: The horizontal development of drives and crosscuts from a mine shaft.

Lode:	A mineral deposit in solid rock.
Marginal ore deposits:	Lower grade ore bodies which are close to being economically disadvantageous to exploit.
Matte:	Molten material in the course of the recovery process in a smelter: it is not completely pure metal and requires further processing.
Mineral:	A substance which may or may not be of economic value, that occurs naturally in the earth. It is homogeneous, has a certain chemical makeup and usually appears in crystal or grain form.
Muck:	Development ore or rock that has been broken by blasting.
Ore:	A mixture of minerals and a gangue from which at least one of the minerals can be extracted at a profit.
Ore dressing:	The treatment process in a mill.
Overburden:	Waste rock overlying an orebody.
Placer:	A sand or gravel deposit which contains a valuable mineral such as gold, platinum, tin, rutile or diamonds.
Raise:	A vertical or inclined underground tunnel that has been excavated from the bottom upward.
Rock burst:	The sudden failure of walls or pillars in a mine caused by the weight or pressure of the surrounding rocks.
Rod mill:	A rotating cylindrical mill which employs steel rods as a medium for grinding ore into small pieces.
Run-of-mine:	Ore of average grade in a mine.
Shoot:	That part of a vein or zone carrying values of ore grade.
Shrinkage:	A method of stoping which utilizes part of the broken ore.
Stoping:	As a working platform a support for the walls.
Smelting:	The partial recovery of metal in molten form from processed ore. The latter will have been treated and concentrated at a mill, but smelting is required to actually recover the metal content and convert it to a form that is ready for refining.
Sump:	An excavation for the purpose of catching or storing water. The bottom of a shaft is commonly used for this purpose.
Tailings vein:	Waste material from a mineral-processingmill. An opening, fissure or crack in rock containing mineralized material.

SUMMARY

This document deals with the four most common non-ferrous metal ores i.e. copper, nickel, lead, zinc - frequently referred to as base metal ores, and with gold ore as well, the mining and production of which continue to be essential to our society.

While the development of a mining project necessarily modifies the local natural environment, technology and control procedures are often available to limit these impacts to acceptable levels. Old existing mines and those which have been closed may present difficult environmental control problems.

Many of the environmental, safety and health issues related to non-ferrous metal mining do not differ significantly from those created by other parts of the mineral being exploited. The specificity of non-ferrous operations results from the compositional nature of the ore, the benefication process reagents and the potential toxicity of the metal and its compounds extracted. Underground mines require particular measures in the area of health and safety.

Potential contaminants and their impacts

Potential sources of water contaminants include drainage from surface and underground mines, wastewater from beneficiation, and surface run-off.

The volume and the chemical composition of potentially contaminated waters varies widely, depending on the type of mining operations, hydrology of the mine, nature of the ore, beneficiation process, concentration, tailings disposal method, and site location. Potential contaminants include acids and dissolved metals, such as copper, iron, zinc, cadmium and lead resulting from acid mine drainage. Acid mine drainage may be defined as the inorganic chemical water pollution resulting from the oxidation of sulphide-containing minerals. Acid mine drainage may affect underground, as well as surface mine water, drainage from waste rock stock piles and concentrator tailings deposits. It can occur while the mine is in operation and after the closure of the mine. In the latter case, the control of water pollution is frequently more difficult to ensure. Cyanide and mercury contained in gold treatment effluents may be of concern and often require specific treatment facilities.

Special care is needed for cyanide transportation and storage operations; the development of an emergency plan is recommended to prevent excessive environmental damage in case of spillage. Other potential contaminants, such as ore treatment reagents in effluents, dust and gases also have to be considered, especially as far as the working environment is concerned.

Water pollutants mainly affect aquatic flora and fauna as well as deteriorating drinking water; they may enter the food chain by accumulating in fish tissue and consequently affect animal and human life. The toxicity of water contaminants depends on the nature and the concentration of the elements dissolved in water and the occurrence of factors which limit the bioavailability of metals, alkalinity, hardness, etc. Sedimentation of rivers due to excessive salt discharge can also be a serious problem.

Dust elements in suspension in the air and gaseous pollutants are of concern mainly to mine workers' health. Fall-out of particles may contaminate soils, vegetation and water. Other potential impacts of mining on the environment such as the effects of noise, vibrations due to blasting and the use of machinery, the impact of large open-pit excavations and the socio-economic effects of mining have also to be considered.

Control technology

The control of environmental impacts must be an integral part of the operation. Proper planning will limit the risk of environmental damage.

While there are many different methods for controlling the various sources of contamination, it should be borne in mind that no general rule regarding their applicability exists. In each specific case, the constraints imposed by site and process conditions limit the technologically and economically feasible options that can be chosen.

The main techniques for water control include the physical control of volume and routes of water at the mine site and, when necessary, wastewater treatment. Some treatments, such as pH adjustment, heavy metal precipitation or cyanide destruction are frequently carried out in tailings disposal. Such a possibility no longer exists once a mine is closed. If acid mine drainage occurs, the installation of a water treatment plant may be required if passive techniques for dealing with the problem are not effective.

Particulate and gaseous contaminants arise from point sources such as loading points, or chutes in haulage systems, and from more general sources, such as roadways and stockpiles. The control of dust emission from point sources can be achieved by preventing its formation, usually by wetting the ore. The use of water sprays can be effective in preventing dust emission from dispersed sources. After mining has ceased, revegetation is usually the most effective way to control dust emissions and to make the land available for further use.

Environmental concerns of waste rock piles and tailings impoundments include deposit stability, solid transportation and dissolved metal in run-off water, as well as dust emissions and visual impact.

The lack of stability of tailings deposits in some places has resulted in environmental disasters. Geotechnical methods to build rock piles and tailings dams which guarantee an acceptable stability are now available.

Basic techniques to control noise include reducing the noise energy generated at source, isolating the source by enclosure of fixed equipment and absorbing the noise between the source and the listener.

Blasting operations may create overpressures in cases of open-pit mining and ground vibrations resulting in damage to buildings in the vicinity. Controls available to the mine operators to minimize these nuisances consist mainly in avoiding overcharging and designing proper blasting patterns.

Working environment

The main occupational health hazards in the base metal mining industry are related to airborne contaminants, noise and vibration. The thermal environment, lack of illumination, handling of chemicals and biological contaminants are also of concern in some cases.

Base metal ores may contain elements such as lead, nickel, cadmium, mercury or arsenic which can be toxic in certain chemical forms. The potential toxicity of metals contained in ore and gangue material dust has to be carefully investigated in each case.

The major potential hazard arising from airborne particles is fine crystalline silica, the inhalation of which may lead to silicosis.

Carbon monoxide and nitrogen oxides are usually present in exhaust released by diesel engines. Blasting fumes have to be carefully monitored. The most important element of air quality control in an underground mine is a properly designed ventilation system which achieves a significant dilution of airborne dust and gases. If airborne contaminants cannot be reduced to acceptable levels, anti-dust masks or respirators will have to be used.

In addition to some airborne contaminants such as dusts, some toxic chemicals are used in beneficiation plants. Special care must be taken when handling these products.

Workers in underground and open-pit mines are often exposed to high noise levels emitted by machinery. In addition to improvements to the design of mine machinery, efficient personal noise protection of workers is necessary.

In order to determine the extent of occupational exposure, a routine monitoring program including air and particle sampling analysis, noise, air temperature and humidity measurements should be established in each case.

Regular monitoring of workers' health parameters including biological monitoring, medical surveillance, pre-employment and periodical examinations, should enable early detection of health impairments caused by occupational exposure, but it does not replace control measures.

Safety and accident prevention is essential at any installation. In many countries, safety and workers' health protection regulations constitute a Mineral Industry Safety Code which applies to the whole mining industry. They are established by a group of experts composed of government and mining industry representatives. In each operation, specific internal work rules may be added to the Mineral Industry Safety Code; they should be established by the mining company and appropriate government agencies in consultation with workers' representatives.

Within each operation a Health and Safety Committee should be created to complement the action of personnel representatives who are responsible for safety and hygiene.

Environmental regulations, management systems

Mining operations should be subject to governmental regulations that relate, among other things, to safety and workers' health protection, and to environmental protection. Where environmental standards and regulations do not exist, or are inadequate, they should be either esbablished nationally or on a site-specific basis. When the latter is chosen, they should be based on an Environmental Impact Assessment; regulations relevant to one mining site may not necessarily be appropriate in another location.

The evaluation of the impacts - environmental, social and economic - of a new mine development can be carried out through an Environmental Impact Assessment. While this should as far as possible be based on sound scientific evidence, it should also be recognized that sound and prudent judgement may have to be exercised where background data are incomplete, inaccurate or non-existent. Environmental standards relating to air, water, waste and noise exist in many countries. Such standards are based on the ability of the environment to assimilate without undue harm the impact of pollutants and wastes. They may also stipulate mine closure and after-care requirements. The development of environ-mental standards usually also takes into consideration the availability of control technology and to the economic impact of control measures.

Close co-operation between the standard-setting authorities and the mining industry will be helpful in developing requirements that are both effective and practical. In many countries public involvement in the standard-setting process is common.

Environmental standards should take into account the available technology as well as the economic constraints of the specific mining industry or project. Environmental and economic trade-offs should be clearly identified for discussion and public input.

Critical parameters regarding pollution and the industrial environment during all stages of the mine life and after closure have to be monitored as appropriate.

The effective protection of the environment requires the co-operation of everyone, from top management to workers. In large mining operations, a special department should be in charge of environ-mental concerns; in smaller operations, this task should be assured by the different plant superintendents under the General Manager's supervision.

Regular training should be provided to inform and create awareness to the whole workforce on environmental and health and safety issues related to their jobs. Training sessions may be organized by the mining company or by experienced consulting groups.

A community awareness programme should be established to inform the nearby communities of the potential environmental health hazards posed by the mine, and of the programmes undertaken by the company to minimize them.

1. GENERAL BACKGROUND

1.1. Historical

Gold and copper were probably the first metals ever used by man: gold is found in nature in its native form and vestiges of copper metallurgy dating back to about 6300 years B.C. have been found in Turkey (actually as a bronze alloy). The use of lead is almost as old: its extraction by roasting and smelting was known in 5000 B.C.

Zinc, as a brass alloy, was in use during antiquity, near 4000 B.C. Its use as a pure metal is more recent and was achieved in the 19th century.

Nickel, however, is a "young" metal, identified as a specific element in 1790 and for which a metallurgic extraction process has developed only since 1850.

With the exception of nickel, therefore, base metal mining is not recent : only the development of industrialization made their production quantitatively significant. These metals and their compounds are used in many domains: electric cables, batteries, stainless steels, anti-corrosion coatings, whereas gold keeps its role as monetary standard and reserve.

1.2. Production

Mineral production for 1988 is given in terms of contained metal, by Table 1.

Over the last ten years, probably in relation to a major economic crisis, the mineral production expansion rate was low, and was even negative in the case of lead; only gold exhibited a marked growth rate.

Metal	Growth rate per annum
Copper	0.8 %
Nickel	0.4 %
Lead	- 0.7%
Zinc	0.8 %
Gold	2.8 %

Africa, Asia and the Americas (except Canada and the US) produce a major proportion of the mineral output: about 50% of copper and 30% for the other base metals.

Table 1

World Mine Output of Selected Non-Ferrous Metals (1988)

Area	Copper	Nickel	Lead	Zinc	Gold
	1000 metric tonnes				tonnes
Africa	1218	69	194	273	657
Canada + USA	2141	203	760	1604	329
Other America	2068	103	416	1073	149
Asia	1028	99	516	1111	131
Europe (+USSR)	1849	246	1064	2278	306
Oceania	452	129	466	759	201
Total	8756	849	3416	7098	1773

Source : Minemet Yearbook, France (2)

1.3. Metallic Ores

Mineralogic composition

Unlike gold, base metals are seldom found as native elemental metals, but rather as compounds of other elements in metallic ores. Table 2a indicates the major mineralogic species of copper, nickel, lead and zinc ores, as well as their relative abundances. As a general rule (except for nickel), base metals mainly occur as sulphides, whereas oxidized ores play only a minor role. Nickel is the only noticeable exception with a proportion of 60-40% for sulfide and lateritic ores respectively.

Gold occurs as three mineralogic species: native gold, tellurides, and electrum (a natural gold-silver alloy). A classification of gold ores with respect to mineralogic criteria would, however, have little economic significance: the classification presented in Table 2b is based on mineral associations observed in the most common ores, and the economic importance of the various ore types is more or less identical, the tellurides being the less frequent.

Association with other elements

A non-ferrous metal compound is rarely found alone in its ores but generally occurs in association with other metals.

The most common associations are:

- lead-zinc;
- lead-zinc-copper;
- lead-silver;
- zinc-cadmium;
- copper-molybdenum;
- copper-gold;
- nickel-copper (sulphide ores);
- nickel-cobalt (laterites).

Gangue minerals

The grade at which a metal is present in ore is usually fairly low, in the range of a few percentage points for base metals, a few grammes per tonne in the case of gold. The largest portion of the ore is composed of unwanted soil and rock, commonly called gangue. The most frequent gangue minerals are silica, silicates, carbonates and pyrite; less frequent are fluorite and barite.

Concerning the impact of base metal mining on the environment, an important case is that of sulphide ores in which iron sulphides such as pyrite and pyrrhotite may represent a large portion, if not the largest, of the gangue. Such harmful suphides are the essential cause of acid mine drainage (cf. Section 5).

The impact of a mining operation on the environment, therefore, depends on the composition of the ore. A precise knowledge of the mineralogic and petrographic nature of the ore is necessary in order to appreciate this impact, and thereby undertake appropriate measures to minimize it.

Table 2a
Cu, Ni, Pb and Zn Ore Minerals

Metals	Sulphides			Oxidized Minerals
Copper	***	chalcopyrite	$CuFeS_2$	** malachite $Cu_2(OH)_2\ CO_3$
	**	bornite	Cu_5FeS_4	* azurite Cu_2O
	**	chalcosite	CuS	* cuprite $Cu_3(OH)_2\ (CO_3)_2$
	*	tetrahedrite	$(Cu, Fe, Zn, Ag)_{12}$ $(Sb, As)_4S_{13}$	
Nickel	***	pentlandite	$(Fe, Ni)_9S_8$	** garnierite $3SiO_2, 4(Mg,Ni)O, 6H_2O$
	**	millerite	NiS	***laterite nickel ores
Lead	***	galena	PbS	** cerussite $PbCO_3$
				* anglesite $PbSO_4$
				* pyromorphite $Pb_5,(PO_4,AsO_4)_3Cl$
Zinc	***	sphalerite	ZnS	** smithsonite $ZnCO_3$
				* calamine $SiO_2, 2\ ZnO, H_2O$
				* zincite ZnO
				* willemnite $ZnSiO_4$
				* franklinite $(Fe,Mn, Zn)O\ (Fe,Mn)_2O_3$

*** most important ** occasional ore * rare

Sources: (3), (4), (5), (6), (7)

Table 2b
Gold Ores

1) free gold ores
2) gold with iron sulphides
3) gold with arsenic and/or antimony minerals (arsenopyrite, etc...)
4) gold tellurides
5) gold with copper porphyres
6) gold with lead and zinc minerals
7) carbonaceous ores

1.4. The Case of Base Metal Mining

Base metal ores represent only 15 percent of all tonnages of minerals extracted annually by the world mining industry. In many respects, the potential environmental problems related to base metal mining do not differ, as far as the physical environment is concerned, from those created by the other segments of the mining industry. Many of these problems exist regardless of the nature of the mineral being exploited (coal, iron ore ...). This is, for instance, the case for dust emissions, waste disposals, noise nuisances, explosives handling, etc. Very often, the measures or remedies implemented in the mining of other commodities can be applied in non-ferrous metal operations. The experience in this area therefore serves as a reliable reference, and the abundance of environment-related publications in that sector of the mining industry, as a result of the much larger tonnages extracted, makes these documents potentially very useful.

In fact, the specifics of non-ferrous operations result essentially from the potential toxicity of the metal extracted, the chemical composition of the ore, and the nature of extraction processes.

2. GENERAL PROCESS DESCRIPTION

The purpose of this section is to give a general description of the main mining and ore processing methods used in the base metal mining industry, in order to evaluate their potential impact on the environment.

More detailed information can be found in specialized literature, handbooks, etc., references of which are given in the bibliography.

2.1. Exploration

Exploration of an area previously selected by geological consideration usually encompasses, the following operations:

- preliminary surveys of remote sensing using rising aerial photography and satellite imagery so as to identify major features of geological and environmental interest, and to provide baseline data for environmental assessment and planning.
- detailed geologic mapping of the area, including hand picking of some surface samples for assaying and mineralogic characterization. In gold prospecting, samples may be collected in river beds and concentrated by panning.
- geochemical surveys: the sampling may take place in stream sediments, soils or on rock chips. Small samples are collected, a few grammes each, on predetermined or systematic locations; the conduct of a geochemical survey in forested terrain may require some line-cutting.
- geophysical surveys: the methods most commonly used are the electrical or electromagnetic methods (measurement of electrical characteristics of the ground) and magnetic methods (measurement of anomalies of the earth magnetic field). The surveys may be carried out on the ground with portable instruments, or from the air in airplanes or helicopters.
- trenching and shaft sinking intended to investigate the near surface formations. Shafts, 1 to 2 sq. meters in area, may be sunk to depths of about 10 meters, by pick and shovel, or power backhoes, or motor augers. Trenches, 20 to 30 meters long can also be excavated by pick and shovel (1 to 2 meters wide) or dozed (4 to 5 meters wide). Usually, only a few trenches are excavated in the area of interest, in order to avoid damaging the environment through excessive earth displacement.
- drilling: if warranted by the results of the previous steps, drilling is conducted to confirm the extension of mineralized bodies at depth. Drilling methods include percussion or rotary drilling (air or mud being used as a drilling fluid), which produce rock cuttings from the grinding of the rocks by the drilling bit or core drilling in which subsurface samples are collected as cores for studies and tests.

Drilling equipment may be either independent (Figure 1) or truck-mounted. Frequently, the construction of a road is necessary to permit access to the drilling site. Most of the time, water is recycled.

The drill crew is typically housed in temporary accommodation.

This first work phase is concluded by a technico-economic evaluation which establishes the opportunity of pursuing exploration efforts on the project. If a positive decision is reached, a new phase of work is entered into, which will lead to a feasibility study; it may include underground mining work: shafts, declines, drifts, etc. in order to improve the knowledge of the orebody, define more precisely the reserves and collect larger ore samples on which a treatment process will be developed. The amount of work required may vary from case to case.

Whilst the potential impact of any mining activity on the area will have been previously considered, it will now be necessary to undertake a complete Environmental Impact Study. This study will consider how any development of mines and infrastructure will effect the local population, local land use and overall ecology. Changes to water and land contours, the disposal of gangue mine waste and tailings, together with the export of concentrate will all have to be evaluated.

Simultaneous to these technical tasks, administrative tasks such as application for exploration permits, mining licenses, land purchases, etc. will be undertaken.

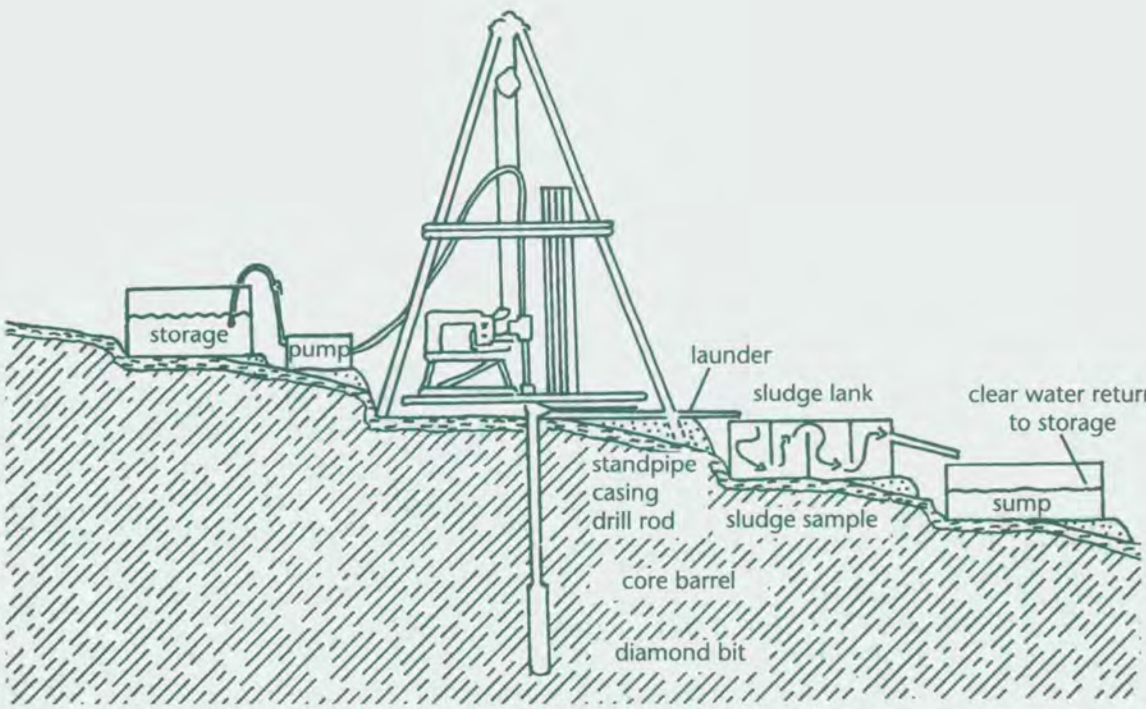


Figure 1 Diamond drilling, collection of sludge samples

Source: USDA, 1983

2.2. Project Development

Once administrative formalities have been completed and the financing arranged, the project development may be initiated. It comprises the following steps:

- detailed engineering of the mining project, of the treatment plant and of the utilities;
- mine development:
    - overburden stripping in the case of an open pit-operation.
    - construction of underground infrastructure to give access to the ore (shaft, ramps, drifts, haulage levels ...), followed by stope preparation.
    - erection of the treatment plant.
    - construction of the surface amenities (workshops, warehouses, laboratory, offices, social facilities, etc.
    - preparation of the mine waste and plant effluent disposal methods.
    - construction of access and service roads, or railway spurs, etc.
    - utilization of a power supply from an existing network or by erection of a power plant.
    - development of a water system to supply water for the mine and the treatment plant. Water can be supplied from the mine exhaust, from water wells, by diversion of a creek, erection of a storage dam, etc.
    - preparation of the social infrastructure: first-aid, change room plus, as the case may be, catering, housing, recreation.

2.3. Mine Operation

2.3.1. Introduction

Depending on the shape and the location of the orebody, mining may be conducted underground or by surface mining. In the latter case, the operation will consist in excavating an open pit. Gold placer mining operations are a special case where near-surface or poorly consolidated sediments of glacial or alluvial origin constitute the ore. All other operations consist of the following steps: ore breaking, loading, then extracting or hauling toward a stockyard from which it is reclaimed for treatment or concentration in the plant.

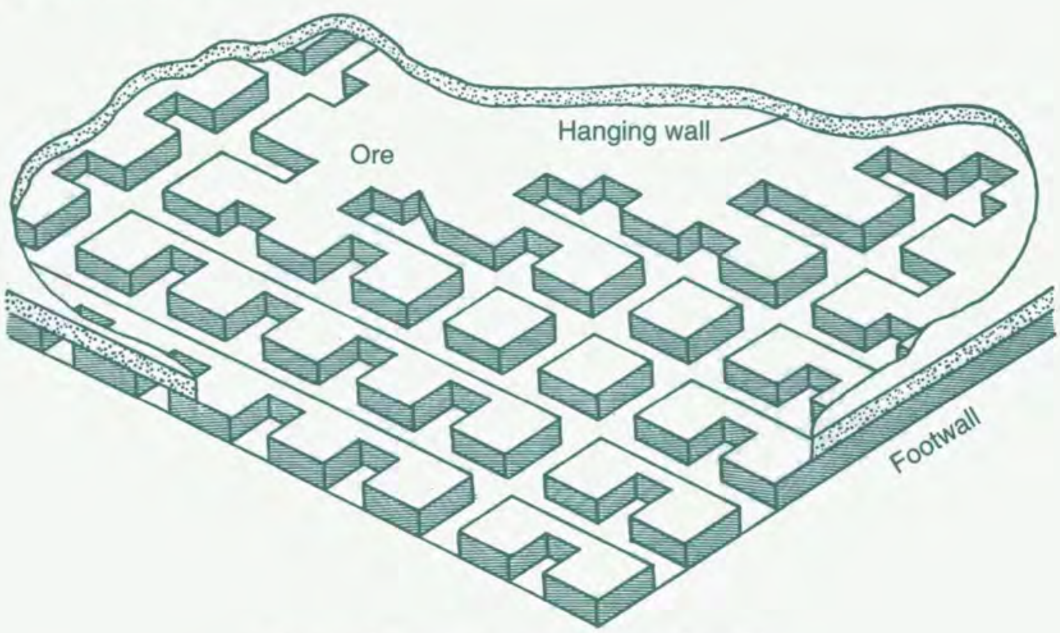


Figure 2 Open stope with regular pillars

Source: (9)

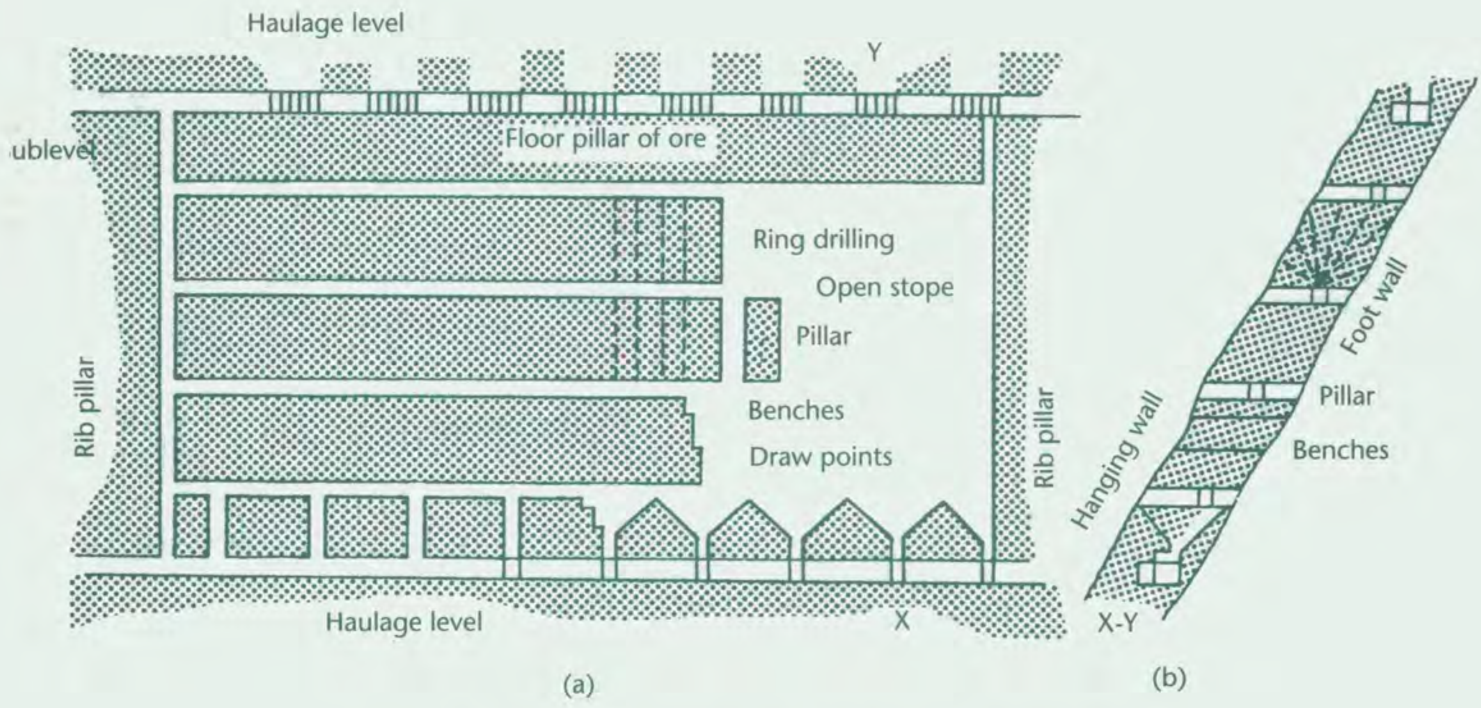


Figure 3 Sub-level stoping longitudinal stopes in narrow veins

Source: (9)

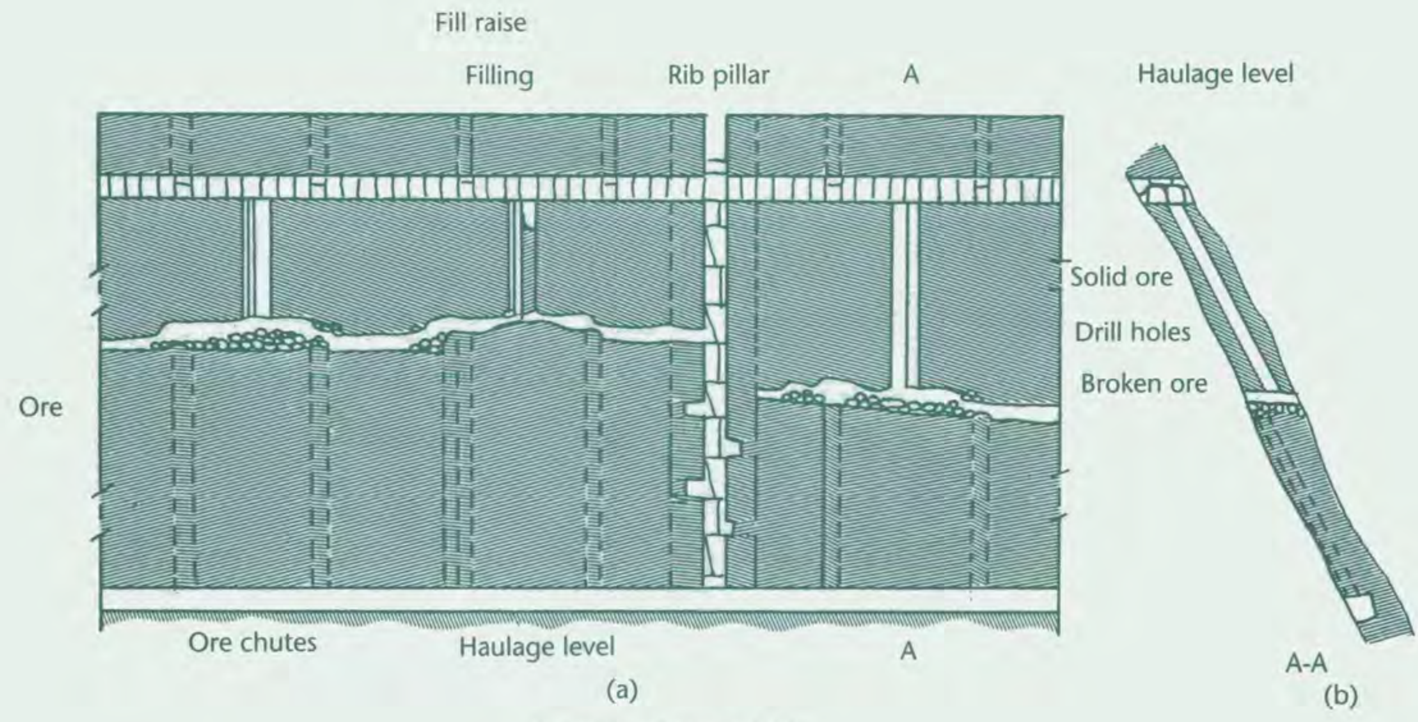


Figure 4 Cut-and-fill

Source: (9)

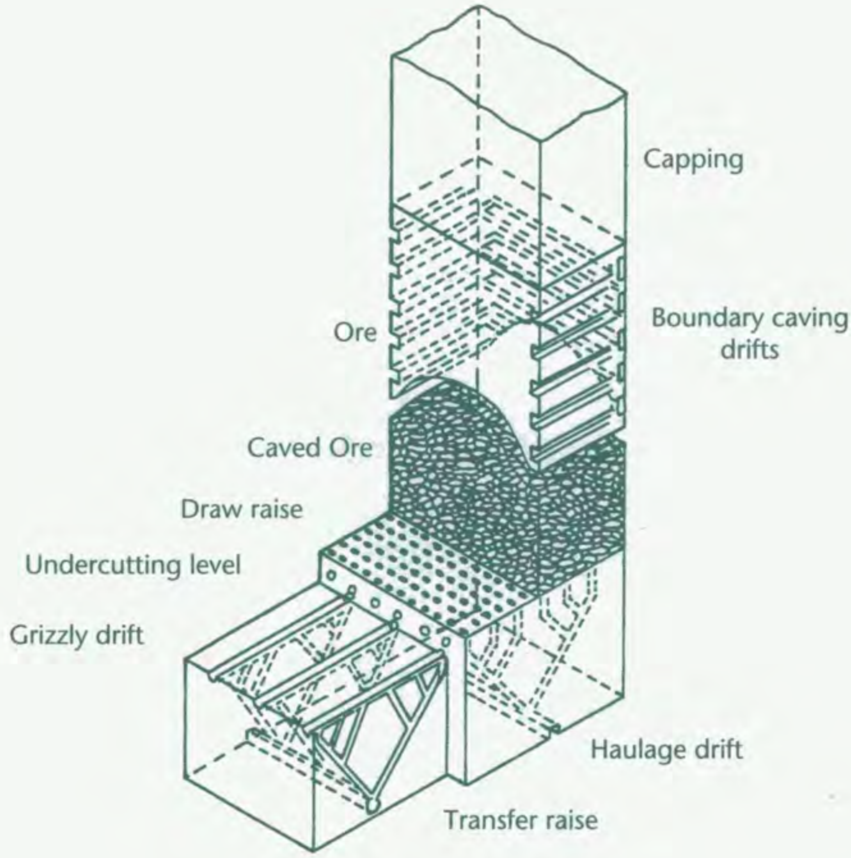


Figure 5 Block caving

Source: (9)

In non-ferrous mines, ore breaking is usually achieved by either of two means :

- in hard rock, by blasting, using explosives loaded in holes drilled by rotary or percussion drills. The most common of the blasting agents are ANFO (Ammonium Nitrate + Fuel Oil), water gels and nitro-glycerine based explosives;
- in softer materials, directly by heavy-duty equipment such as shovels, loaders, ripper-dozers, draglines, scrapers, etc.

2.3.2. Underground mining

The selection of an underground mining method is based on the characteristics of the deposit: size and dimensions, distribution of the ore within it, mechanical characteristics of the ore and the surrounding host rocks, economic profitability criteria, etc.

Table 3
Underground Mining Methods

I. Self-Supporting Opening	II. Supported Openings	III. Caving Methods
A. Open-stope mining	A. Cut-and-fill stoping	A. Sub-level caving
1. Isolated openings	B. Square-set-and-fill stoping	B. Block and panel caving
2. Pillared open stopes	C. Longwall mining	
a. Open stoping with random pillars	D. Shortwall mining	
b. Open stoping with regular pillars	E. Top slicing	
B. Room-and-pillar mining		
C. Sub-level stoping		
D. Shrinkage stoping		
E. Stull stoping		

Source: (9)

Figures 2 to 5 depict the most commonly used of these methods:

After blasting, ore is reclaimed by mechanical equipment such as loaders, scrapers, scooptrams, etc. and directed towards the main haulage level by underground trucks, rail cars or belt conveyors, through ore passes or chutes.

From the haulage level to the surface, ore is transported (extraction) by techniques that depend on the general mine infrastructure:

- in mines with declines or adits, by trucks or conveyors;
- in mines with shafts, by extraction machines composed of a hoist, skip and towers.

Some of the mining methods require that the mine stopes are backfilled after mucking. The backfill material may consist in mine wastes (barren rock), or borrow material (from an outside quarry for instance), or refuse from the treatment plant (tailings). It is transported to the stopes, depending on the case, by truck, pipes, or dumped from the surface through special bores.

A ventilation system is necessary in order to provide fresh air in the working stopes, to extract the fumes emitted by blasting and diesel engines and even to cool the deeper mines where the increase in temperature would make the working conditions unbearable for the workers. In some cases, the geometry of the mine infrastructure is such that a natural ventilation is achieved, but generally, a specific air circuit must be designed with fans (on the surface or underground), based on ducts and special shafts.

Because mines are frequently located below the natural water table, water seeping into the mine must be controlled and directed first toward pumping stations, then to the surface.

The mines generally include all facilities that are necessary to mining operations: power house, change rooms, a restaurant, etc.

2.3.3. Surface mining

Near surface deposits are mostly exploited by open-pit methods and the maximum depth reached depends on the geometry of the orebody and the cost of overburden and waste removal. Figure 6 is a schematic illustration of an open-pit.

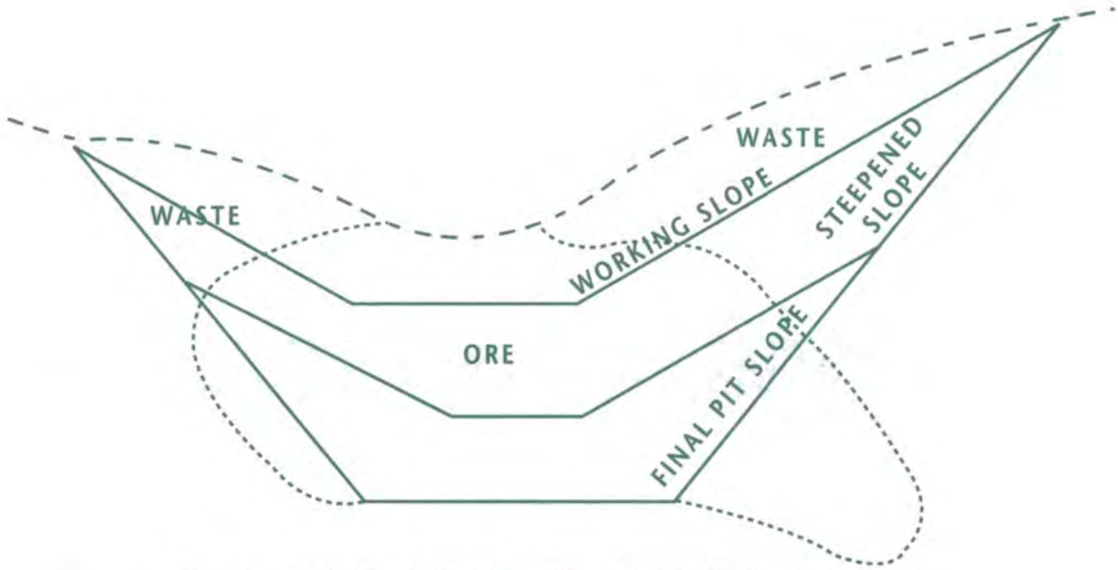


Figure 6 Relationship of working slopes to final pit slopes

Source: USDA, 1983

Mining steps or operations are:

- the removal of overburden materials to waste disposal areas, ore blasting, loading and hauling to the processing plant.

Mining and loading equipment includes hydraulic shovels, backhoe, front-end loaders, draglines. Haulage is by dumpers, conveyors, trains, even cable cars when necessary.

Frequently, the pit bottom must be pumped out to remove the water resulting from the rainfall or natural seepage.

2.3.4. Placer mining

Placer deposits consist of heavy minerals in non-consolidated detrital materials. We shall deal only with gold placer deposits, although other minerals are found in similar deposits (diamond, tin, columbo-tantalite, monazite, etc.) The main mining methods are:

(a) Land-based plant:
- bucket scraper and wire-line;
- mobile power equipment such as dozers, draglines, shovels and trucks, small bucketwheel excavators and trucks;
- hydraulic mining, which consists in loosening in-situ material by high pressure water.

(b) Floating plant:
- dragline and washing plant;
- hydraulic dredging;
- bucket line dredging.

On a commercial scale, the main method used to extract gold from placer deposit materials consists of a primary gravimetric concentration by a riffled sluice or a jig, followed by mercury amalgamation or gravimetric cleaning of the pre-concentrate.

2.3.5. Small-scale mining

Small-scale mining in this report refers to artisanal gold mining operations often undertaken by a few workers as individuals or in co-operatives. In several parts of South America, Equatorial Africa and in South-East Asia, hundreds of thousands of workers recover gold by hand panning and other basic extraction methods. In some countries, such a practice is encouraged by the government (10), elsewhere, however, it is not regulated or is carried out illegally. The environmental consequences of small-scale gold mining are treated in Chapter 9.

2.4 Beneficiation

Non-ferrous metals ores are usually processed on the mine site to produce marketable concentrates or a bullion in the case of gold, except for lateritic nickel ores which are directly fed to a smelter or an hydrometallurgical plant producing a metal or a matte.

The most common beneficiating processes in use are:

<table>
<tr><th>Metal</th><th>Sulphide Ore</th><th>Oxide Ore</th></tr>
<tr><td>Copper</td><td>G, F</td><td>G, F, L</td></tr>
<tr><td>Nickel</td><td>F, M</td><td>-</td></tr>
<tr><td>Lead</td><td>G, F</td><td>G, F</td></tr>
<tr><td>Zinc</td><td>G, F</td><td>G, F</td></tr>
<tr><td>Gold</td><td colspan="2">G, F, L</td></tr>
</table>

Physical process
G: Gravity
F: Flotation
M: Magnetic separation

Chemical process
L: Leaching

Physical processes are not effective if the marketable mineral species in the ore cannot be liberated from the undesirable material (gangue). Liberation requires a size reduction operation, called comminution, before the beneficiation process can take place. It should be noted that, very often, it is also the case in leaching processes.

2.4.1. Comminution

The liberation size of sulphide minerals is usually less than 100 microns, while particle size distribution of a run-of-mine ore ranges from a few microns to several hundred millimeters. Two main types of flowsheets are operated presently to reduce the particle size of an ore to the required dimension.

(a) Crushing-grinding

Size reduction of ore particles to about 10 mm is conducted on dry solids in a crushing plant which comprises a primary crusher - jaw crusher or gyratory crusher in large capacity operations - followed by one or two stages of secondary giratory crushers. At each stage, vibrating screens extract material with the desired dimension.

Subsequent size reduction of the crushed material is achieved by grinding, in rod mills and/or ball mills, after addition of water to the ore.

(b) Autogenous grinding

After primary crushing, the run-of-mine ore is directly fed as a slurry to an autogenous (or semi autogenous) grinding mill. Fine grinding is achieved in pebble-mills or conventional ball-mills.

(c) Classification

Depending on the final required grain size and on the capacity of the processing plant, up to three grinding stages can be used. Classifiers, including rake classifiers, spiral classifiers or, more often, hydrocyclones are installed in each grinding stage to remove and direct to the process the ore grains having the specified final dimensions.

2.4.2. Flotation

Flotation is the most widely used method of beneficiating base metals sulphide and oxides ores (except nickel oxide ores). It is also implemented to process ores in which gold is associated with sulphides. Flotation is a complex physico-chemical process taking place in an ore pulped with water, by which the surfaces of one or more minerals in the finely ground pulp are made water-repellent and responsive to attachment with air bubbles. Minerals are caused either to float or to sink by the judicious use of chemicals (or flotation reagents) mixed with the ore pulp.

Flotation separation takes place in a series of agitated cells or in columns, both of which have systems for air dispersion. Often, several stages of flotation are employed to obtain the desired concentration.

Marketable concentrates are dewatered in thickeners and filters. Figure 7 gives an example of a Pb-Zn flotation concentrator. Wastes are directed through ditches, launders or pipe systems to disposal ponds where water is recovered by decantation before recycling to the processing plant or released into the environment.

2.4.3. Gravity separation

Gravity concentration is a method implemented to separate solids of different specific gravities in a fluid medium, such as water or a suspension of magnetic and/or ferrosilicon in water.

This process when applied to non-ferrous metal ores is, in most cases, used as a pre-concentration step to discard from crushed ore a significant tonnage of material before the ore undergoes the more costly processes of grinding and flotation. In such a case, gravity concentration takes place usually in rotating drums or in cyclones after the ore has been mixed with the appropriate fluid medium.

Free gold ore is recovered by numerous gravity concentration devices using water as a medium, from hand pans to spirals, jigs, shaking tables, blanket tables, Johnson concentrators, etc.

2.4.4. Other physical processes

Besides flotation and gravity concentration which are the most frequently used physical beneficiation processes, one may also mention:

- Magnetic separation, used to separate pyrrothite from nickel sulphide ores;
- Electrical sorting, used to reconcentrate sulphide ores.

2.4.5. Leaching

(a) Copper ores:

Sulphuric acid leaching and chloride extraction are used to beneficiate copper oxide and very low grade sulphide ores.

Leaching may take place in vats, in heaps or dumps. Copper is recovered from pregnant solution by concentration on iron scraps or by solvent extraction.

(b) Gold ore cyanidation:

The solubility of gold in a diluted aqueous solution of alkaline cyanide is the basis of an important method of beneficiating gold ores. It can be appreciated from Table 4 that cyanidation may be applied to many gold ores types.

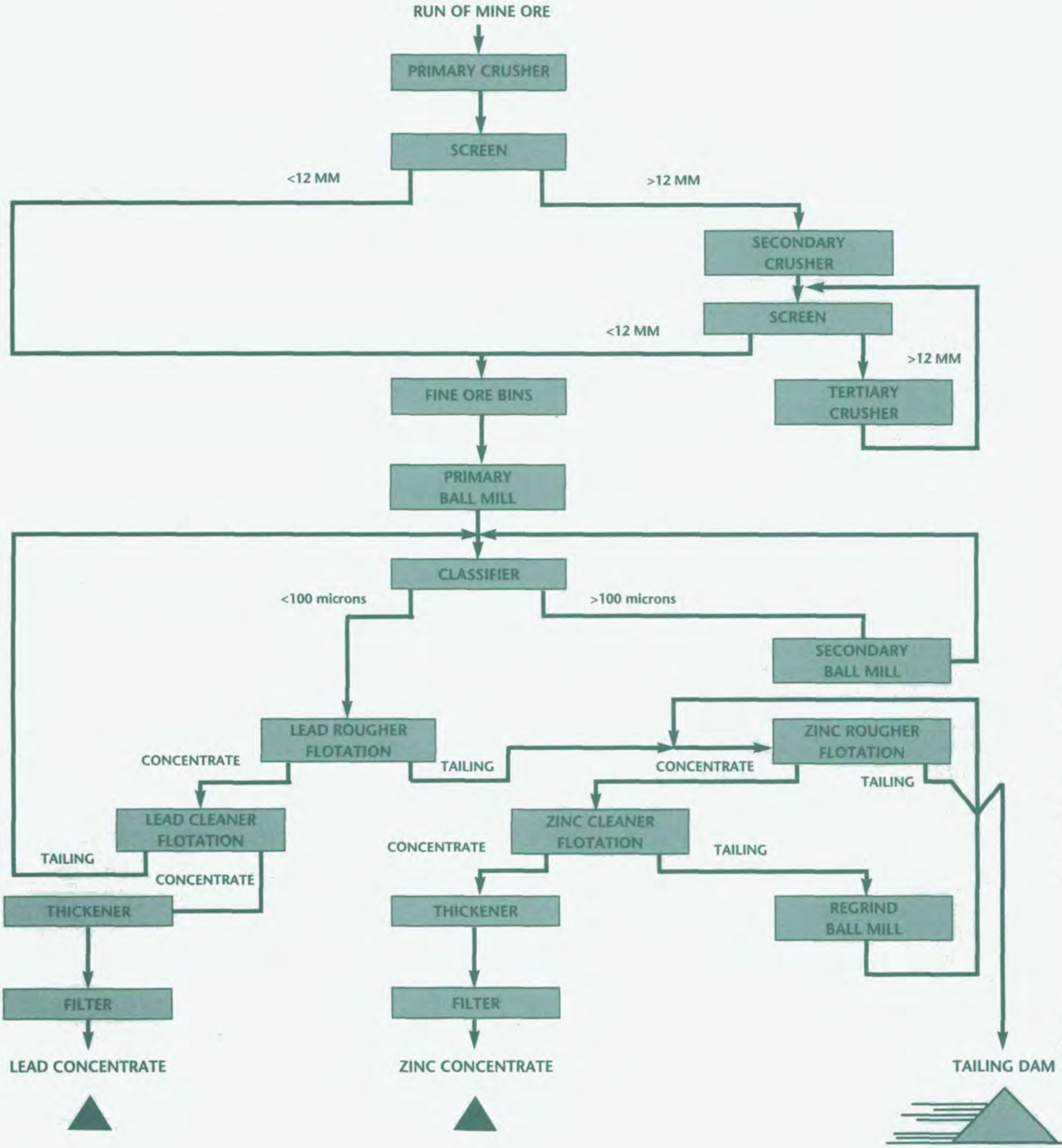


Figure 7 Typical Pb - Zn Concentrator flow sheet

Table 4

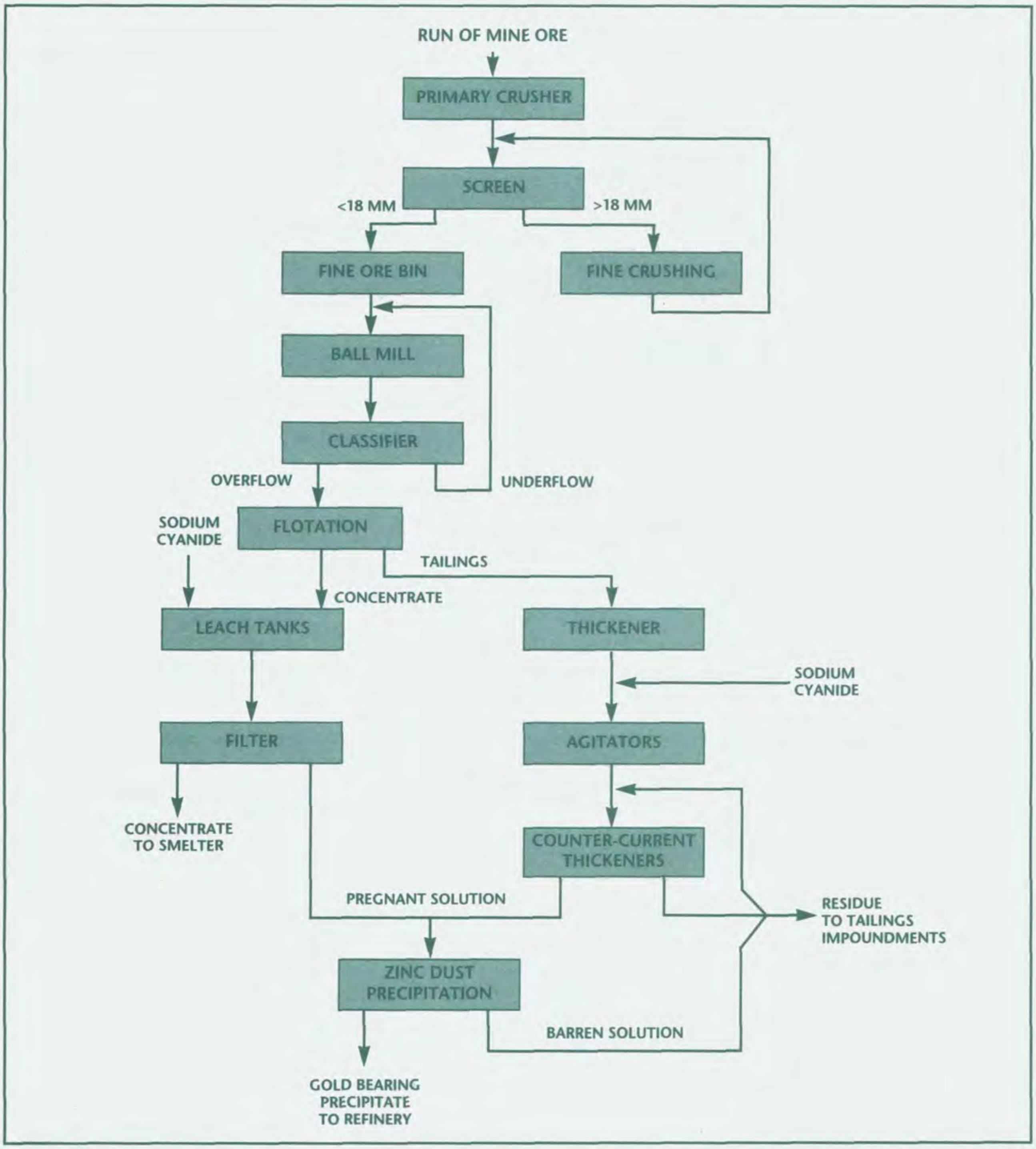
Summary of Gold Ore Processing Methods

Mineral Occurrence	Treatment Method
Alluvial gold	1. Gravity concentration 2. Amalgamation
Free milling lode ores	1. Gravity concentration 2. Amalgamation 3. Direct cyanidation, activated carbon in pulp
Free milling sedimentary ores	1. Direct cyanidation 2. Treatment of refractory carbon, direct cyanidation
Gold tellurides	1. Bulk flotation-roasting cyanidation 2. Direct cyanidation-SO_2 roasting of concentrates cyanidation 3. Flotation-cyanidation of concentrate-roasting of residue-recyaniding 4. Direct cyanidation with added bromo-cyanide
Gold with pyrite and marcasite	1. Flotation-smelting of concentrates 2. Flotation-cyanidation of concentrates
Gold with pyrrhotite	1. Direct cyanidation with pre-aeration at low lime alkalinity 2. Direct cyanidation-flotation of cyanide tailings-regrind and recyanide flotation concentrate or roast and recyanide.
Gold with arsenopyrite	1. Direct cyanidation 2. Flotation-roasting of concentrates 3. Roasting ore-washing-cyanidation 4. Autoclaving 5. Nitric acid oxidation
Gold with copper ores	1. Flotation-smelting of concentrates-recovery during electrolytic refining 2. Flotation-cyanidation of molybdenum
Gold in refractory	1. Roasting-cyanidation carbonaceous ores 2. Chlorination of ore-cyanidation 3. Flotation of graphitic material-cyanidation of tailings
Gold with lead-zinc ores	1. Flotation-smelting of concentrates 2. Jigging-amalgamation-retorting

Source: (11)

Cyanidation may take place in different ways:

- leaching of run-of-mine or crushed ore;
- vat leaching;
- leaching of ground ore, flotation concentrates, etc. in agitated tanks. Gold concentrators may combine flotation and cyanidation (Figure 8).



Source: (13)

Figure 8 Gold concentrator flowsheet (Hecla Mining Co.)

Gold is recovered from pregnant solutions by precipitation on Zinc powder (Merrill-Crowe process) and subsequent direct melting of the precipitate. More recently, activated carbon has come into wide-spread use to recover gold dissolved by cyanide in ore pulps (carbon-in-pulp process) or in clear pregnant solutions (carbon-in-column process) as indicated Figure 9.

Gold is desorbed from carbon with a dilute alkali solution and deposited by electrolysis on an iron sponge which is then melted and the gold is separated and poured as a crude bullion or Dore. The tailings of cyanidation plants are typically deposited into an impoundment where the solids settle, and the solution is decanted and recycled to the plant. In those instances when it is necessary to discharge the solution (e.g., locations with a net precipitation gain), the solution may be diluted or de-toxified by one of several methods prior to discharge (see Section 7.2.4.2.).

Further information about gold and base metals ores beneficiation is available in (8), (11), (12), (14).

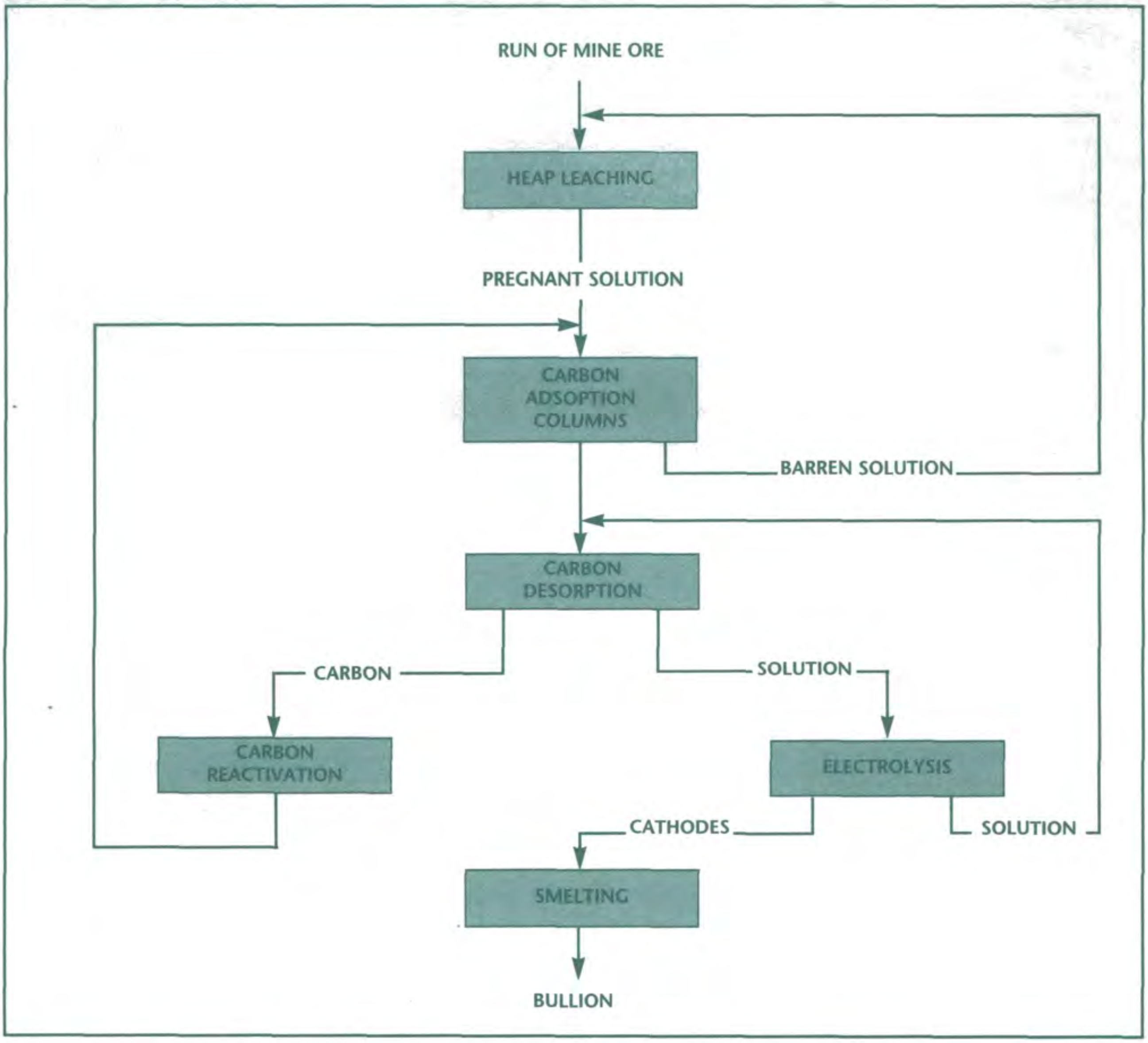


Figure 9 Ortiz gold mine - Gold recovery flowsheet

Source: E and MJ, Sept. 1983

2.5. Transportation and Handling

Run of mine ore surface haulage methods are described in Section 2.3.3.

Usually, storage facilities are installed ahead of the concentrator. They include:

- bins (circular, rectangular);
- stockpiles (conical, rectangular, kidney-shaped, ramped).

Bin material is extracted with apron feeders, vibrating pans, belt feeders, etc.

Stockpile material may be reclaimed with a below-ground tunnel conveyor or an above ground mobile bucket-wheel reclaimer: shovels, loaders and dozers are also used for smaller stockpiles.

Within the concentrator, drier material is handled with conveyor belts, ore pulps with pumps and pipes.

Usual handling and transportation means for concentrates are summarized below.

Concentrates	Handling	Transportation
Slurry	Pump	Pipeline
Thickened slurry	Pump	Railroad car
Filter cake (10-16% H_2O)*	Conveyor belt Front-end loader	Container truck Sideways dumping truck
	Clamshell bucket (covered)	Open railroad car
		Flat-bottom gondola
	(covered)	
Dried filter cake (<9% H_2O)	Conveyor belt	Bags; Big-Bags; Containers
Bone dry product	Pneumatic handling	Road and rail tankers

** Care must be taken with sulphide concentrates to avoid spontaneous combustion.*

2.6. Mine Closure

Measures to be taken when closing a mine are reviewed in Section 6.

3. POTENTIAL IMPACTS OF MINING ON THE ENVIRONMENT

Potential environmental impacts of mining are summarized in Table 6.

3.1.Potential Contaminants:

Water contaminants may include:

- acids;
- mercury;
- metals as ions or complexes, from copper, lead, zinc, nickel, iron, arsenic, cadmium;
- thiosulphates, polythionates also resulting from acid mine water;
- sodium cyanide for gold recovery;
- process reagents (see Table 5), directed to the various process effluents;
- nitrogen compounds from blasting materials;
- oil and fuel-oil used for engines, power plants, lubrication;
- suspended solids: mine water, surface drainage, and process effluents usually contain suspended solids which may range from colloidal to settleable materials. Such materials may be part of the ore, waste rock or soil surrounding the surface installations.

Contaminants in the atmosphere include:

- dust elements, whose nature is similar to the elements composing suspended solids in liquid effluents;
- gases produced by combustion processes such as blasting, internal combustion engines: carbon monoxide, carbon dioxide, nitrogen oxides, sulphur dioxide;
- natural gas occurrences such as methane, although not frequent in base metal mines;
  Underground atmosphere problems are dealt with in Section 8.
- noise and vibrations produced by blasting, mine equipment, processing plant operations, etc.

Table 5

Typical Ore Processing Reagents

Reagents	Comments
Acids (H_2SO_4, HCl, HNO_3)	-
Alkalis (CaO, $Ca(OH)_2$, $CaCO_3$, Na_2CO_3, NaOH, NH_4OH, NH_3)	
Frothers and Collectors	Surface active organics
Modifiers	Surface active organics and various inorganics such as NaCN, Na_2SO_3, $CuSO_4$, $ZnSO_4$, Na_2S, $AlCl_3$, $Pb(NO_3)_2$, silicates and chromates.
Sodium Cyanide	Used for precious metals cyanidation and as depressant in copper, lead, zinc flotation processes.
Flocculants, Coagulants,	Aluminium and iron salts, and organic polymers.

Source: (15)

3.2. Potential Effects on the Environment

Water pollutants

While damage to human health due to the mining water pollutants is rare, in some places, lethal pollution levels are experienced by aquatic organisms. Many acquatic organisms are more sensitive to pollutants than are humans.

Base metals

Many metals, such as copper and zinc, are necessary to health in small concentrations but are highly toxic when present in excess. Depending upon their form and their concentration, heavy metals can be lethal to fish, prevent reproduction or enter the human chain by accumulating in fish tissue, as for example cadmium and mercury which may occur in zinc sulphide ores. Toxicity may be acute or chronic.

The toxicity of heavy metals in fresh water is not only dependent on metal concentration, but also on other factors such as pH, water hardness, occurrence of other metals and the occurrence of absorption or complexing agents.

For example, toxic levels of copper and zinc for fish are dependent on water hardness:

Water Hardness	Cu	Zn
(mg/l CaCO)	(mg/l)	(mg/l)
10	0.005	0.3
50	0.02	0.7
100	0.04	1
500	0.11	2

Source: EEC Council Directive N° 78 - 659

Acidity

Acidity which may result in an increased concentration of dissolved heavy metals can increase the toxic effects of metals.

However, factors such as the buffering capacity of the receiving stream and the nature of the acid are important in the overall impact of acid-containing effluents.

Thiosulphate

Thiosulphates may create environmental problems through their oxidation to acid in receiving waters.

Cyanides

Cyanides are lethal to fish at very low concentrations, as little as 0.04 mg/l CN for trout.

Organic reagents

Some of the organic reagents used in base metals ore processing operations may be toxic. While the concentration of most of the elements detected in effluents from concentration tailing ponds are usually well below the threshold of acute toxicity, the possibility of longer term chronic toxicity cannot be ignored.

Oils

Oil forms a thin film over the water surface and can interfere with the re-oxygenation of water. It may also coat the gills of fish.

Nitrogen

Nitrogen contributes to eutrophication of waterways.

Suspended solids

Many water systems contain varying concentrations of suspended solids. However, depending upon their nature and concentration, suspended solids may interfere with self-purification of water by diminishing light penetration and hence photosynthesis reactions. Nevertheless, some water systems may already be light-limited by the occurrence of natural sediment material. In extreme cases, silt deposition can lead to flooding and interference with navigation.

Combined effect of water pollutants

An effluent containing a mixture of contaminants may have an overall toxicity which is different from that of its individual components. Biological testing of the effluent could be carried out to identify its potential for environmental damage.

Air contaminants

Dust in suspension in the air is potentially of concern to human health (cf. Section 8). Fall-out of particles may cause contamination of soils, vegetation and water. The precise effects depend on the nature and the concentration of particles which are deposited.

Gaseous pollutants related to base metals mining are of concern mainly to mine workers (cf. Section 8).

Sites around smelters can have high levels of heavy metyal fallout and SO_2 release.

Other contaminants

A variety of chemicals associated with mining or with management of the site may cause environmental mining problems if they are released. Such chemicals include pesticides and herbicides, paint solvents and oils, and transformer fluids in heavy electrical equipment.

Other effects

Aesthetics

Excavation of large quantities of material in open-pit operations, disposal of wastes above ground and erection of mining facilities - these activities often have considerable negative aesthetic impacts on the local geography. Anciliary works such as access roads, ports, airstrips, and powerlines etc. can be particularly unsightly, throughout mine operations and after closure.

Socio-economic

Population growth and infrastructure development are commonly associated with mine development. The positive or negative perception of these effects is largely determined by the degree and success of planning for that population growth. Proper planning can yield significant positive benefits such as better health care, economic benefit to local population, etc.

Remote areas

Potential impacts to the environment have to be specially studied when a mining project is being planned in a remote and relatively unknown area; it should be insisted that environment specialists and consultants be used all throughout the planning and development stages of the project.

Table 6 - Potential Effects of Mining Activity on the Environment.

	Surface water pollution	Underground water pollution	Air pollution	Solid waste	Excavation	Noise and vibration	Remarks
Human health and activity	Soluble contaminants in domestic and/or agricultural use waters Deposition of solids on agricultural lands, in sea shallow zones Withdrawal of water for industrial puroposes	Soluble contaminants in wells, springs, etc. Natural water sources drying up as a consequence of water - table lowering	Dust blown on inhabited, agricultural lands (2)	Hazards related to lack of stability of waste deposits		Effects of noise on human health Damage in buildings due to blasting vibration	(1) Occurence of such impacts on underground waters is not a general case ; it depends essentially on the hydrogeology of the area (2) Plant, and especially underground mine atmosphere see Section 8
Fauna	Alteration of aquatic fauna including destruction of fish species, accumulation of toxic elements by fish				Loss of habitat	Disturbance of habitat feature (3)	(3) Issues regarding unique habitat features (migration corridors, watering areas, etc...) for threatened or endangered species should especially be addressed
Flora	Alteration of aquatic flora		Accumulation in plants of toxic elements carried by dust		Loss of habitat		Spatial requirements of mining operations are normally quite restricted ; within that area the disturbance can be significant. Effects on species with limited geographic extent are essentially to be considered
Land use	Sand deposition in river channels, sea shallow zones			Land disturbance Withdrawal of agricultural land	Land disturbance Land subsidence due to underground mining		

4. POTENTIAL SOURCES OF CONTAMINANTS

4.1. Water Pollution

4.1.1. Drainage from surface and underground mines

The most significant source of liquid waste in the non-ferrous metal mining industry is acid mine drainage. Acid mine drainage is common in areas where mine openings intersect the water table and where the rocks contain iron sulphides (pyrite and/or pyrrhotite) or, less commonly, certain other sulphides; where such pyritic ores are mined, rainfall leaching of rock waste stockpiles may be responsible for environmental damage. The subject of acid mine drainage is addressed in Section 5.

Less significant, although rather frequent as a source of waste, is the amount of suspended solids in mining operation drainage.

The volume and quality of mine water vary widely depending on the type of mining operation, geochemistry, and hydrology of the specific mine.

For open-pit operations, the volume of water depends on the ingress of groundwater and the precipitation into the surface area of the pit. The water is normally collected in sumps in the pit bottom.

For underground operations, the volume of mine water is influenced by the local hydrogeologic conditions, the infiltration of surface water into the mine, water used for drilling and dust suppression, and water contained in tailings back-fill where this method is used.

The volume of mine water varies widely from one mine to another, and even within a particular operation. Mine water is pumped to the surface from collection sumps where most of the suspended solids are decanted. Chemical characteristics of mine water vary depending on the mine. An indication of the variability in mine water quality is given in Table 7a.

4.1.2. Wastewater from beneficiation

Tailings from beneficiation plants are in most cases composed of a slurry which contains particles of ground material (gangue minerals; minor amounts of valuable minerals) in suspension in water. Basically, two tailings disposal methods are used:

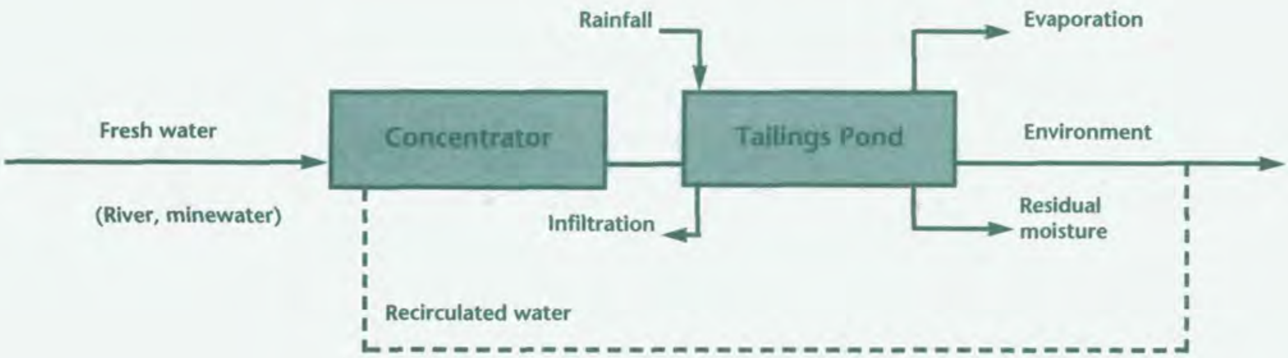
(a) Tailings are discharged directly into the environment.

Tailings discharge in rivers is usually not practical, nor is it desirable from an ecological point of view.

The direct discharge underwater in lakes or coastal waters presents the advantage of greatly reducing the rate of oxidation for acid-generating tailings. However, the discharge of tailings into lakes or into the sea should be discouraged given the potential environmental problems connected with the long term presence of contaminants and their potential impact on aquatic flora and fauna. It should be considered only in those instances where the impact can be demonstrated to be negligible.

In the Philippines and Canada examples of this method are given in (16).

(b) Tailings are disposed of in a tailings pond.



Most frequently, concentrator tailings are discharged into a specifically designed area - the tailings pond - where solids are allowed to settle. Depending on the balance between rainfall, decanted water on one hand, evaporation, infiltration in the site ground, residual moisture of tailings on the other hand, depending also on the possible influence of recirculated water on the metallurgical process in the plant, supernatant water may be partially or totally discharged into the environment. Construction methods of tailings ponds are reviewed in Section 4.3

Depending on the mining methods used in underground operations, tailings material may be used for backfill. However, only the coarse fraction is generally used and a tailing impoundment is still required for fine materials. Consequently, the major liquid waste from a beneficiation plant consists of water decanted from the tailings pond.

The contaminants in tailings pond effluents include suspended solids composed of elements of the ore treated in the plant, heavy metals in solution, thiosalts and chemicals used for the treatment.

The characteristics of effluents are highly dependent on the specific operation as indicated in Table 8a. This table shows clearly that, each mining project should be considered as a separate case. A brief review of tailings pond effluent contaminants is given below. Whenever possible water from tailing ponds should be recycled rather than discharged.

Suspended solids

Provided the tailings disposal facilities are properly operated, the amount of suspended solids in the effluent remains at a very low level (see Table 7b). Turbidity may arise from the non-settleable fraction of the suspended solids load. It may either be a true colloidal dispersion, or a very fine suspension of coarser particles. In either case the effects of turbidity on fish life appear to be relatively small.

Heavy metals in solution

A source of metals in tailings water may be mine water, when it is used as process water, and/or flotation reagents such as zinc sulphate, copper sulphate used in lead-zinc beneficiation and potassium dichromate in copper-lead-zinc ore treatment.

Table 7a
Range of Chemical Characteristics of Raw Minewater from Lead and Zinc Mines

Parameter	Mines with Acidic Characteristics Concentration mg/l	Mines with No Acidic Characteristics Concentration mg/l
pH*	3.0 to 8.0*	7.4 to 8.1*
TSS (Total suspended solids)	< 2 to 58	2 to 138
COD	15.9 to 95.3	< 10 to 631
Oil and Grease	0 to 3	3 < 29
P	0.002 to 0.075	0.03 to 0.15
Ammonia	< 0.05 to 4.0	< 0.05 to 1.0
Hg	0.0001 to 0.0013	< 0.0001 to 0.0001
Zn	1.38 to 38.0	0.03 to 0.69
Cu	<0.02 to 0.04	< 0.02
Cd	0.016 to 0.055	< 0.002 to 0.015
Cr	0.17 to 0.42	< 0.02
Mn	< 0.02 to 57.2	< 0.02 to 0.06
Fe	0.12 to 2.5	< 0.02 to 0.90
Sulphate	48 to 775	37 to 63
Chloride	< 0.01 to 220	3 to 57
Fluoride	0.06 to 0.80	0.3 to 1.2

* *Value in pH units*

Source: (17)

Table 7b
Examples of Tailing Pond Wastewater Quality at Base Metal Mills

	(I) Examples of Cu-Pb-Zn Swedish Mines	(II) Examples of Cu-Pb-Zn Canadian Mines
pH	7.5 - 8.1	6.5-9
Turbidity (mg/l)	1 -	8
Conductivity (µS/cm)	600 - 1700	
Cu (mg/l)	0.01 - 0.003	<0.1
Fe (mg/l)	0.11 - 0.23	<1.0
Zn (mg/l)	0.14 - 0.32	<0.5
Pb (mg/l)	0.013 - 0.026	<0.1
SO_4(mg/l)	190 - 330	n.a.
Thiosalts (mg/l S_2O_3)	n. a.	<50

Source: (21) (15)

Flotation processes used for non-ferrous metals beneficition are generally carried out at basic pH values: in such conditions, heavy metal solubility in water is low and an important fraction of the heavy metals contained in process water is precipitated with the solid tailings (cf. Table 7(b), I). However, where iron sulphides are a major component of tailings and a fraction of the tailings is used to build the tailing dam, low pH effluents may be experienced (as seepage water) and phenomena similar to acid mine drainage may occur (cf. Table 7b, II).

Thiosalts

Thiosalts originate mainly in grinding and flotation of a number of sulphides, under alkaline conditions. Thiosalts are of concern because they generate sulphuric acid as further oxidation forms the more stable sulphate ions.

Presence of thiosalts in tailings pond effluents at concentrations of a few hundred milligrams per litre or less, can create serious environmental problems through their oxidation to acid in receiving waters. Information about thiosalt generation during sulphide ore processing and thiosalts oxidation may be found in (15), (19).

Process reagents

Comprehensive information about reagents used for beneficiation of non-ferrous metals ores by flotation is given in mineral processing handbooks such as (11), (12).

Reagents used most frequently in base metal flotation plants and in gold cyanidation plants are listed in Table 8. Typical examples or reagent consumptions are also given.

When the process is properly executed, most of the chemicals used for flotation, except pH modifiers, are absorbed at the surface of minerals. It may happen that some of them, when used in excess, remain in solution in the mill tailings. Most of the organic chemicals in solution in the tailings slurry are oxidized in the tailings ponds and are not found in the final effluent.

The kinetics of this oxidation depend on the temperature. Organic chemical concentration in the effluent may be of concern in certain conditions during cold seasons.

Table 8a

Flotation Reagents used in Base Metal Concentrators

Acids: Sulphuric acid	**Collectors:** Potassium amylxanthate Potassium ethylxanthate Potassium isopropylxanthate Aniline Dicresyldithiophosphate Diesel oil Amine
Alkalis: Lime Sodium carbonate Sodium hydroxide	
Modifiers Copper sulphate Sodium cyanide Zinc sulphate Sodium sulphide Sodium silicate Sulphur dioxide Starch	**Frothers:** Dowfroth 250 Hexylic Alcohol Pine Oil HBTA frother

Table 8b - Typical Flotation Reagent Consumption in Non-ferrous Metal Mill (g/t of ore)

Concentrator	Pb-Zn (sulphides) Les Malines (France)	Pb-Zn (oxide + sulphides) Zellidja (Morocco)	Cu-Pb-Zn Brunswick Mining and Smelting (Canada)	Ni (sulphide) Falconbridge (Canada)	Cu (sulphide) Lornex (Canada)	Au (cyanidation + CIF) Homestake (US)	Cu-Zn pyrite Pyhasalai (Finland)
Acids :							
H_2SO_4				500-600			5000 (2)
Alkalis :							
Lime	1000		2500	225-400	1100	1200	3150
Sodium carbonate		550	3300				
Sodium hydroxide		246					
Modifier :							
Copper sulphate	200	120	815	35-60			330
Sodium cyanide	10	13				550	28
Zinc sulphate	60	91					1450
Sodium sulphide		2800					
Sodium silicate		2700					
Sulphur dioxide			700				
Starch			100				
Collectors :							
X-Amylxanthate	45	130	270	60-85	35		220
X-Iso propyxanthate					30		
X-Ethylxanthate	5	20					
Diesel oil		69					
Amine		250					
R-242 (1)		60					
Frothers :							
Dowfroth 250				20-25	14		
Hexylic alcohol	40						
Pine oil					20		
HBTA frother		85					
Carbon						30	

Source : (11) (8)

(1) R242 : Aniline Dicresyl dithiophosphate + thiocarbanilide
** By Courtesy of METALEUROP SA*
*** Outokuaru documentation*
(2) Sulphuric acid is used for pyrite recovery

Cyanide is a reagent mainly used in lead-zinc ore flotation and for gold beneficiation.

The amount of cyanide used in flotation operations is low enough to allow its removal from flotation tailings by natural degradation. The principal mechanism involved in natural cyanide degradation is the loss of volatile hydrogen cyanide.

In gold mills, although cyanide consumption is much higher (see Table 8b), removal of cyanide by natural degradation is the method most commonly used. Prolonged exposure of wastewaters in the tailings pond is required. Where this is not economically feasible and/or where an acceptable low effluent concentration of cyanide is not achieved, further treatment is necessary. Table 9 gives some examples of final effluent compositions. More comprehensive data about gold mill treatment process and effluent characteristics are given in (28).

Table 9

Composition of Final Effluents from Twelve Ontario and Quebec Gold Mines - 1978 and 1980

Constituent, mg/l					
CN_T	Cu	Fe	Pb	Ni	Zn
0.30	0.3		0.005	0.40	0.19
0.87	0.1		0.10		0.06
1.2	0.5		0.03	0.02	0.13
2.8	1.4		0.02		0.05
3.3	3.6				3.04
4.8	1.0		0.04		1.32
6.8	2.3	0.3	0.10	0.10	0.20
13.0	2.4	0.6	0.02	0.04	0.82
21.0	0.3	0.02		2.54	
25.0	8.2				2.64
33.0	1.1	0.10	0.60	0.70	
61.0	16.5	0.04		16.60	

Source: (20)

4.1.3. Surface run-off

Run-off after rain or snow-fall can give rise to pollution problems. The disturbed land caused by open-pit mining is usually susceptible to erosion, and silting may be a widespread result.

Roads used for ore and concentrates transportation, ore storage areas, non - or partially covered workshops, when subject to rainfall, may become significant sources of water contaminants if adequate control measures are not undertaken.

In fact, it is recommended that where practicable, surface run-off be diverted away from mining areas and surface facilities. If conditions permit, the different waste water flows - mine water, surface run-off, tailings from the beneficiation plant - can be collected in a single point for a possible treatment before release into the environment.

As an example, Figure 10 shows the water process diagram of Tara Mines in Ireland.

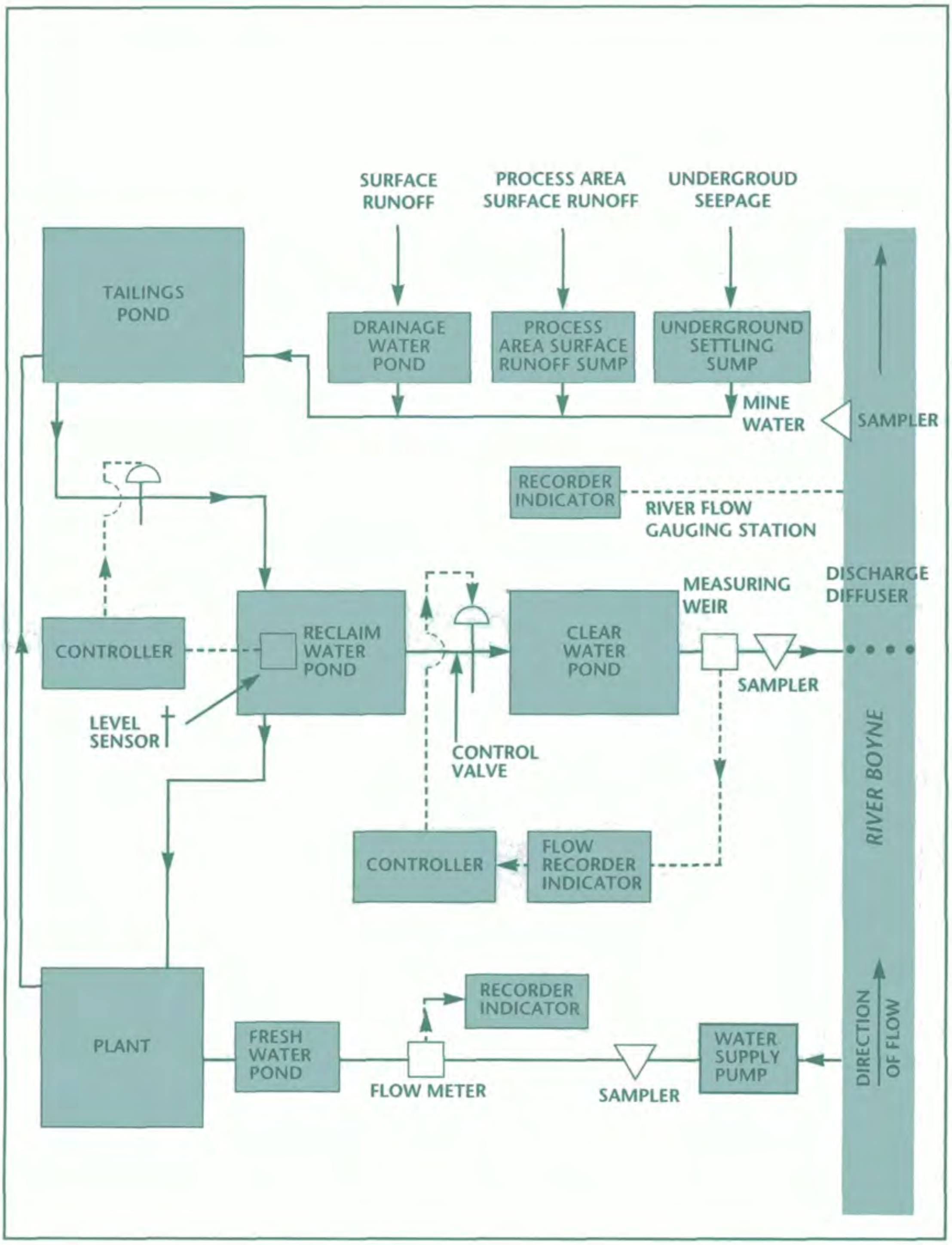


Figure 10 Tara Mines - Water process diagram

Source: (22)

4.2. Air Pollution

Air pollution in underground mines is addressed in Section 8. Outside of the mine, and with the exception of relatively high production of dust in specific areas which will be examined later, the non-ferrous metals mining and beneficiating industries have negligible air pollution problems compared with metallurgical industries.

Potential main atmospheric contaminants were listed in Section 3.1. Open-pit mining produces to some extent carbon monoxide, oxides of nitrogen and sulphur (blasting; diesel operated equipment). Only in very rare cases have these contaminants been known to cause external problems. However hydrogen cyanide can build up over gold tailings dams in still air conditions. This can be sufficient to cause bird deaths, for example.

Particulates liable to remain in the atmosphere are usually classified by size as follows (cf. 23):

- < 0.1m : aerosols resulting from combustion processes.
- 0.1m - 1.0m : formed by vapour condensation.
- > 0.1m : dust particles formed by comminution.

Dust particles are the main concern in external air pollution related to mines and concentrators. They come from two types or sources: point or easily defined sources, and fugitive or dispersed sources.

It should be noted that dispersed sources may generate dust both while a mine is in operation as well as after closure.

Main sources of dust in mining operations are listed below:

Point Sources	Dispersed Sources
Ore and waste loading points,	Waste dumps
in trucks, railroad cars, etc.	Ore stock piles
Ore chutes in haulage systems	Haulroads
(bin, conveyors,)	Tailings disposals
Screens in outdoor crushing plants	
Exhaust from dedusting installations	
Dryer chimneys	

4.3.Solid Wastes and Residues:

4.3.1.Open-pit overburden

Inert material located on top of an ore deposit which is to be exploited by surface mining methods must be removed first. The stripping ratio, i.e. the ratio of waste removed to ore tonnage, depends on the geology of the orebody and on economic factors such as recoverable value per tonne of ore, production cost per tonne of ore and stripping cost per tonne of waste. 2/1 is an average value for non-ferrous metal open-pit operations; however much higher values, 5/1 for example, may be experienced in specific cases.

Overburden material removal is usually carried out by classical surface mining methods: shovels and trucks, draglines, bulldozers. Waste is stored in piles located close to the open-pit. Material characteristics are those of a run-of-mines ore, with blocks up to 1 m^3.

Environmental concerns of overburden stockpiling include:

- visual impact;
- pile stability;
- solid transportation and metal solubilisation in run-off waters (acid generation in waste stockpiles is addressed in Section 5);
- dust emission;
- runoff of solids.

4.3.2. Waste from underground mining operations

Underground mining methods produce material which may first be used as backfill and then remain within the mine. Otherwise, waste has to be hoisted out of the mine and stockpiled by methods similar to open-pit waste storage.

4.3.3. Tailings impoundment

As already discussed in Section 4.1.2., tailings from beneficiation plants are composed of a slurry which is most frequently discharged into a specifically designed containment area. Tailings disposal is briefly reviewed hereafter.

4.3.3.1.Tailings disposal methods

Tailings disposal methods include:

- Subaqueous discharge into tailings pond :

Although lower in-situ densities are produced than with sub-aerial methods, transfer of oxygen to tailings is inhibited, which is a great advantage when acid-generating tailings are concerned.

- Layered method of tailings disposal (26):

The tailings slurry is deposited in thin layers of uniform thickness (10 - 150 mm). The slope of the deposited layers depends on slurry characteristics, and varies between 0.5 and 1.0%. Once a section of deposit has been covered with the desired thickness of fresh tailings, discharge is started on another section of deposit and the newly deposited layer is left to settle and dry from several hours to a few days. The final configuration is a gently sloping mass of tailings, made from uniform layers with a resulting vertical permeability several orders of magnitude lower than its horizontal permeability.

The advantage of the method is mainly that tailings are well drained and fully consolidated upon mine decommissioning. Conversely, it requires a high capital cost due to site preparation.

- Thickened tailings disposal (27)

The tailings slurry is thickened prior to its discharge from one or more spigotting points within the tailings disposal area. Tailings form a cone with a slope ranging between 2 and 8% . Typical percent solid required to achieve a slope of 6% ranges from 55 to 75%.

This method enables a greater storage capacity within a given disposal area than with a conventional method as long as a high concentration may be obtained after thickening; it does not require the large dams associated with conventional disposal schemes, but the need to thicken the slurry results in higher operational costs than conventional methods.

- Tailings disposal behind a dam:

Comprehensive information related to tailings dams design and development may be found in (15), (18), (24), (25), (28).

The coarse fraction of tailings is usually used to build the dam. The tailings slurry can be discharged from a single point, through a series of spigots from a header, through spray bars or through cyclones for the mechanical separation of tailings sands for the dam construction. Where tailings are spigotted from the crest of a retaining dam, the coarse material deposited close to the point of discharge provides a source of material for the raising dam.

Discharge of the tailings through cyclones is preferred because a greater degree of control over the size distribution of sand used for dam building is provided.

When the beneficiation process requires too fine a grind of the ore, there may not be enough coarse material to build a tailings dam. In such a case, the dam has to be built with borrowed materials, which is an advantage in that the quality of the materials and their placement can be controlled, but with the result of a higher cost because of material excavation and placement on the dam. Some sites may require the construction of an engineered earthen dam with key, core and/or drainage features.

A summary of tailings dams construction principles is given hereafter.

4.3.3.2. Tailings dam construction methods

The environmental impact of the material used to build a tailings dam should be considered. Figure 11 shows the standard methods of tailings dam construction where coarse fractions of tailings are used.

(a) Upstream methods:

It was used extensively in the past. It is now avoided because of the difficulty of ensuring its stability, particularly under seismic conditions. As shown in Figure 11, a typical upstream section incorporates the finely divided slimes fraction of the tailings into the structure, resulting in a heterogeneous dam susceptible to failure.

(b) Downstream methods:

The dam is built with the coarse fraction of tailings. This method provides a dam capable of meeting acceptable geotechnical specifications - even when seismic conditions occur. When cyclone classification of sand fraction is used, the slope of the dam is adequate and sand mass is properly drained.

The major disadvantage of this method is the large volume of sand required.

(c) Centerline method:

As before, the dam is built with the coarse fraction of the tailings. The dam centerline is maintained in the same vertical plane as the height increases. Downstream of the centerline, the dam has the same characteristics as the downstream method; therefore an acceptable structure can be provided.

Whatever the dam construction method used, the most common causes of failure associated with tailings impoundment structure are those related to spillways, decants and diversions. If the hydraulic capacity of these facilities is exceeded during periods of peak flow, a failure in the dam structure can result, leading to the liquefaction and release of the stored tailings.

All tailings impoundments must be evaluated at the design stage to ensure that likely rainfall/run-off events can be accommodated through storage, diversion around the facility, or discharge via a spillway or decant structure. In establishing design criteria, a statistical assessment of the occurrence of an inherent run-off event should be made. Events which occur only once in a thousand years have been used in some cases.

Where potential failure of a tailings system has life-threatening implications upper limits should be used, although it is highly recommended not to install tailings disposal facilities where such risks can occur.

Devices used to release excess supernatant water from tailings disposals include decant towers, siphon systems and barge-mounted pumps. In the latter case, tailings systems must be designed so that peak run-off events can be safely stored within the impoundment and subsequently released.

4.3.3.3. Tailings impoundment environmental concerns.

Environmental concerns related to water release from tailings impoundments were reviewed in Section 4.1.

When considered as a solid waste disposal structure, a tailings impoundment presents similar environmental concerns as those waste disposal. However, due to the physical properties of stored material, stability problems are far more critical in tailings impoundments. It is recommended, when designing a tailings disposal facility to include in the project team a geotechnician, a hydrologist and a good specialist of tailings dam operations.

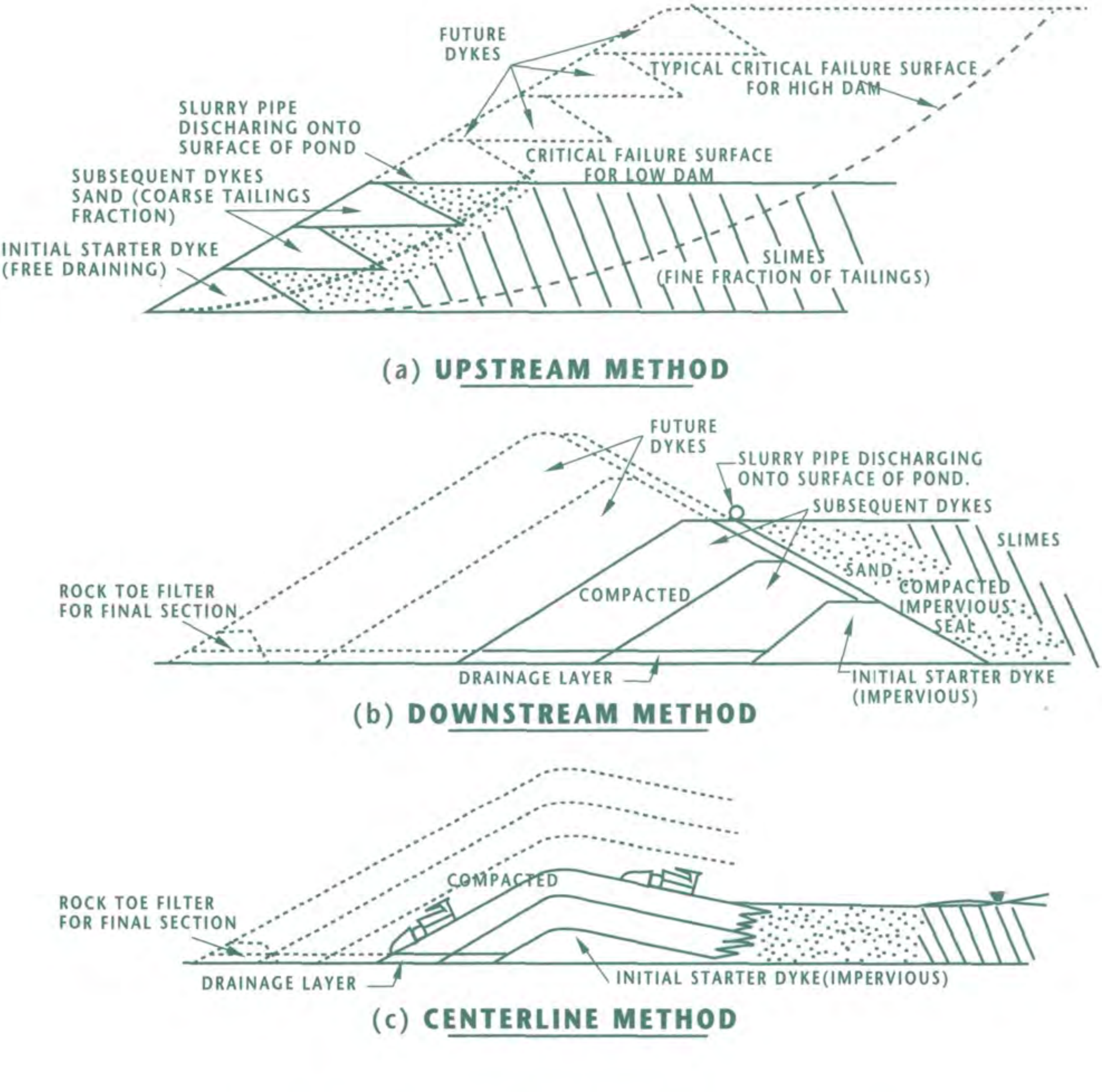


Figure 11 Standard methods of tailing dam construction

Source: (25)

4.3.4. Other wastes

Other wastes which may be of environmental concern include:

- out of date chemicals, mainly flotation reagents;
- PCBs from electrical equipment;

(PCBs are highly persistent in the environment and may seriously affect certain species of animals and birds. They also have a moderate human toxicity. Fires involving electrical equipment containing PCBs may generate highly toxic-breakdown products, require special precautions for disposal and for destruction).

- obsolete pesticides and herbicides used around a mine site. Also empty containers that in fact still contain residues of chemicals adhering to the sides;
- wastes from maintenance operations, such as paints, oils, cleaning agents.

4.4. Subsidence

The removal of material by underground mining creates a potential for ground movement and consequential deformation of the surface. The circumstances under which this may arise vary widely; the main parameters are:

- the geometry of the mineral deposit;
- the method of mining;
- the nature of the mineral deposit and the overlying strata.

In many cases, application of rock mechanics enables a fairly reliable qualitative prediction of subsidence.

Damage from subsidence may include:

- major fracture of the ground surface which can cause severe damage to buildings and installations. Discontinuous fractures can vary in magnitude from millimeters to meters.
- continuous surface deformation, such as a surface trough. Uniform displacement seldom causes major damage. Differential displacement may cause interference with groundwater flow, changes in the gradients of roads, railways, water or gas pipes, etc..

Abandonment of open-pits can result in significant failure of the pit walls. It is suggested that a designated safety zone be left around abandoned open pits. A number of organizations have produced guidelines concerning such safety zones and other measures, which are generally adapted to the local geological and climatic conditions.

4.5. Noise and Vibration

4.5.1. Noise

The major categories of noise sources in the mining industry are fixed plant, mobile equipment in mining operations and transport movements. Noise problems in underground mines are reviewed in Section 8 which deals with the working environment, while environmental problems related to ore and concentrate transportation are addressed in Section 4.7.

Stationary plants consist of a very wide range of equipment including crushers, screens, grinding mills, air compressors, ventilation fans, workshops and loading facilities.

Stationary plants are frequently enclosed so as to protect workers men and equipment from the elements. In such cases, it is be meaningless to give typical overall noise levels emanating from a plant site, because they are essentially dependent on the type and quality of building construction.

However, in certain countries where weather conditions are acceptable, beneficiation plants are open-air installed. Table 10 indicates the range of noise levels associated with various fixed plant installations.

Table 10
Noise Levels from Plant Installations

Equipment	Noise level (dB (A))	Measurement location
Electrical ventilation fans	90 - 100	At 5 m (16 ft)
Compressed air fans	up to 110	At 5 m (16 ft)
Jaw crusher	90 - 100	Operator position
Cone crusher	92 - 98	Operator position
Compressed air hammer	104 - 112	Operator position
Drill sharpeners	102 - 122	Operator position
Ball mill	up to 100	Operator position
Flotation equipment	63 - 91	Inside flotation building

Source: (23)

Mobile equipment is associated with drilling, blasting, loading and haulage operations. Some examples of noise levels are given in Table 11.

Table 11
Noise Levels from Mobile Equipment

Equipment	Noise level (dB (A))	Measurement location
Compressed air rock drill	110 - 115	At 1 m (3 ft)
	98	At 15 m (50 ft)*
Large portable compressor	80	At 7 m (23 ft)
	81	At 15 m (50 ft)*
7 m^3 (10 yd^3) dragline	90 - 92	Operator's cab
Diesel trucks	74 - 109	Driver's cab
	88	At 15 m (50 ft)*
Electric shovels	78 - 101	Operator's cab
Graders	76 - 104	Operator position
Dozers	84 - 107	Operator position
	87	At 15 m (50 ft)*
Locomotives	75 - 95	Driver position
Rotary drills	72 - 100	Operator position
Front end loaders	83 - 101	Operator position
Scrapers	92 - 104	Operator position
	88	At 15 m (50 ft)*

** Figures used by Environmental Protection Agency, USA.*

Source: (23)

Noise levels given in the above tables are measured close to the equipment. With the consideration of external nuisance, a reduction factor should be taken into account. From different mine experience, a continuous noise level exceeding 75 dB(A) is unusual at the perimeter of the mining property. It is usually accepted that a 50 - 70 dB(A) is a maximum level.

4.5.2. Air Blast

Air blast is the term used to describe the air vibrations generated by blasting operations.

Factors within the control of the mine operator are:

- the type and quantity of explosive;
- the degree of confinement;
- the method of initiation.

Uncontrolled factors are:

- climatic conditions;
- local geology and topography;
- the distance and conditions of structure.

Air blast waves may give rise to damage and nuisance. Table 12 indicates effects of air blast over-pressure upon structures.

Normal mine blasting results in general over-pressures well below those indicated in Table 12. The damage potential of air blast is largely confined to structurally unsound buildings, bad blasting practice and unusual atmospheric effects.

Table 12

Effects of Overpressure upon Structures

Overpressure		Structural effect
lb/in²	g/cm²	
0.03 - 0.05	2 - 4	Loose window sash rattles.
over 0.1	7	Failure of stressed or badly installed window panes.
over 0.75	52	Failure of correctly installed window panes begins.
2.0	140	All window panes fail.
over 2.0	140	Plaster cracks begin and, at higher pressures, masonry cracks may be evident.

Source: (32)

4.5.3. Ground vibrations from blasting

In blasting operations, an undesirable result of detonation is that the surface of the ground in the vicinity of the blast undergoes displacement, whose amplitude depends on the distance from the blast, the energy released in the explosives and the local geological conditions.

Among the factors used to asses the effects of ground vibration, peak particle velocity appears to be the most directly related to damage caused.

The frequency of the vibration also has an effect upon damages resulting from blasting: the lower the frequency, the greater the damage for a given peak particle velocity. Table 13 gives indications of the effect of ground vibrations upon structures.

Table 13

Effect of Ground Vibration upon Structures (After Langefors)

Peak Particle Velocity (in/s)	(mm/s)	Damage
2.8	70	Nil
4.3	110	Fine cracking and fall of plaster
6.3	160	Cracking
9.1	230	Serious cracking

Source: (23)

4.6. Exploration

The main sources of contaminants during exploration operations are discussed below:

Drilling sludges:

Water is the drilling medium used in base metals exploration. The material ground by diamond bits is carried up with water to the surface. When not completely decanted, drilling sludges may be an environmental concern. However, as drilling water is in most cases recycled, sludges have to be well decanted.

Land disturbance; erosion

The primary environmental effect of most exploration operations is the surface disturbance resulting from road and drill pad building, and equipment use. Those disturbances are relatively minor in the context of an entire mining project.

Aquifer connection

Drilling operations that penetrate multiple aquifers should monitor aquifer isolation to avoid the possibility of cross contamination and aquifer elevation changes.

4.7. Transportation

Transportation operations are associated with ore and waste material haulage from mine to beneficiation plant, or stockpiling and concentrate transportations.

Potential sources of contamination for different transportation methods are shown below.

Transportation Method	Water Pollution	Air Pollution	Noise and Vibration	Other
Road	Spillage Run-off on roads after rainfall	Dust from truck load Dust on the road by wind blown from the movement of vehicle	Vehicle engines Ground vibration	
Rail		Loss of dust from load	Vehicle engines Ground vibrations	
Sea	Nil except during loading and unloading operations			
Conveyors	Dust blown by wind and spillage			Visual impact
Aerial conveyors	id.			

5. ACID MINE DRAINAGE

5.1. Introduction

Acid mine drainage (AMD) may be defined as the inorganic chemical water pollution resulting from the oxidation of sulphide-containing minerals, mainly pyrite (FeS_2) and pyrrhotite ($Fe_{1-x}S$). Consequently, acid effluents containing elevated levels of dissolved metals including iron, zinc, cadmium, manganese, and lead are produced.

AMD potentially affects:

- sulphide ores underground and surface mine water;
- drainage from sulphide-bearing waste rock stockpiles;
- seepage and drainage from sulphide bearing concentrator tailings.

Base metals sulphide ores are mainly concerned. Coal deposits which contain a significant amount of pyrite may also produce AMD. Coal mines are not within the scope of the present document. However, important research work concerning prevention and treatment of AMD from pyritic coal mines such as Appalachian mines, has resulted in a number of publications which can be usefully referred to.

AMD is a problem that not only takes place while the mine is in operation, but also after closure. Control measures are not the same for both cases. In a closed mine AMD can affect not only underground waters, but also waste rock stockpiles and treatment plant tailings. An important research programme (The Mine Environment Neutral Drainage Program) is presently being undertaken in Canada.

The mechanisms of AMD have received considerable attention during the past 20 years or so, and continue to be of worldwide interest. A comprehensive summary AMD can be found in (15).

ACID MINE DRAINAGE MECHANISM

Stage 1:

1. $FeS_2 + 7/2\ O_2 + H_2O \longrightarrow Fe^{2+} + 2\ SO_4^{2-} + 2\ H^+$

Stage 2:

2. $Fe^{2+} + 1/4\ O_2 + H^+ \longrightarrow$ - $FE^{3+} + 1/2\ H_2O$
3. $Fe^{3+} + 3\ H_2O \longrightarrow$ - $Fe(OH)_3 + 3\ H^+$

Stage 3:

4. $Fe\ S_2 + 14\ Fe^{3+} + 8\ H_2O \longrightarrow$ - $15\ Fe^{2+} + 2\ SO_4^{2-} + 16\ H^+$

5.2. Mechanism of AMD formation

AMD formation involves chemical and biological phenomena. It is not the purpose of this present section to give a description of the complete process, which is complex and still not yet fully understood.

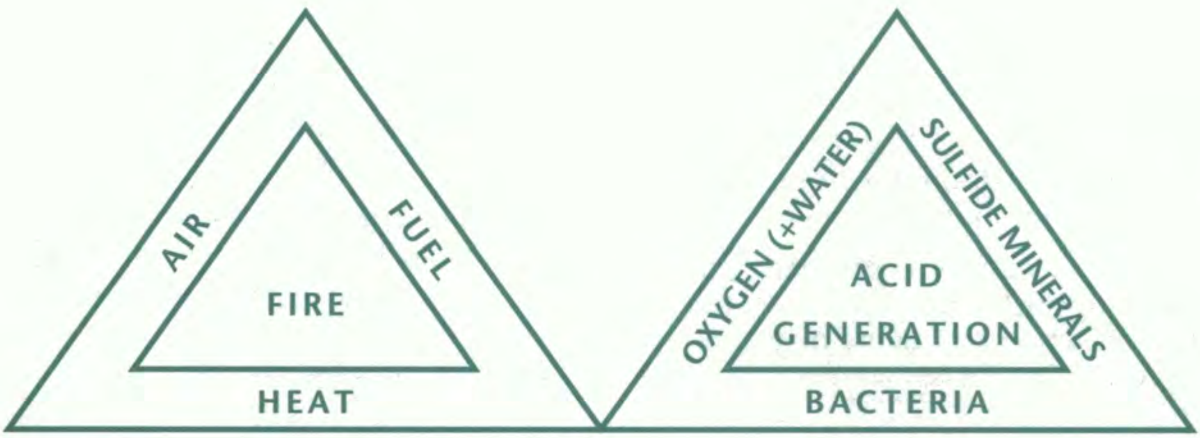
However, the model developed by Kleinman (29) is a good approach. Three stages are considered in the generation of AMD (chemical equations are given above).

Stage 1 involves the relatively slow chemical or biological oxidation of pyrite and other sulphide minerals near neutral pH, producing ferrous iron and acidity. This step may be catalyzed by the bacteria Thiobacillus ferroxidans through direct contact with sulphide minerals.

In stage 2 and in presence of oxygen, ferrous iron is oxidized into ferric iron which precipitates as ferric hydroxide and releases more acidity. As the pH falls even further, below about 3.5, ferric iron remains in solution and oxidizes the pyrite directly.

In stage 3, the bacteria rapidly catalyzes the process by oxiding ferrous iron into ferric iron and the overall rate of acidity production is increased by several orders of magnitude. Large quantities of acid associated with the release of heavy metals in solution are produced. It may be seen that, while the abundance of sulphide minerals is an important factor of AMD, both oxygen and water are required reactants, with bacteria acting as catalyzers.

An analogy between requirements for fire and bacteria metal oxidation is given by Dr M. Silver (30).



Water also plays an important role in removing the oxidation products from the surface of sulphide minerals: acid and metal sulphate salts may accumulate within a waste deposit during relatively dry periods and be released at times of higher precipitation.

Carbonate minerals such as calcite and dolomite are the principal natural acid neutralizing components of mine waste. Those minerals can neutralize the acid produced by sulphide oxidation and prevent the establishment of low-pH environments required by micro-organisms. Under these conditions, the AMD process cannot develop.

5.3. Characteristics of Acid Mine Drainage Water

A range of chemical characteristics of raw mine waters from lead and zinc mines with acidic conditions were given in Table 7a.

However, in some cases, where severe acid mine drainage is experienced, chemical characteristics may be far worse. The example shown in Table 14 may be considered as an extreme limit in that respect.

Table 14

Characteristics of Acid Mine Drainage at a Lead and Zinc Mine

Constituent	Concentration (1)	Constituent	Concentration (1)
pH	2.2	Magnesium	1,500.0
Sulphate as SO_4	63,000.0	Calcium	31.6
Total iron	16,250.0	Potassium	0.7
Zinc	14,560.0	Sodium	0.5
Nickel	4.8	Chrome	0.3
Copper	13.4	Chloride	38.0
Manganese	2,625.0	Nitrate as NO_3	77.5
Aluminium	347.0	Conductivity	48,000
Lead	0.8	(Micromhos)	
Cadmium	22.5		

Note: Sample collected and analyzed by B. Trexler, College of Mines, University of Idaho.

(1) in mg/l (except pH and electrical conductivity).

Source: (39)

From Table 14, one can see some of the objectionable features of AMD: low pH, high sulphate, iron, and heavy metals levels. Usually ferrous iron is high; when it is transformed into the ferric form, ochre ferric hydroxide precipitates, which is generally considered as aesthetically objectionable.

The above figures highlight the importance of minimizing the occurrence of acid mine drainage, and also of ensuring that, where it does occur, steps are taken to prevent it from affecting the environment.

5.4. Prediction of Acid Mine Drainage

Qualitative prediction of AMD is the critical step in determining the impact a mine may have on the aquatic environment.

A number of methods exist to predict AMD. A description of possible tests may be found in Environment Canada Report EPS 2/MM/3. Prediction of AMD in Canada is now a commonly phased programme using Acid-Base Accounting, followed by humidity cells if necessary, and sometimes columns on test pads for specialized testing (15).

Prevention of AMD and control techniques, are reviewed in Section 7.

6. CLOSURE OF MINES AND ABANDONED MINE SITES

6.1. Reclamation

When a mining operation is closing down, measures should be taken to reclaim the site and to the ensure the safety of persons and domestic animals. All too often, old mines were abandoned without adequate reclamation measures having been undertaken in due time.

Reclaiming the mine site when a mine is closing may be quite different to reclaiming a mine which has been abandoned for many years. In the first case, mining operations could incorporate measures such as specific tailings disposal which anticipate reclamation works.

As a rule a mine closure programme should be incorporated into any new planning proposal, and even into mine operations during its active lifetime.

An important parameter that determines measures to be undertaken is the possible acid-producing character of the mine site.

At non-acid-producing mines, reclamation measures may be instituted so that no long-term waste water treatment facility is needed.

Conversely, at acid producing sites, contaminated drainage can occur, resulting in the requirement for long-term treatment if the drainage is not effectively controlled.

Drainage control

Drainage water may come from the mine, waste stockpiles, and/or tailings disposal facilities. At non-acid mines, minewater usually meets environment al requirements and stockpile and tailings impoundment surfaces only have to be treated so that surface erosion by water is prevented.

At acid producing sites, the final objective of post-operational measures is to reduce the volume and strength of acid-drainage to a level where passive techniques are sufficient to treat the residual drainage before discharge. However, in most cases, such an objective is not achieved, and a long-term treatment of acid drainage water has to be undertaken. The cost of this can be very high. In this case, the objective is to develop methods to minimize the cost; some of these are reviewed in Section 7.

Acid water treatment produces sludge, the disposal of which may sometimes cause a problem as an active tailings impoundment is no longer available.

Abandoned underground workings

For obvious safety reasons, all access to underground workings must be closed carefully. When treating an abandoned mining site, location of access to ancient workings may be a problem.

Shafts were usually sealed with wooden plugs topped with some fill, or more recently, with concrete caps. Nowadays, it is recommended to completely fill the shaft with inert material. Adits should be plugged with concrete.

Long-term subsidence has to be evaluated to determine if surface deformation could result in damage to buildings. If this is shown to be the case, subsidence control can be required if feasible.

After use, various possibilities exist as in the case of mines worked by the room-and-pillar method. Such mines have been usefully employed as high security storage, warehousing, and even for mushroom cultivation.

Abandoned open-pits

Most often, base metals open-pits are very large and backfilling with the waste overburden previously removed during mine operation is not economically feasible. Rehabilitation of such sites can then be difficult.

In some cases, abandoned pits are used for water storage purposes or recreation.

Waste stability of the pile and/or the impoundment

When non-acid generation conditions prevail, the main issues during the post-operational phase are:

- Geotechnical stability of the pile and/or the impoundment;
- Stabilization - usually by vegetation - to prevent wind and water erosion. With acid-generating tailings, ways to deal with the effects of acid seepage and run-off resulting from the oxidation of sulphides in the waste material have to be found. Furthermore, vegetation development in such conditions may be unsuccessful.

Nevertheless, even supposedly inert stockpiles and tailings are potential sources of AMD problems, and plans should strive to solve both these and stability problems.

UNEP has produced a management guideline for the restoration and rehabilitation of land and soils after mining activities (32) in which one can find recommendations for reclamation.

Revegetation of waste dumps and abandoned tailings impoundment is covered by an abundant literature (see references given in bibliography). A comprehensive approach worth particular attention is given by N.A. Williamson and M.S. Johnson in (33). It is also of interest to note that successful revegetation operations were undertaken under diverse climatic conditions such as in the U.K., Australia, Rocky Mountains in the USA, and Zimbabwe, (34), (35), (36).

Building: general mine facilities

The buildings and plant facilities usually require demolition and/or salvage.

6.2. Legislation and Financing

Reclamation of abandoned and closed mine sites is regulated by law in many countries; such practice should come into general use.

Reclamation projects should be designed by skilled staff and should be accepted by local administrative authorities before implementation.

Financial incentives should be made available to assist and encourage the reclamation of abandoned sites. The ownership of long-closed mines is sometimes hard to establish, and the current owner may not be the original mining company.

The conditions under which new mining projects are allowed to open should include provision for reclamation. Funding required for reclamation could be deposited throughout the mines operation into a special account, or other methods could be used such as bonds or self-assurance based on financial tests assessments.

6.3. Socio-Economic Impact

Mines are quite often located in areas where they constitute the main economic resource; the closure of such operations therefore has significant socio-economic impact.

The reconversion of the workforce and of the local industry depending on the mine operation should be effected if local conditions permit. Close cooperation between mining companies, governmental authorities and local communities is recommended to solve these problems in the best possible manner.

7. CONTROL TECHNOLOGY

7.1. Introduction

There are numerous methods that can be used to control the different sources of contamination in the non-ferrous metals mining industry. It should be borne in mind that no general rule exists, but that in each specific case, the constraints imposed by site and process conditions limit or dictate the option that can be chosen. Flexibility in the approach to the design and performance of project facilities is critical for achieving controls that are technologically and economically feasible.

The conditions to be integrated into siting and design decisions include: geology, hydrology, topography, water supply, infrastructure, mineralogy, metallurgy, land ownership, market, and project economics.

The purpose of Section 7 is to indicate some of the most common and effective control technologies used to address environmental concerns arising in the base metals mining industry. It is not possible to review all presently available technologies.

7.2. Water Pollution

7.2.1. Monitoring

Successful control of water pollution is based on the knowledge of the quantities and quality of all waters which may be affected by mining activities; quantities of water required during mining and beneficiation, and the quality of process waters after use.

Unless a properly designed monitoring programme has been carried out, any control measures which are taken are unlikely to result in the desired result at the optimum cost.

The main features that should be contained in a monitoring programme include:

- definition of objectives: baseline studies prior to mining; assessment of any current damage, prediction of the effects of mining and water-reuse possibilities are typical.
- selection of parameters to be measured: some of the more important factors to be measured are summarized in Table 15. These vary from mine to mine, depending on site-specific considerations. Seasonal variations must also be investigated.
- Selection of sampling locations: locations should enable a representative sample to be taken and to be easily accessible for routine sampling. There should be sufficient sampling locations to allow monitoring of all important locations at which the mine may affect water quality.
- Sampling procedures: sampling is not a simple operation and adequate equipment should be available. Taking a sample at a given depth in a lake or at the discharge of a several hundred cubic meter per hour mine water pumping station requires different equipment. Frequency of sampling depends on the possible intermittent character of the flow to be sampled. Trained personnel are most often required.
- Analysis: analysis can be carried out at the sampling stations for some parameters. Usually samples are transmitted to a qualified laboratory. Preparation of the samples may be necessary before transmission to the laboratory and such procedures have to be carefully specified. Standardized analytical methods should be selected and rigorously followed throughout, as different methods of analysis frequently give different results.

Table 15

Main Components of a Monitoring Programme

Physical	Chemical	Biological
Temperature	Conductivity	Phytoplankton
Turbidity TDS	Alkalinity	Zooplankton
Water flows	pH	Benthic organisms
	Hardness	Fish
	Colour	Water fowl
	COD/BOD	
	Nitrogen	
	Phosphorus	
	Metals	

Source: adapted from (31)

7.2.2. Main water control techniques

The physical control of volumes and routes of water at a mine site is a major task. The volume of water used in mining and beneficiation facilities should be minimized to prevent contamination of unpolluted water. Any polluted water flow should be intercepted and diverted to an appropriate place for possible treatment. The procedure implemented at Tara mines, as shown Figure 10, is an example of adequate practice.

The Tara Mine combines all flows to a single point for treatment. In many cases it is preferable to segregate flows for separate treatment, as this reduces the complexity of the treatment operation.

7.2.2.1. Underground mines

Where possible, it is recommended to collect all mine water at a single point where can be directed to: (a) a concentrator as process water (b) a treatment facility - knowing that the plant tailings impoundment is usually the best one - or (c) to the environment if its chemical characteristics allow to do so.

The opportunity of reducing the volume of underground mine water is limited: the main methods are to seal and grout old bore holes and to reduce water penetration through shaft linings.

7.2.2.2. Surface mining

Water control in surface mining operations depends on the site topography.

Where an open-pit is developed under the topographic surface, run-off water should be collected at the lowest point and dealt with as indicated in previous section. Where surface mining operations are operated on hill sides, the purpose of water control is to limit the amount of run-off water coming from upstream. Interception ditches are frequently used. Run-off waters flowing on the mining operations are collected downstream in ditches and directed to decantation ponds installed behind draining dams. Such a technique is successfully operated in lateritic nickel mines (46).

7.2.2.3. Beneficiation plant

Liquid effluent controls in beneficiation plants consist mainly of collecting any liquid spillage within the plant in one or several sumps and directing this effluent with the tailings towards the tailings disposal system.

Reagents used for the process, including flotation reagents and cyanide in gold treatment plants, require special care within the plant and in storage facilities. Holding tanks and distribution piping have to be properly designed to prevent any spillage. Reagent storage and preparation plants should be equipped with a concrete sump of sufficient capacity to contain the total quantities of stored reagents, at least for highly toxic products such as cyanide, to avoid any release in the environment in case of leakage.

Accidents while transporting large quantities of cyanide may result in environmental disasters. It is therefore recommended to establish an emergency plan to prevent such detrimental consequences.

7.2.2.4. Mining site

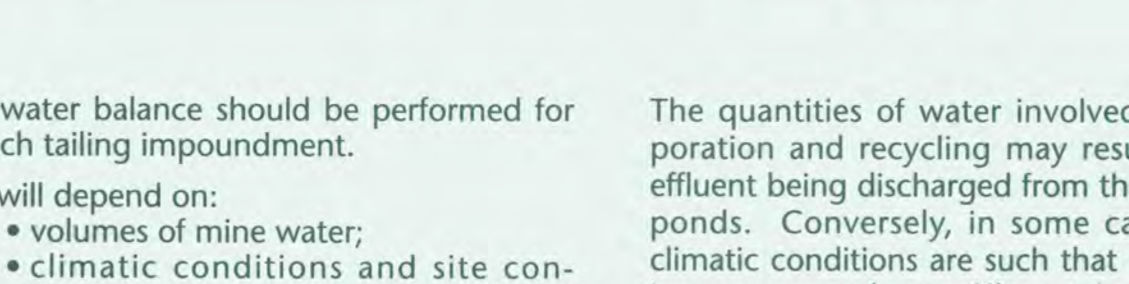
Run-off waters from the mining site should be diverted by a ditch, whenever possible.

Run-off waters from the processing site should be collected for treatment where required: tailings disposals can be used for that purpose.

Effluents and spillage from mechanical workshops often contain oil, fuels, and hydrocarbons, which generally are harmful to the flotation process. Therefore, sending them in a tailings impoundment where supernatant water is recycled should be avoided. They must be collected separately and conveyed to a specific treatment unit.

7.2.2.5. Tailings impoundment

Water flows to be taken into account in a tailing impoundment are schematically depicted by the diagram below:



A water balance should be performed for each tailing impoundment.

It will depend on:
- volumes of mine water;
- climatic conditions and site configuration which will influence rainfall and evaporation;
- nature of the ore;
- geologic characteristics of the underlying ground.

The quantities of water involved in evaporation and recycling may result in no effluent being discharged from the tailings ponds. Conversely, in some cases, the climatic conditions are such that rainfall is in excess and an effluent has to be discharged from the facility either continually or periodically. The composition and volume of such an effluent has to be such that no environmental damage will occur, either in the short or the long term.

Once again, each specific mining project is a particular case to be studied as such.

Run-off waters from the area surrounding the tailings ponds should be diverted for two main reasons:

- excessive run-off may ruin the tailings dam by submersion (cf. 4.3.3.2.);
- unpolluted run-off water should be kept separate from contaminated water. Control techniques related to run-off waters on the tailings dam and to acid-generating seepage are reviewed in Sections 7.1.3. and 7.4.

7.2.3. Control of acid mine drainage

Though contaminated waters resulting from acid mine drainage can be readily treated (cf. Section 7.2.4.) steps should be taken to reduce the volume and improve the quality of contaminated waters. Passive treatment methods should be preferred whenever technically feasible for obvious cost reasons. All techniques attempting to control one or more of the basic elements of acid generation - oxygen, water, bacteria, sulphide minerals - should be considered.

7.2.3.1. Operating mine

Prevention and control of acid mine drainage in a mine while in operation is most often difficult because of the constant evolution of underground (or surface) workings, waste and tailings disposals.

Acid underground mine and/or open-pit waters must be neutralized and have their metals removed. This can be achieved in a treatment plant specific to mine drainage, or more commonly, in the tailings ponds. Removal of metals from dilute solution in a treatment plant results in the production of concentrated heavy metal sludges which should be carefully managed to prevent their introduction into the environment.

Hydrogeologic conditions should be carefully examined: under some specific conditions, it is possible to minimize the recharge of groundwater and the motion of groundwater in the vicinity of the mine in such a way that the production of acid mine drainage can be minimized (47).

Precautions which can be taken for solid disposal include:

- selective placement/covering of acid generating material;
- avoiding or minimizing the exposure of sulphide minerals where possible;
- avoiding the use of sulphide bearing materials for the construction of dams, roads or other fill requirements;
- placing acid-producing wastes in areas where seepage can be controlled;
- segregating clean and contaminated drainage to the maximum degree feasible;
- designing and constructing drainage control facilities to accepted criteria for surface run-off intensity and duration;
- designing surface drainage facilities as an integral part of both the operational and post-operational control systems.

An underwater tailings disposal prevents the oxidation of sulphides contained in concentrator tailings. However, few data concerning the long-term impact of such a practice on the quality of the water-body used for disposal are presently available. In any case, a site-specific evaluation is recommended if such a disposal is taken into consideration.

7.2.3.2. Closed mine

When a mine has ceased operation complementary measures can be taken.

Minimizing the access of air to sulphides in underground closed mines, which is the most effective measure to reduce the rate of acid generation, can be achieved by flooding and/or sealing the mine.

Post-operational acid drainage control techniques that can be applied to waste and tailings disposals include:

- capping waste with clay, plastics, grout, asphalt, etc...;
- surface application of top soil and revegetation;
- combination of both preceding methods (39) (40).

The main disadvantage of these techniques is a cost which may be prohibitive when large waste dumps are to be treated.

Other control techniques are under investigation but have not been validated at present. They include surface covering of lime or limestone placed on waste, use of bactericides to kill bacteria responsible for acid generation, and in-situ neutralization by addition of carbonate mixed with waste (41) (42).

Studies of low-cost passive treatment systems as an alternative to conventional chemical systems have increased in recent years (43)(48). Serious consideration of these systems is necessary because acid mine drainage treatment may continue for many years after mining operations have ceased.

7.2.4. Wastewater treatment

Comprehensive information about base metal and gold mining wastewater treatment is given in Environment Canada EPS2/MM/3 publication (15). Main processes used and some applications examples are briefly reviewed in the following.

7.2.4.1. Removal of free acid and heavy metals

The most common method of chemical treatment of acid mine drainage water consists in neutralizing free acid and precipitating metals as hydroxides under alkaline conditions. As ferric hydroxide is far less soluble than ferrous hydroxide, waste water is aerated to oxidize ferrous iron which normally occurs in acid mine waters. For cost reasons, other chemical oxidants (ozone, hydrogen peroxide, chlorine, permanganates) are rarely used.

Table 16 shows the relative costs of neutralizing reagents in Canada. Calcium carbonate, which would appear to be the cheapest is not suitable in most situations because the pH that can be achieved is less than 7, a value at which most metal hydroxides do not precipitate completely. Hydrated lime is the most frequently used reagent.

Table 16

Relative Costs of Neutralizing Reagents in Canada

Alkali	Cost of Reagent/Cost of Equivalent $Ca(OH)_2$
Calcium carbonate	0.3
Calcium oxide	0.8
Calcium hydroxide	1.0
Sodium carbonate	4.7
Sodium hydroxide	16.0

Source: (15)

A consequence of the use of lime is the possible precipitation of gypsum (hydrated calcium sulphate). Precipitation of gypsum increases the quantity of sludge generated by wastewater treatment and forms a concrete-like crust which may clog equipment if not removed periodically.

The separation of precipitated metal hydroxides from the liquid phase is possibly the most difficult aspect of the treatment of acid wastewaters. Metal hydroxides precipitate as amorphous solids with low settling rates and poor sludge de-waterability. Various methods are used to improve the de-watering of hydroxide precipitates. These include the recycling of sludge to the neutralization system and the use of polymeric flocculates. Flocculates are costly reagents and the exact amount to be used is to be determined as precisely as possible. This requires bench-and-pilot case studies.

Treatment sludges contain metals removed from wastewaters. They are usually disposed of with mill tailings in separate disposal lagoons by burial in on-site landfills and in some cases in underground and open-pit mine workings. Whether the sludges are mechanically de-watered prior to disposal depends on the particular situation; in any case such a de-watering process is expensive.

All such sludge or residue disposal sites are a potential source of pollution due to hydrological processes. Hence their design, operation and eventual abandonment require careful consideration.

To reduce costs, passive treatment systems which require low capital and operational costs and little maintenance have been tested and are still under investigation (see Section 7.2.3.2.).

Figure 12 shows the acid mine water treatment system operated at Brunswick Mining's operation (New Brunswick, Canada) for metal containing acid mine water treatment. Metal hydroxide precipitation takes place in the tailings pond. The capital cost of the system was approximately CDN $800,000 (1985), and the annual operating costs were approximately CDN $550,000 (1985).

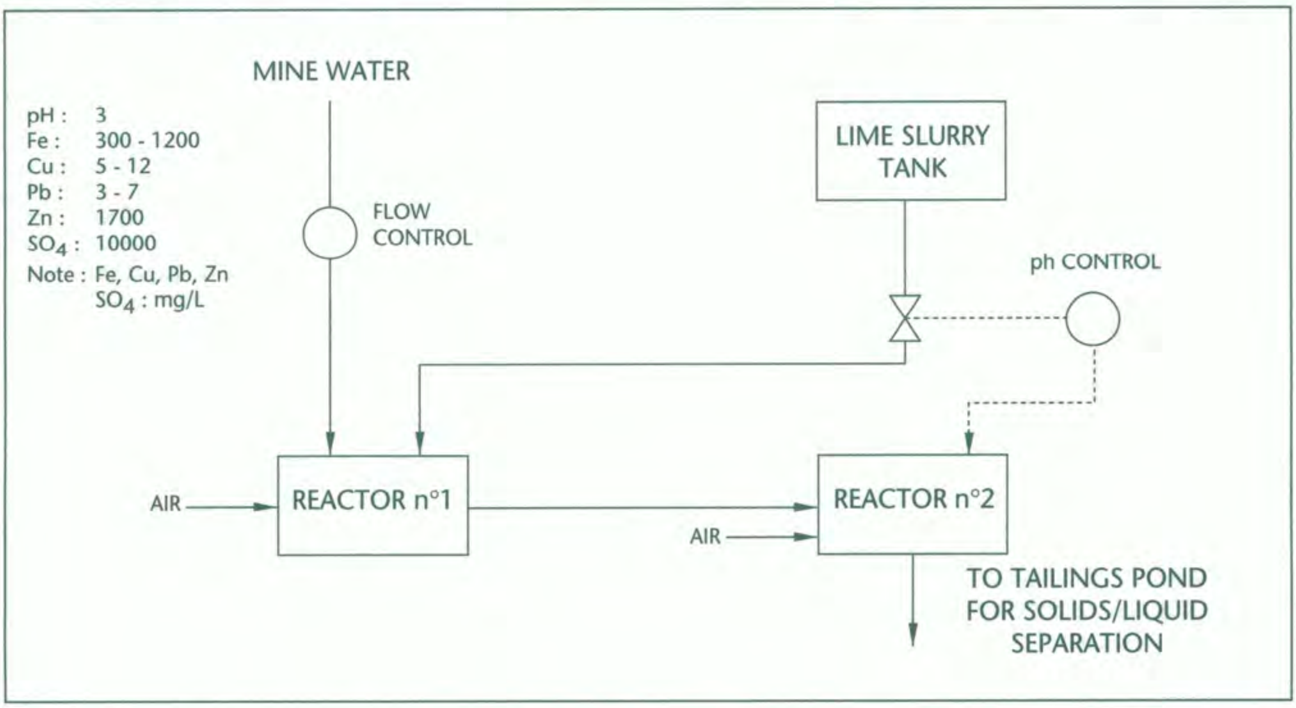


Figure 12 Brunswick Mining - acid mine water treatment system

Figure 13 shows the flow diagram for the treatment of acidic seepages at Noranda's inactive Waite Amulet mine. Sludge from the clarifier (about 4% by weight solids) is permanently disposed of in sludge drainage beds underlain by sands.

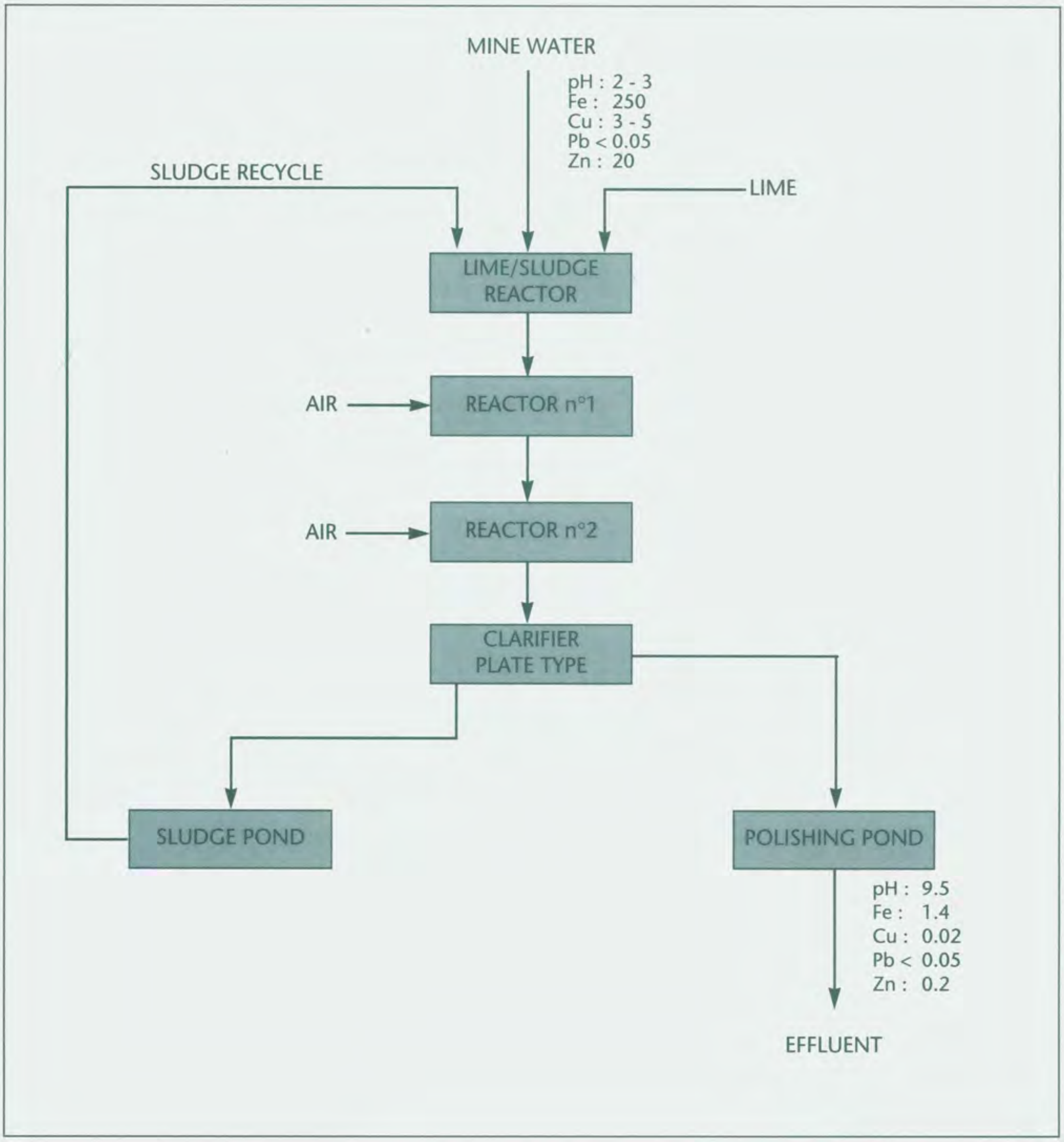


Figure 13 Waite Amulet Mine - acid mine water treatment high density sludge process

7.2.4.2. Removal of Cyanides

Wastewaters from gold mining operations can contain cyanide in the range of 100 to 400 mg/l and should be treated.

A comprehensive review of the treatment of cyanide-bearing wastewater in the gold mining industry was completed in 1987 by Ingles and Scott, and updated by Scott in 1989 (20).

7.2.4.3. Removal of thiosalts

Potential methods for thiosalt removal are reviewed in (49) and (50). Prohibitive operating costs limit the use of chemical oxidation methods in the mining industry.

Biochemical oxidation and neutralization prior to discharge into the environment is the most promising process, provided long residence time of wastewaters in ponds can be achieved. Experience of various Canadian mining operations may be found in (51).

7.2.4.4. Removal of arsenic

Wastewaters from gold-arsenopyrite mining operations may require the removal of arsenic. Arsenic can be very effectively removed by precipitation as either calcium or ferric arseniates: arsenide-containing waters should be oxidized prior to arsenic precipitation.

Co-precipitation of arsenic with ferric hydroxide at alkaline conditions is also used. Information on that subject may be found in (52) and (53).

7.3. Air Pollution

7.3.1. Measurement and monitoring

A review of the many methods which have been devised for measurement of air pollution levels is given in (54).

In the base metals mining industry, much of the air pollution is mainly due to dust. The amount of dust at a specific point can be measured with different equipment:

- standard dust deposit gauge which provides an integrated record of total fall-out over the period of exposure;
- directional deposit gauge to measure horizontally borne dust;
- smoke filter.

Methods are also available to measure total suspended particulates actually in the air.

The amount of dust collected can be measured; chemical analysis can also be done on the collected dust sample. Details about dust collecting sampling equipment can be found in (54), but also in different standards publications such as British Standard 1747 for example.

Monitoring programmes include geochemical and dust deposit gauge surveys of sensitive areas.

Measurement of certain toxic gases such as cyanide can be done by using special equipment, either portable or fixed.

7.3.2. Control of dust from point sources

The most effective way to control dust emission is to prevent its formation by controlling the handled product moisture.

Run-of-mine ore moisture depends on the hydrogeology of the deposit. Concentrates produced in the mill are frequently filtered; filtration control provides means to control concentrate moisture, and therefore its potential to emit dust. Basically, an 8 - 10% moisture content prevents dust emission from sulphide ore concentrates.

When required, water, normally incorporating a wetting agent, is used to increase the surface moisture in places where dust may be produced: in crushers, screens, ore chutes, etc... Water sprays are far more effective in preventing dust production than in knocking down dust in the air. An effective dust suppression system requires careful selection and positioning of the spraying equipment to enable pre-wetting with water.

An effective alternative at transfer points is to limit the height of fall of the product or to enclose it during its fall.

Use of totally enclosed storage areas is frequently necessary to prevent dust emission by wind from finely ground products such as mill concentrates.

In some cases, wetting the ore is impractical; removal of dust is achieved with a forced extraction system which draws dust-laden air from its point of origin into a separator.

Most commonly used separators include:

- mechanical collectors: gravity settling-chambers,cyclones;
- bag filters;
- wet scrubbers;
- electrostatic precipitation (expensive, rarely used in mining industry).

7.3.3. Control of dust from dispersed sources

Surface mining excavations, waste rock piles

These sources usually produce dust as long as they are in active use. Dust emission normally lessens rapidly after abandonment because the supply of fine particles is exhausted. At active locations of this type, water sprays, which can be automated have been found adequate.

Tailings dam

While in operation, dust emission problems are similar to those discussed previously. Chemical fixatives can be used for temporary dust control on a tailings dam. When abandoned, dust emission becomes a more significant problem due to the fine material tailings dams contain, which dries quickly on the surface. As spraying an abandoned tailings dam is not economically feasible, revegetation is usually the most effective way to control dust emission (see Section 6.1.).

Haulroads

Haulroads, where dust emission takes place by spillage from trucks and by abrasion from their wheels, are a major but intermittent dust source. The most usual approach is to spray water on the roads by means of tanker vehicles. Control is facilitated on properly compacted and graded haulroads. Paved and coated haulroads enable a very efficient dust control; such measures however are rarely practical for cost reasons.

Concentrate transportation

Flotation concentrates are fine materials, usually with a high value. If no measures are taken, losses due to spillage can be significant and costly, whatever the environmental concern.

Open trucks or railroad cars should be avoided. Wholly-sealed containers are more commonly used.

7.4. Solid Waste Disposal

Water pollution and air pollution concerns resulting from solid waste disposal are addressed in previous sections. Control technologies related to tailings and waste rock disposal stability are reviewed in the present section.

7.4.1. Tailings disposal

In selecting a site, the following conditions have to be taken into account to ensure the stability of the tailings deposit:

- adequate capacity to store the quantities of tailings projected for the expected life of the mine, with some potential for expansion in the event additional reserves are discovered;
- suitable geotechnical conditions of underlaying rocks.

Where borrowed material is used to build the tailings-containing dam, the rules applying to earth dam construction are to be used (55), (56).

Methods of construction of tailings impoundment using the coarse fraction of tailings to build the dam where given in Section 4.3.3.2. As already indicated, the downstream or centerline method is generally preferred to the upstream method, especially where severe seismic conditions prevail.

Important features, as far as tailings dam stability is concerned, include:

- homogeneity of the dam built with the coarser fraction of tailings;
- close control of the separation between coarse and fine fraction of tailings. Hydrocycloning should be preferred to spigotting;
- installation of properly sized drains where the dam is to be created;
- permanent monitoring of phreatic surface within the dam;
- control of possible seepage on the downstream slope of the dam by a complementary draining device or any other adequate measure;
- close control of the dam slope. Maximum admissible value of the slope depends on the material used to build the dam, possible seismicity of the area, etc. Usually, a 0.25 slope ensures a good dam stability;
- run-off water on the slope of the dam can carry down some sandy material. To prevent this material from being discharged into the environment, construction of a rock filtering dam is recommended.

Surface water should be diverted around the impoundment by ways of tunnels, diversion canals etc., properly designed and corresponding to accepted statistical return criteria for intensity and duration. The amount of free board provided above the maximum pond level should be selected as a function of the maximum amount of run-off water which can enter the pond during peak events. Each case has to be evaluated individually.

7.4.2. Waste rock disposal

Geotechnical considerations apply to waste rock disposals:

- suitable geotechnical conditions of underlying rocks;
- diversion of structural water around the storage area;
- proper drainage of the waste rock pile;
- design of the pile slope as a function of the geotechnical properties of stored materials.

In some cases, such as limonites in lateritic nickel ores mines, compaction is required.

Figure 14 shows an example of waste laterite material in a New Caledonia nickel mine.

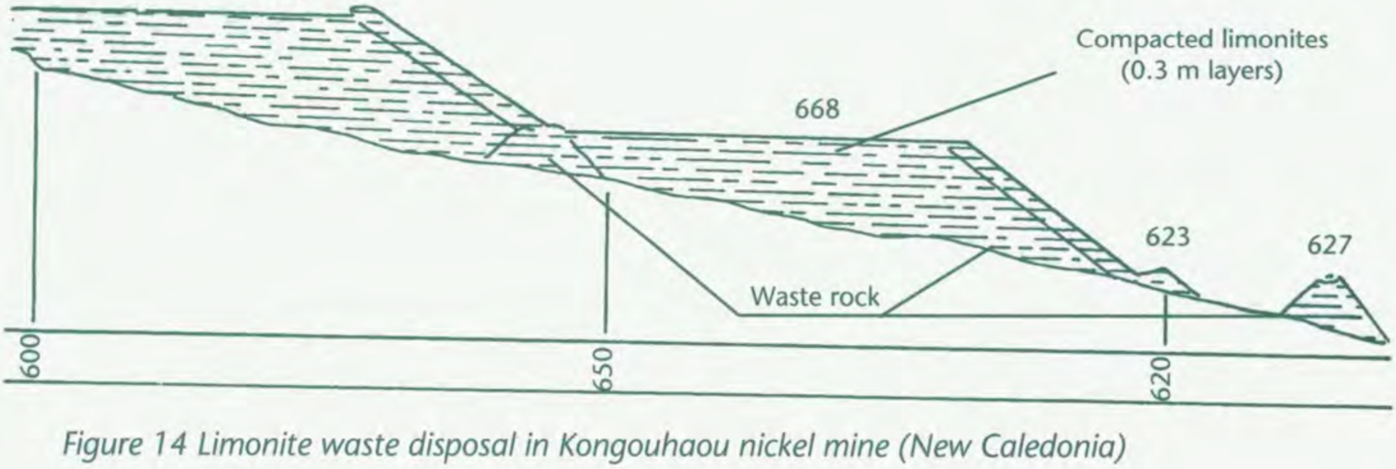


Figure 14 Limonite waste disposal in Kongouhaou nickel mine (New Caledonia)

Source: Société Métallurgique le Nickel

7.4.3. Revegetation of solid waste disposal

Revegetation of abandoned solid waste disposal was reviewed in Section 6.1.

7.4.4. Waste utilization

Waste utilisation could reduce the environmental problems of conventional disposal. However, the large amount of material involved, the frequently remote location of mines, the occurrence of undesirable elements (acid-generating minerals for example), are important drawbacks to a significant external use of mining wastes and tailings.

The most widespread use for tailings is as hydraulic backfilling for support purposes in underground mines. Usually, only the coarsest fraction is used, while the fine material has to be disposed of in a surface impoundment.

7.5. Subsidence

The alleviation of subsidence damage may be undertaken either by precautionary measures on surface to protect installations, or by modification of the mining method so as to minimize deformation of the surface.

Precautionary measures on surface include:

- avoiding locating new installations in areas of geological discontinuity such as the outcrop of faults;
- designing new buildings in subsidence areas either completely rigid or completely flexible;
- flexible pipes and flexible joints for pipelines (water, sewage, etc.).

Precautions which have to be taken vary widely and depend on many parameters such as the geometry and the nature of the mineral deposit. They include leaving safety pillars of mineral and/or filling with backfill the excavated areas.

7.6. Noise and Vibration

7.6.1. Noise

Basic techniques available to control noise in mining industry include:

- changing to slower running equipment, altering the design, construction or installation;
- improving maintenance;
- replacing compressed air powered equipment by electrical devices;
- using properly designed air silencers, resilient mountings;
- isolating the source by enclosure of noisy fixed equipment;
- increasing the noise absorption between the source and the listener by locating noisy activities as far as possible from areas of potential nuisance and by erecting some form of screening structure between the source and the listener, taking into account the direct and the indirect (or diffracted) sound effect as indicated in Reference (23).
- screens used in practice include walls, waste banks and trees.

7.6.2. Vibration

Controls available to the mine operator to minimize air blast over-pressure and blasting vibration nuisance include:

- avoid overcharging;
- design blasting patterns in conformity with maximum instantaneous charge permissible;
- limit the maximum instantaneous charge detonated by use of delays;
- use low energy rather than high energy detonating fuse;
- avoid blasting when unfavourable atmospheric conditions prevail (temperature inversions, adverse wind direction, low cloud ceiling).

Determination of vibration propagation laws in the specific conditions of the mine may be required; the use of experts in this area is recommended.

8. WORKING ENVIRONMENT

8.1. Main Occupational Hazards and Health Effects

Safety and health issues in mining operations are in a number of ways similar to those of any industrial complex. However, due to the nature of mining operations, there are a number of areas which require special consideration.

For example, by its very nature, mining involves the handling, transportation and processing of large quantities of material. Thus, the chemical composition of the material, its concentration in the working environment and control of some parameters are critical to assure workers' health.

8.1.1. Airborne contaminants

8.1.1.1. Airborne particles

Airborne dust is a hazard in underground and surface mining operations: it can also be of concern in beneficiation plants, especially in crushing operations.

The dust has essentially the same composition as the material which is mined, namely: (a) the ore containing the minerals; (b) waste rock removed from drifts, adits, etc. which are excavated to give access to the ore, and (c) any surface material which is disturbed.

In the base metal mines covered in this document, two very toxic metals mined are lead and nickel. In addition, other hazardous components associated with base metal ores, include free crystalline silica (quartz), lead (also associated with other ores), cadmium (very toxic, but which usually occurs as insoluble sulphides), and, to a far lesser extent, arsenic associated with gold in sulphide ores. A number of polymetallic ores contain mercury, the presence of which must definitely be investigated due to its high toxicity. High quartz content is usually found in dust resulting from hard rock mining for lead and zinc ore.

Health hazards resulting from exposure to dusts are related to their chemical and, for certain types, their mineralogical composition. For example, free silica can cause silicosis only if in the crystalline form. It should be said that, although it is important to know the chemical and mineralogical composition of the ores and rocks to be mined, such determinations must also be made for the dust itself since the proportions of the different components are not necessarily the same in the dust as in the parent rock.

The health hazard is also related to the deposition site of the dust in the respiratory system. For soluble particles which can pass into the blood stream after deposition in the respiratory system, any particle which can be inhaled is of interest for the assessment of the health risk. On the other hand, for insoluble particles whose action is in the innermost parts of the lung such as the alveoli, for example silica dust, the particles which are of interest for the assessment of the health risk are only those whose size characteristics allow their penetration and deposition in the pulmonary spaces (i.e., respiratory bronchioli to the alveoli), the "respirable" fraction of the dust (the characterization of respirable dust in terms of size is presented in subsection (8.2.1.)

Consequently, the assessment of the health hazards resulting from exposure to dusts requires the determination of their chemical and mineralogical composition, particle size, concentration of particles in the air, as well as the conditions and time exposure.

Chronic exposure to free crystalline silica dust, under certain conditions of concentration, particle size and time, may lead to silicosis, a pneumoconiosis which is a serious, progressive and irreversible disease (fibrosis of the lung). (ILO, 1983; WHO, 1984b and 1986a).

The main health effect associated with exposure to toxic metals, such as lead, nickel, cadmium, mercury and arsenic, is systemic intoxication (NIOSH, 1977, 1985, 1981-88; Patty, 1981; WHO, 1980, WHO EHC 1, 3, 18 and 101). The effect is related to the absorption of the metal by the organism; this is related to its solubility. Lead can occur with varying degrees of solubility whereas arsenic and cadmium most frequently occur as insoluble sulphides. Nickel can cause sensitization of the skin and dermatitis.

Since the composition of ores and surrounding rocks varies, other hazardous agents (besides the ones hereby mentioned) can occur; therefore it is important that, for each case, the constituents be determined and their toxicology researched in adequate sources of reference.

8.1.1.2. Gaseous contaminants

The main hazards in underground mines come from exhaust gases released by diesel engines and blasting fumes. Contaminants which have to be carefully monitored are carbon monoxide and nitrogen oxides.

In diesel engine exhaust gases, in addition to carbon monoxide and nitrogen oxides, significant amounts of heavy hydrocarbons, sulfur dioxide, and carbon dioxide may also occur (Enjalbert, 1988). Urethane foam systems used to seal brattice and leaks may release diphenyl methane diisocyanate (Burgess, 1981).

Nitrogen oxides and ozone can accumulate when electric welding is performed in confined spaces. This may happen in maintenance work in mines, for example.

Methane is not common in base metal mines, but carbon dioxide resulting from decay of timbers in abandoned mines or emanating from rock strata is not uncommon.

Attention should also be paid to decaying organic material which can lead to hydrogen sulphide, and also to oxygen deficiency. Oxygen deficiency can be a serious hazard in underground mines: whenever there is the presence of reducing ore, the oxygen deficiency can be aggravated.

Effects of asphyxia by carbon monoxide are well-known (WHO EHC No 4) and the alarming feature is that, due to its low solubility in water, it may penetrate unsuspectedly (with little reaction of the upper respiratory tract) into the alveoli and cause a delayed pulmonary edema.

Aldehydes and sulfur dioxide (WHO EHC No 8) are irritants to the upper respiratory tract; heavy hydrocarbons, for example, benz - d - pyrene (fine aerosol), can be carcinogenic (IARC).

8.1.1.3. Specific Hazards in Beneficiation Plants

In addition to some airborne contaminants such as dusts from crushing (already mentioned), some toxic chemicals can occur in beneficiation plants. Other harmful agents include organic collectors (xanthates, etc.) utilized as a powder.

Cyanide

Cyanide is extremely toxic when ingested. One particularly dangerous characteristic is that it penetrates through skin; therefore skin contact as well as inhalation must by all means be avoided.

Mercury

The standard approach for gold recovery from placer gravity concentrates was amalgamation with mercury. However, it is quite clear that the use of mercury in metallurgical processes is being reduced.

Amalgamated copper plates were used as a gravity-concentrating device for fine gold slimes all over the world until amalgamation was replaced to avoid the use of mercury. Unfortunately, mercury is still used in some parts of the world.

8.1.1.4. Occupational exposure limits

Occupational exposure limits in France, USA and USSR for main airborne contaminants in the base metals mining industry are shown in Table 17. Exposure limits may also be set for chemical agents, heat, noise and radioactivity in certain situations.

Table 17

Occupational Exposure Limits in Various Countries

Contaminants	France mg/m³ (1)	U.S.A. mg/m³ (2)	U.S.S.R. mg/m³ (3)
Dust containing free silica	10* x + 2	0.1	-
Lead	0.15	0.15	0.01 - 0.07
Cadmium (dust and salts)	-	0.05	-
Nickel + Copper (ores)	-	-	4
Zinc (sulphide)	-	-	5
CO	55	55	20
NO_2	6	6	2

Source: (66)

(1) Average exposure limits.
(2) Threshold Limit Values - AGGIH - 1984 - 1985.
(3) Threshold Limit Values - GOST - 12.1.005 - 1976.

** Amount of respirable dust as a function of x = percentage of quartz in respirable dust.*

8.1.2 Noise and vibration

8.1.2.1 Noise

Workers in underground and surface mines are often exposed to high noise levels emitted, for example, by drilling equipment, loaders, scoop-trams, diesel locomotives, trucks. In beneficiation plants, grinding mills and air compressors are the noisiest equipment.

Continuous exposure to intense noise may cause hearing loss. Temporary hearing losses, also called auditory fatigue, are decreases in hearing capacity which last only a limited period of time. With prolonged and repeated exposure to high noise levels, the hearing loss may become permanent and irreversible. Evidence from workers with hearing losses resulting from occupational exposure to noise shows that such losses start and are most prominent in the frequencies around 4000 Hz. As the hearing loss progresses, it involves other frequencies to the point that the person becomes permanently deaf. While there is already some risk of hearing loss at 75dB(A), many countries have set the regulatory standard at 85 dB(A) on the basis of "acceptable risk".

Noise can also have extra-auditory effects which include cardiovascular changes and fatigue.

The health effects of noise have been covered in a WHO Environmental Health Criteria document (WHO EHC 12 1980a), and discussed in specialized literature (ILO, 1983; ISO, 1973; Kryter, 1970; NIOSH, 1973a, 1977a; Burns, 1973; Patty, 1978).

Noise levels as specified by EEC regulation are as follows: 85dB(A) for daily exposure level with no peak sound pressure exceeding 200 PA (or 140 dB(A)). Regulations in different countries vary but are usually between 85 dB(A) and 90 dB(A) for an 8-hour work day, with higher levels allowed for shorter periods.

8.1.2.2. Vibration

The main vibration problem in mines arises from the use of hand pneumatic tools. The localized vibration may lead to:

- neurovascular alterations in the hands, including Raynaud's phenomenon (i.e. "dead hand", "white fingers");
- bone alterations, including cysts on some of the bones of the hand;
- muscular weakness and muscle atrophy;
- degenerative alterations, primarily in the ulnar and median nerves;
- tenosynovitis.

The health effects of vibration have been fully discussed in the specialized literature (NIOSH, 1977a and 1983a; ILO, 1983).

8.1.3. Thermal environment

Health problems due to heat stress are very common in deep underground mines. The main sources of heat in mines are the adjacent rock walls (the increase in rock temperature with depth varies from as much as 1°C per 150 m), adiabatic auto-compression of the intake air and machinery and human occupancy.

The four environmental factors which determine heat stress are: temperature, humidity, velocity of the air and radiant heat. In many operations in the mining industry, combinations of these factors may result in serious heat stress to the workers, who may be performing heavy work and producing large amounts of body heat, thus adding appreciably to the heat stress problem. Air temperature and relative humidity affect thermal comfort in inverse proportion. For instance, 100 per cent humidity at a temperature of 30° C are practically unendurable conditions.

In open-cast mines, with light coloured rocks (such as quartzite), there is increased radiant heat load both from the sun and from reflected infra-red radiation. This not only increases the heat stress but also affects the eyes if not adequately protected. When the rocks are dark coloured (such as basalts), there is absorption of heat and the hot rock then acts as an additional heat source.

The most usual types of heat disorders (WHO, 1969; 1977; Patty, 1978; NIOSH, 1977a, 1980b; ILO, 1983; Desoille et al, 1978) include heat stroke, heat cramps, water depletion, heat exhaustion (dehydration).

In addition, abrupt changes in temperature when leaving a hot mine under cold external climatic conditions may aggravate existing respiratory illness.

8.1.4. Atmospheric pressure

In mines located in high altitudes, the lack of oxygen may be of concern when no acclimatization period is allowed.

8.1.5. Illumination

Lack of illumination can present safety problems because obstacles may not be easily identified when visibility is poor.

8.1.6. Biological agents

The mine climate conditions (temperature and humidity), the presence of stagnant water, of scraps of food, and lack of hygiene may contribute to the transmission of parasites and other biological agents; for example, ankylostomiasis and mycosis are still widespread in some countries. Also, there may be rodents and insects, some of which may act as vectors in the transmission of diseases (ILO, 1983; NIOSH, 1977).

8.2. Environmental monitoring

In order to establish the extent of exposure to occupational hazards in underground and surface working areas, it is recommended to establish routine monitoring programmes. These programmes can be extended to measure off-site impacts onto neighboring populations, and animals and plants.

8.2.1. Airborne contaminants

The presence of air contaminants in the workplace can be assessed through techniques of air sampling and analysis. The concentration of airborne contaminants in the workplace air varies with respect to time and location, therefore an important aspect of hazard evaluation is to ensure "representativeness" of any sampling procedure. For this, an adequate sampling strategy must be designed and followed. The main decisions when designing a sampling strategy refer to "how", "where", "when" and "for how long" to sample, as well as to the required "number" of samples (Valic, 1983; WHO, 1984b; Linch, 1981; Patty, 1978, 1979).

8.2.1.1. Airborne particles

Airborne particles can be evaluated by means of continuous-sampling devices or by direct-reading instruments. The latter are not recommended in the case of dust causing chronic effects since the results are not cumulative.

Sampling for airborne particles in the work environment has been covered in WHO publication (WHO, 1984b) and is well discussed in the specialized literature (ACGIH, 1983, 1985; Linch, 1981).

As well, it is useful to consult (58).

For airborne dusts, which may cause pneumoconioses, it is important to evaluate the "respirable" fraction, i.e. the portion of the airborne dust which can penetrate to the pulmonary spaces.

There are different criteria for size separation of the "respirable" fraction of dust (WHO, 1984b). The most widely accepted are those recommended by the Medical Research Council of Great Britain (Great Britain, 1952) and the United States Atomic Energy Commission (US AEC, 1962), the latter slightly modified and adopted by the American Conference of Governmental Industrial Hygienists (ACGIH, 1988).

The frequency of sampling depends on the situation. An initial survey should be carried out and, if the air concentrations are found to exceed the adopted standards, control measures should be implemented. Evaluation should be made right after the implementation of control measures in order to evaluate their efficiency and thereafter routinely, often at about one-year intervals.

It is also necessary to analyze the airborne dust for chemical and mineralogical composition. In order to assess the risk of silicosis, it is necessary to evaluate the content of free crystalline silica.

Dust containing lead, nickel, cadmium and arsenic compounds should be evaluated in a similar way. However, when dealing with a soluble compound, the total dust should be measured.

8.2.1.2. Gases and vapours

Sampling procedures for airborne contaminants in the gaseous state are basically the following:

(a) utilization of direct-reading instruments;

(b) collection of an air sample, for further analysis;
(c) withdrawal from an air sample of the airborne contaminant in question for further analysis;
(d) utilization of passive monitoring (or sampling) devices, also called "passive dosimeters", "passive samplers", or "diffusive samplers".

Unless a direct-reading device is used, the collected sample has to undergo further analysis, which is carried out in a specialized analytical laboratory. There are analytical techniques particularly useful for occupational hygiene applications. The National Institute for Occupational Safety and Health (USA) carries out an extensive programme dealing with such sampling and analytical methods which are periodically published (NIOSH, 1984a); the UK Health and Safety Executive publishes methods for determining hazardous materials, e.g., HSE, 1981 and 1983.

There are direct-reading devices with built-in alarm systems. Such instruments are very useful for atmospheres which can be immediately dangerous to life, for example, where there is the hazard of excessive concentrations of carbon monoxide, or of appreciable oxygen deficiency. In fact, there are instruments which combine alarms both for oxygen deficiency and for carbon monoxide. Hydrogen cyanide is another substance for which such instruments are available.

8.2.2. Physical agents

8.2.2.1. Noise

To determine the extent of workers' exposure to noise, measurements must be made and the results compared to the adopted standards. It is also necessary to observe the exposure time.

Fundamentals of acoustics, basic concepts and definitions, and noise measurement, including details on sound level meters and other measuring equipment, have been widely discussed in the specialized literature (AIHA, 1975b; Darabont, 1983; Hassall & Zaveri, 1979; ILO, 1976, 1980a, 1983a & b; INRS, 1980; NBS, 1976; NIOSH, 1973, 1978a; Peterson & Gross, 1974; WHO, 1980b). An essential source of information are the international standards and recommendations by the International Standards Organization *(ISO) - "Technical Committee 43 - Acoustics" (ISO, 1973, 1974, 1975a & b, 1979a & b, 1982b), and the International Electrotechnical Commission ** (IEC) (IEC, 1979, 1982, 1984).

The basic instruments for noise measurements are:

- sound level meter;
- noise dosimeter;
- frequency analyzer;
- impact or impulse noise meter;
- calibrator.

A practical guideline on noise evaluation and control is being prepared by the Office of Occupational Health, WHO, Geneva.

8.2.2.2. Vibration

Assessment of exposure to vibration is difficult; however, there is an international standard (ISO, 1986). The subject is discussed in the literature (NIOSH, 1983a; ILO, 1980; ACGIH, 1988).

8.2.2.3. Heat stress

The main environmental parameters which influence heat stress are temperature, humidity, movement of the air, and radiant heat, which are accounted for, in addition to type of activity and sometimes clothing, in a number of indexes designed for the evaluation of heat stress.

The Wet Bulb-Globe Thermometer (W.B.G.T.) Index is very simple to determine, requiring inexpensive and easily available equipment. The index accounts for the factors which affect the environmental heat load (i.e., air temperature, humidity and movement, as well as radiant heat) and its interpretation considers the main factors affecting the metabolic heat load (i.e., type of activity performed by the workers). The methodology has been widely discussed in the specialized literature (ACGIH, 1988; Goelzer, 1983a; ILO, 1983; NIOSH, 1973; WHO, 1977).

* Lists of available standards in the field of acoustics can be obtained from:

ISO - Case Postale 56, 1211 Geneva 20, Switzerland,

IEC - 3, rue de Varembe, 1202 Geneva, Switzerland.

8.3. Monitoring of Workers' Health Parameters

Techniques to monitor health parameters include: biological monitoring to detect overexposure and to determine whether the working environment is under adequate control, and early detection impairment caused by occupational exposure, which helps to identify hypersensitive workers as well as contribute to the assessment of the control strategy.

These techniques do not replace control measures, but rather help to detect an otherwise overlooked failure in the strategy to control exposures.

Relevant biological monitoring procedures exist for the assessment of exposures to lead, cadmium, arsenic, mercury (WHO, 1980 and 1986c; ILO, 1983), including blood and urine analysis.

Chest X-rays for the early detection of silicosis should be interpreted in the light of the ILO International Classification (ILO, 1983). The frequency depends on the dustiness. If there is good dust control, the X-ray exam should take place every 3 years (WHO 1986c). However, regulations differ among countries.

It should be emphasized that one should not wait for radiographic changes to appear before taking action; this is already too late as the changes are irreversible and even progressive. What has to be done is to control dust in the work environment and utilize such tests to monitor the situation and detect failures in the control strategy.

Lung function tests are particularly useful for the diagnosis of lung diseases not readily demonstrated by radiographic findings.

A characteristic feature of noise-induced hearing loss is that it starts around the frequency of 4000 Hz. Therefore an audiometric test to evaluate the hearing capacity can detect early changes before the impairment is noticeable by the patient.

For workers in noisy jobs, audiometry should be carried out during the pre-employment medical exam to establish the hearing states of the worker. Audiometry is well discussed in the literature (ILO, 1980 and 1983).

8.4. Control Strategies

8.4.1. General considerations

Measures to protect the working environment include engineering controls, adequate work practices and personal measures. Control technology is discussed in the specialized literature (Burgess, 1981; Corn, 1983; Goelzer, 1983b; ILO, 1977, 1983; NIOSH, 1973).

Environmental control measures consist of changes in the work processes and/or working environment with the objective of eliminating hazardous agents or reducing them to levels acceptable as to not be harmful to health. Such measures include:

- substitution of harmful materials;
- changes in process or equipment;
- ventilation, which can be local exhaust, or, general (dilution) ventilation;
- enclosures, wet methods (for dust only);
- good housekeeping, adequate storage;
- labelling, warning signs.

Adequate work practices consist of specific work procedures designed to minimize the generation and release of, as well as the exposure to, hazardous agents in the work environment. Ergonomic factors also, are of particular relevance to the mining industry and include bad work postures and inadequate handling of loads (NIOSH, 1981).

Personal control measures consist of measures related solely to the workers and include:

- personal protective equipment;
- limitation of exposure time;
- personal hygiene (including clothing and personal protection);
- health education.

As to personal protective equipment, distinction should be made between two types: (a) that which should be used independently of environmental controls, to protect from accidents, for example: hard hats, gloves, safety boots, safety glasses, etc., and (b) personal protection for hazards which can be controlled by engineering methods, for example, respiratory and hearing protection. Category (b) should be considered as a last resort, while environmental control measures are being designed and implemented (temporary solution), when environmental measures are technically unfeasible, for sporadic or short duration operations, or, for operations involving a very small number of workers.

Since it is not always possible to control exposure to hazards, personal protection is needed. In every case, training in the use of such protection should be provided.

Measures of a medical nature such as pre-employment and periodic medical exams are discussed in the next section. However, all measures, including those for accident prevention (safety) should be integrated and well coordinated.

8.4.2. Application of control technology to specific operations and specific hazards

8.4.2.1. Dusty operations

Wet methods can greatly reduce the dust generated. For example, hydraulic drilling can significantly reduce dust emission during blast-hole drilling (Burgess, 1981; ILO, 1977 and 1983)(59).

Use of water sprays in operations such as transfer of dusty material and crushing is highly efficient (Grenier, 1988; ILO, 1983; Jayaraman and Jankowski, 1988).

Wetting agents can be used to increase efficiency of wet methods for dust suppression (Le Bouffant et al. 1975; Metrico and Pelizza, 1974; Bolstol et al. 1981; Breuer, 1980). Water detergent (Burgess, 1981) is one wetting agent.

A properly designed ventilation system is the most important element of air quality control in an underground mine. This is a very specialized field and ventilation engineers should be consulted (ILO, 1983; Burgess, 1981).

If at all unfeasible to reduce dust to acceptable levels, anti-dust masks and, if necessary in critical situations, respirators should be used.

8.4.2.2. Blasting

Blasting can generate both dust and gaseous contaminants. Measures to control exposures resulting from blasting operations include:

- segregation in time, that is, wait sufficient time before re-entry;
- wetting down with water before blasting;
- ventilation.

It should be emphasized that respirators for particles do not protect against contaminants in the gaseous state.

8.4.2.3. Noise

All efforts should be made to reduce noise to acceptable levels, for example utilization of less noisy equipment. When it is not feasible to achieve the required reduction, hearing conservation programmes should be implemented including limitation of exposure, personal protection and routine audiometric tests.

Workers in noisy areas should undergo periodic audiometric examinations, not only to detect the most sensitive but also to check the efficacy of hearing protection when this is the control method utilized.

Noise control is well discussed in the specialized literature (ILO, 1983). The ILO has a publication (ILO, 1980b) specifically dedicated to the problems of noise and vibration.

8.4.2.4. Heat stress

In mines, the prevention of heat stress relies mainly on general ventilation and personal measures

- acclimatization;
- adequate work-rest schedules;
- adequate clothing;
- adequate water and salt ingestion;
- adequate work practices;
- medical surveillance.

In certain cases, mechanization of operations can contribute to reduce heat stress, as a lower level of activity decreases the internal heat generation, hence the internal heat load.

8.4.2.5. Reagents used in beneficiation plants

Some chemical reagents used for the flotation of base metal minerals were shown in Table 5. Some of these have significant toxicity either as liquids or dusts. For example inhalation of organic collectors (Xanthates, etc.) as a powder should be avoided. The use of dust masks is recommended when handling these products.

Special care should be taken with cyanide used for the froth flotation of base metals and gold ores processing, as well as with mercury, still in use in some gold processing plants.

Cyanide

A list of the symptoms of cyanide poisoning and detailed procedures for rescue and first aid in cases of poisoning should be posted in the plant where cyanide is used, as well as in the infirmary. It is recommended to place an adequate emergency kit at all places where there is any risk of cyanide poisoning.

The major cyanide vendors are concerned that their customers apply proper safety standards when using cyanide which adequately protect the workplace as well as the environment. Some of them provide seminars for potential users.

A comprehensive information review regarding the use of cyanide and the hazards involved can be found in a publication by the Department of Mines, Western Australia (Dept. of Mines, 1986)(60). When handling solid cyanide, the use of adequate respiratory protection, as well as of skin protection and gloves is necessary.

Mercury

The use of adequate respiratory protection is recommended when handling mercury, keeping in mind that mercury also occurs as a vapour and penetrates the skin.

8.5. Medical Surveillance

Miners should undergo pre-employment as well as periodical medical examinations with a frequency depending on the potential hazard or occupation.

Pre-employment examination is of particular importance to ensure that workers' health and physical capacities are compatible with the demands of their jobs.

Periodical medical exams should detect the most sensitive workers and also contribute to the evaluation of the efficiency of the adopted control strategy. Medical supervision should include biological monitoring and early detection of health impairment due to occupational exposure (WHO, 1986c) to the potential risks in question (previously discussed).

The role of the occupational physician should be essentially preventive. When mines are in an isolated location, the mine medical service should take on extensive responsibilities in the health protection field, as well as to render curative medical services to the miners, their families, and frequently the surrounding population. Prevention and treatment of endemic diseases (e.g malaria) may have to be included.

8.6. First Aid and Emergency Procedures

A particularly important task of the mine medical service is that of organizing and/or supervising the first-aid service. Formally considered, first aid is help given an injured person before he receives medical attention, but in practice it is all non-professional medical assistance. Training of first-aid attendants is very important and should aim at situations requiring immediate treatment to save life or to prevent compounding an injury through improper care. International organizations such as the Red Cross provide first-aid training in many areas upon request.

Although standardized first-aid kits are sold by many suppliers, the mine medical service has to take in the responsibility to elaborate kits adapted to the mine environment. Information about first-aid kits of miners may be obtained from specialized agencies, e.g., the US Bureau of Mines. Depending on the location of the mine, it may be necessary to employ full-time medical staffs and maintain hospital facilities if possible.

As to emergency procedures for accidents, the installation of emergency evacuation facilities on every mine site is necessary. Depending on the mine situation, such facilities may include a good quality road connection to the nearest hospital, an air strip or a helicopter landing zone. Effective means of communication (telephone, radio, etc.) are required.

8.7. Safety and Accident Prevention

To protect the working environment, the prevention of accidents and occupational diseases must be considered as a necessity. It requires the workers to abide by general safety regulations and a Mineral Industry General Code - Mines and Quarries - to be drafted, as well as internal work rules established by either the company or appropriate government agencies, in consultation with workers' representatives.

The workers should be given specific training enabling them to fully comprehend the applicable texts and directives; any non-observance of the same should result in disciplinary penalties. Sanctions should be taken against managements who do not adhere to the regulations concerning the provision of a safe working environment.

8.7.1. Recommendations for a specific Mineral Industry Safety Code

This set of measures should be instituted in the same spirit as regulations now in use or being revised in other countries, such as France and other EEC members. It is advised for the texts to be drafted jointly by government bodies and representatives of the mining operators in consultation with worker's representatives so as to take into account the evolution of local conditions: occupational diseases, existing or future equipment, accident and fatality statistics, etc.

This code should include rules related to:

- transport, use and storage of explosives;
- mining methods;
- ventilation;
- hot stopes;
- dust;
- noise nuisance;
- personnel vehicle and mobile equipment circulation in underground or in surface operations, including underground haulage trains;

- shafts and declines giving access to working stopes;
- fire protection;
- storage of fuels;
- belt conveyor;
- shaft sinking;
- internal combustion engines;
- isolated personal work in mine stopes;
- work in high elevation areas;
- electricity.

8.7.2. Creation of company's Safety and Health Committee

The Safety and Health Committee (SHC) complements the action of personnel representatives who take care of the safety and hygiene conditions underground and in the surface installations; they are entitled to intervene when they have good reason to think that hazardous conditions exist.

The following composition is recommended for the SHC:

- the head of the mining unit or his deputy as chairman;
- members of the workforce;
- the company's doctor, the head of the Safety Department, the person in charge of the Training Department.

Among others, the SHC duties shall comprise:

- general: protection of the workers health and safety, improvement of the working conditions, analysis of the potential risks;
- specific: set up of internal by-laws, new provisions, inquiries into accidents, safety measures training.

8.8. Sources of Information

Information regarding occupational hazards in the mining industry is available in mining handbooks (Cummins 1973; Hustralid, 1982; Dowon and Stocks, 1988).

A list of references is given in Appendix 1.

9. SMALL SCALE GOLD MINING

9.1. Definition

Small scale mining refers to artisanal gold mining carried out by single workers or by small groups of workers. Some governments in Africa or in Latin America have attempted to organize such operators into co-operatives in order to better monitor and control their activities, to improve their economic viability, and to minimize the loss of revenue due to the smuggling of gold through the borders with neighbouring countries.

Small scale gold mining takes place in many countries, especially in developing nations such as the Philippines, Brazil, Venezuela, West or Central Africa, etc . This phenomenon is not new and has existed for centuries in some of them where it is periodically and sporadically revived by the high gold price cycles, and to a lesser extent by discoveries of new concentrations.

9.2. Processes

By nature, small scale mining can only take place where gold mineralization occurs near the surface and in fairly unconsolidated rocks. The most frequent are deposits in river bed alluvions, eluvions and colluvions, and altered upper parts of quartz veins.

The extraction processes used by the workers are for the most part fairly crude and they rely almost solely on human power. They may consist, depending upon the local conditions, of winnowing (wind fanning), water panning or sluicing. The concentrates produced may be hand-sorted, or amalgamated in mercury, or smelted.

9.3. Environmental Impact

Mining activity has many potential impacts or the environment such as.

- Mining itself may be hazardous when workers attempt to excavate at depth with no, or only primitive, roof support. Fatalities are frequent but do not discourage the other workers: the bodies are abandoned on the spot and mining continues around and even underneath the fatal working place.
- Dust emitted by winnowing creates a serious hazard resulting in lung lesions and other respiratory diseases (the quartz or clay dust clouds can be seen from distances of several kilometers): poisoning of workers may be induced by the improper use of mercury in the amalgamation processes.
- Environmental nuisances include anarchic destructions of the environment, such as deforestation (Brazil), replacement of grazing or agricultural lands by huge chaotic areas of overturned dirt. Intensive use of mercury amalgamation in some areas results in land and water pollution.
- Social turmoil is often a consequence of the "gold rush fever" that sometimes results in small areas with no facilities or infrastructure supporting population in precarious human and working conditions. Under these circumstances, epidemics would be impossible to control and the benefits from mining accrue to only a few.
- Diseases new to the area may be brought in by immigrant miners.

9.4. Measures to Implement

Recommendations for control of small scale mining have to be made with caution because of the important role of local governments who often ban company mining activities in order to reserve land for "traditional" mining to achieve equitable sharing of non-renewable resources.

Some sensible measures, however, can be taken if based upon a rationalization of the existing mining traditions. They should encompass:

- making sure there is legislation applicable to small scale mining, and that it is enforced;
- providing technical assistance through the creation of co-operatives of individual workers with skilled mining and process supervision;
- providing some simple mining and process mechanical equipment to be substituted for hazardous and wasteful techniques, as well as infrastructure development (housing, medicare, security). Use of mercury amalgamation should be prohibited;
- setting commercial circuits of gold collection through which the workers are paid a fair price for their production, placement with a minimal delay, so as to discourage the influence of illegal dealers;
- implementing systematic geological and technical surveys of the mining areas in order to determine the economic viability of their exploitation by industrial methods, in which case the individual operators would be given incentives to join the mine workforce.

Several countries are already pursuing this course of action and their example could serve as a model for implementation in others.

10. PROCEDURES FOR ENVIRONMENTAL CONTROL

10.1. Policies and Approaches to Environmental Control

Solving environmental issues one at a time is generally not cost-effective. A single-media approach to pollution control often merely shifts the problem to other sectors, where it exerts a different but equally damaging impact. Extracting toxic contaminants from wastewater, and disposing of the resulting hazardous sludge on land is one example of this.

It is now generally acknowledged that the most cost-effective environmental approach:

- systematically integrates environmental issues into the project planning phase;
- considers all environmental media (air, water, soil);
- prefers to reduce waste at its source rather than install expensive treatment afterwards;
- makes maximum re-use of waste components.

This approach depends on an effective mobilization of technical and human resources. Two actions which can help a company to achieve such organization are:

(i) a corporate environmental policy with clear goals, responsibilities, actions and targets;

(ii) establishment of a proper environmental management structure to ensure implementation of the policy, to allocate adequate resources, and to monitor (and report) the results.

Such action should be initiated at the highest level in a company. Assigning environmental responsibility to lower level staff without senior level back-up is generally unsuccessful.

Industry associations can assist their members by reporting on environmental issues, publishing environmental guidelines, providing information backup, and organizing environmental awareness and training seminars. Some national associations have already produced policies as a guide for their member companies. The recent environmental policy adopted by the Mining Association of Canada is reproduced below.

Government, for its part, needs to provide a regulatory framework that defines the environmental performance objectives to be met, and the control measures to be used. This regulatory framework may be complemented by actions which provide technical infrastructure, training facilities and information on lower impact mining options. Government monitoring and environmental review can complement in-house environmental auditing carried out by companies. Environmental assessment is an important planning function. For small-scale mining, co-operative bodies or the government must assume the environmental management roles normally attributed to enterprises.

The following guidelines for action reflect the ouput of a number of recent consultative meetings between government and industry.

Environmental Guidelines for Mining Activities

1. Environmental management should be given a high priority, during the planning of mines, during the licensing process, and through the development and implementation of environmental management systems. Environmental management includes early and comprehensive environmental impact assessments, pollution control and other preventive and mitigative measures, monitoring and auditing activities, and emergency response procedures.

2. Environmental accountability within industry and government rests with the highest management and policy-making levels.

3. Employees at all levels have an individual responsibility for environmental management. Management must ensure that adequate resources, staff, and requisite training is available to implement environmental plans.

4. Effective management requires the participation and dialogue with the affected community and other directly interested parties on the environmental aspects of all phases of mining activities.

5. Environmentally sound mining technologies and practices should be adopted in all phases of mining activities. There is a need to increase the transfer of appropriate technologies which mitigate environmental impacts, including those from small-scale mining operations.

6. Best current practices should be adopted in all mining projects to minimize environmental degradation, notably in the absence of specific environmental regulations.

7. Infrastructure, information systems, service, training and skills in environmental management need to be reinforced in relation to mining activities.

Adapted from conclusions of the UNDTCD/DSE International Round Table on Mining and the Environment, Berlin, 24-28 June 1991.

10.2. Regulatory Framework for Environmental Protection during Mining

Mining, like most industrial activity, is subject to laws, regulations, standards and norms in every aspect of its operation. Among these are laws aimed directly at regulating environmental impact. In some cases environmental impact may be mitigated by clauses inserted into other laws, including mining laws themselves.

A noteworthy feature of environmental requirements is that few of them can be fully respected by making last-minute changes in an already established operation. Compliance with environmental norms must be planned into a project, not added on afterwards.

In order to ensure such consideration of environmental performance, early review of project proposals through Environmental Impact Assessment (EIA) has become common. In many countries, such an assessment is now a legal requirement. Of course much will still depend how eventual operations are managed on a day-today basis. For existing mines, therefore, management tools such as environmental auditing are coming into more widespread use. Such tools are not yet legal requirements, however a number of countries and international administrations are examining the possibility of making such auditing a statutory requirement in the future.

Assessment and auditing are essentially review instruments. The actual environmental performance to be achieved is commonly set by regulatory instruments such as regulations, standards, and licences which are established under a variety of different laws. This section looks at such instruments under three principal areas:

- mining laws;
- environmental legislation;
- other legislation on health, safety, and chemicals.

The Mining Association of Canada - Environmental Policy

Member companies of The Mining Association of Canada are committed to the concept of sustainable development which requires balancing good stewardship in the protection of human health and the natural environment with the need for economic growth. Diligent application of technically proven and economically feasible environmental protection measures will be exercised throughout exploration, mining, processing, and decommissioning activities to meet the requirements of legislation and to ensure the adoption of best management practices.

To implement this policy, whether in Canada or abroad, the member companies of The Mining Association of Canada will:

- *assess, plan, construct and operate their facilities in compliance with all applicable legislation providing for the protection of the environment and the public;*
- *in the absence of legislation, apply cost-effective best management practices to advance environmental protection and to minimize environmental risks;*
- *maintain an active, continuing self-monitoring programme to ensure compliance with government and company requirements;*
- *foster research directed at expanding scientific knowledge of the impact of industry's activities on the environment, of environment/economy linkages, and of improved treatment technologies;*
- *work pro-actively with government and the public in the development of equitable, cost-effective and realistic laws for the protection of the environment; and*
- *enhance communications and understanding with governments, employees and the public.*

10.2.1. Mining Laws

In many countries there exist specific mining laws which aim to regulate the sector in several important aspects. Environmental requirements such as waste disposal, occupational safety, control of water contamination are sometimes incorporated into such laws. Mining laws are rarely specific enough to provide a sound basis for broad environmental control programmes, nevertheless, this approach is a useful first step towards pollution control in countries where discharge standards etc. do not yet exist.

For example the Mining Act of Uganda states that:

"Any person who shall, in the course of prospecting or mining operations, or work connected therewith, permit any poisonous or noxious matter to be discharged into any natural water supply shall be liable to a fine (... 10,000 shillings). ...".

Note that this law does not define what is "poisonous" or "noxious", nor does it enable control of purely environmental factors such as high nutrient discharge etc.

Some environmental matters that mining laws can incorporate into specific schedules or regulations are:

- safety of structures and operations through technical norms given as annexes. Limiting exposure to chemical and explosive hazards may be included;
- establishment of wastewater retention and treatment techniques, and safe management of contaminated runoff;
- soil erosion control and revegetation procedures during the operation as well as afterwards;
- a requirement to prepare plans for solid waste and soil disposal prior to approval of operations;
- mandatory reclamation and restoration of sites and disturbed areas, and removal of all unused structures and machinery;
- proper transport, storage, handling and disposal of chemical substances, including detailed schedules for specified chemicals of concern such as pesticides, oils, fuels, extraction chemicals;

Enforcement of such provisions is necessary if they are to be of any practical use. Special environmental training of enforcement personnel is necessary, as ecological issues are often poorly understood by industrial inspectorates.

10.2.2. Environmental Legislation

Environmental concerns commonly cover a broad range of ecological, conservation, pollution and health issues. Often each of these are covered by separate laws, perhaps administered by different agencies.

Among the matters that may be covered by environmental legislation are:

- environment assessment (EIA), or other environmental planning. Regulations may require only that a formal assessment report be prepared for approval, or else may involve some form of project permit. The structure of an EIA report is discussed in Section 10.3.;
- nature conservation, national parks, protection of flora and fauna, endangered species and special scientific sites. Mining and ancillary activities may be limited in certain zones, or require special measures to avoid impact on natural species or the environment;
- cultural heritage and landscape protection. Impact on indigenous cultures may also be regulated;
- water quality - Water laws or pollution regulations may limit discharges into waterways of acid mine drainage, of wastewater and also polluted runoff. Appendix 2 gives examples of effluent regulations in USA and Canada;
- air emissions may be regulated under "clean air" laws to reduce the incidence of toxic gases or dusts from mining and refining operations;
- control of soil contamination by wastes and chemicals. Introduction of weeds and noxious species of animals and plants can be a particularly important concern in sensitive regions such as wilderness areas or island ecologies. Protection of local commercial species (e.g. fish) may also be a factor needing to be addressed;

- other issues such as noise, waste disposal and chemicals control are also sometimes regulated by environmental laws when they do not appear under health or other legislation.

Issues such as the above may be passed as specific environmental regulations under other Acts, or may be combined into a single basic environmental law. Appendix 2 shows examples of water and air regulations adopted in the USA and Canada, however, the format and content of regulations differ from country to country.

10.2.3. Environmental Quality Standards and Criteria

Environmental criteria, standards and norms are a particular form of subordinate legislation which may appear under almost any basic law, although they are most often associated with environmental regulations. In effect they provide the numerical limits to which industrial operations must be designed and managed. They can include:

- water quality in streams, or effluent discharge standards;
- air emissions, and/or workplace air quality;
- noise emissions, or exposure;
- waste disposal, especially waste materials permitted to be dumped;
- human exposure to dust, toxic chemicals or radioactivity;
- quantities of chemicals or fuels and explosives stored under specified conditions.

There are no international environmental standards which apply around the world; each region has its own needs and must set its own standards accordingly. The exception is where international norms have been suggested for human health e.g. drinking water. These are often copied into national laws. Large companies sometimes develop their own internal standards to guide their project planners. Again, some examples of standards from Canada and the USA are found in Appendix 2.

In the past, industrial effluent discharge standards have often been set on the basis of what is technically achievable in a plant. This depends on available treatment technology and may be more, or less, than the assimilative capacity of the local environment. While this may seem to be a practical approach for the engineer it does not pay any particular regard to the needs of the environment. Where possible, the specifying of environmental quality goals is a more satisfactory approach.

Achieving compliance with a diverse set of environmental standards can be a complex task. Project planners should be closely involved, since if compliance is not built into a project at the outset it may be difficult to make the changes later. Subsequently, good co-ordination at the operational level is required to ensure even compliance across all issues.

In many countries a comprehensive system of environmental regulations and standards will not exist yet. In such cases the mining company must itself ensure that all likely issues are competently addressed. This was for example explicitly stated in the MAC policy shown in Section 10.2. Determining the precise balance of objectives, costs, and benefits will not always be easy, however, common sense and advice from informal consultative groups can provide a great deal of guidance.

10.2.4. Other Legislation

Issues that are now often regarded as environmental may also be found in other Acts such as health, welfare, safety, agriculture, transport, public land management and industry. Each country has its own legal system, and only general guidance can be given as to where to look. As a rule the principal other laws which may apply are:

- health regulations (both public and workplace health). These have a number of variations. Basic sanitation at remote mining sites, and prevention of the spread of insect-borne diseases in tropical and other environments may require special measures by mining enterprises. This must be done in a way compatible with other environmental objectives, i.e., safe discharge of sewage effluents, pesticide impact on wildlife;

- occupational health and safety is a particularly important aspect of engineering operations and includes limiting exposure to noise, hazardous environments (as discussed earlier), physical safety of workers at sites, and safe handling of fuels and chemicals. The provision of safe working conditions themselves was discussed elsewhere in this document. Health legislation may limit human exposure to certain chemicals such as solvents, dusts, or to radioactive elements in the air;
- chemical laws, especially in industrialized countries, may cover the labelling and use of certain specified chemicals, or may prohibit the use of specified biocides, solvents, oils (e.g. PCB's) at industrial sites. Transport and storage of chemicals may be specified under legislation, as well as handling precautions for toxic, flammable or caustic materials on the site. Fuel storage may be subject to certain precautions;
- waste disposal, especially of chemical residues. This may be subject to certain restrictions, or may require special permits. Heavy metal residues, lubricating oils, transformer oils (PCBs), pesticide containers (and surplus pesticides themselves), solvent and paint residues, caustic cleaners and corrosion inhibitors are among the chemicals used in considerable quantities in ancillary operations whose disposal may be difficult. There may be limitations on the use of waste oil for dust suppression on roads.

10.2.5. Enforcement

The effective enforcement of environmental and safety legislation is one of the most difficult aspects of environmental control. As a rule this should be carried out by personnel not attached to departments concerned with promoting industrial production, although of course a close working relationship should be maintained. Where more than one government department is concerned with enforcement of regulations, co-operation in inspection may reduce the load on individual inspectorates, especially for remote sites such as mines. This usually requires a certain amount of additional training for field staff. Again, for remote sites, an agreed self-monitoring regime may also be established through the permit system.

Effective enforcement requires that adequate staff and resources are made available. To this end the industrial licence and permit fees in many countries are set so as to recuperate some of these expenses.

10.3. Environmental Assessment

10.3.1. The Purpose of EIA

The role of EIA is to contribute to the decision-making process by focussing on the environmental issues surrounding major projects. The EIA process serves as input to such decision-making, so as to allow environmental considerations to be placed alongside economic, social and political factors. Nevertheless, the consideration of environmental impacts often leads to the identification of alternative options, and of mitigating measures, and as a result can have a major influence on the design of a project.

10.3.2. EIA Methods and Techniques

Screening and Scoping

EIA is applied to projects that potentially have significant environmental impacts. Accordingly, it is first necessary to "screen" projects for their likely consequences, and to identify the main issues that should be examined ("scoping"). In practice screening and scoping will overlap to some extent. Numerous aids such as interaction matrices, checklists etc. have been developed to assist with screening and scoping. An example of a matrix developed by the Institution of Engineers in Australia is shown in Table 18.

Assessing Direct and Indirect Impacts

Many environmental effects arise directly from the release of a pollutant, from disturbance of habitat, or other changes in the surroundings. Because environmental factors are often related, a change in one particular environmental component will often cause indirect change in others as well. EIA must therefore explore the interrelationships within environmental systems, as well as predicting simple stimulus effects.

Key Steps to EIA

EIA is a dynamic process of examination, review, and reformulation of project options until a consistent view emerges of the likely impact of the various options. The key steps in this cyclic process are:

- identification, i.e. what will happen as a result of the project?
- prediction, i.e. what will be the extent of the changes?
- evaluation, i.e. are the changes significant?
- mitigation, i.e. what can be done to reduce the impact?

The last step in the EIA process is documentation of the considerations and of the conclusions. This is sometimes by way of a formal Environmental Impact Statement (EIS), but other formats of reporting may also be suitable. A sample outline of an Environmental Assessment Report adapted from the World Bank is found at the end of this section.

10.3.3. EIA as a Regulatory Requirement

Many countries have made the EIA process mandatory for certain activities. Large mining projects are generally among these. The legislation commonly defines the type of project for which EIA is required, the type of study or report to be submitted, its timing and the means of public review. Normally projects cannot commence until a formal decision has been made by the responsible authorities or minister.

Many development and leading institutions now also require environmental assessment before approving funds for mining projects. The above table shows the criteria for project assessment required by the Norwegian Agency for Development Co-operation (NORAD).

10.3.4. Preparing an EIA

The carrying out of an EIA is a specialized activity requiring environmental expertise and insight in addition to the technical knowledge about the project itself. Accordingly, a multi-disciplinary team is usually assembled to research further information, to evaluate the impacts, and to propose practical alternative options. Extensive use is made of baseline environmental information. Where this does not already exist, a first step will need to be baseline monitoring and surveys. It is clearly helpful if such surveys are already carried out during the technical feasibility studies for the mine, as this will save considerable time later.

In preparing an EIA for a mining project, care should be taken to include a description of the project, including the sequence of area development and disposal sites. Under process description the EIA should pay particular attention to tailings ponds, overflows and runoff of rainwater. The lifespan of the mine should be discussed, including progressive remedial measures of revegetation, AMD control and decommissioning.

Example of Project Assessment Criteria

Mining projects should be submitted to a more detailed assessment if they fulfill one or more of the criteria set out below, or if insufficient information is available to answer "no" with a reasonable degree of certainty.

Will the project:

- *create substantial pollution problems, and a risk of polluting land outside the actual mining area?*
- *create substantial waste disposal problems?*
- *create a risk of accidents which may have serious consequences for the local population and the natural environment?*
- *affect areas which support animal and plant life worthy of conservation or areas with particularly vulnerable ecosystems?*
- *lead to major changes in the landscape?*
- *affect areas with historic remains or landscape elements which are of importance to the population?*
- *change the way of life of the local population in such a way that it leads to a considerably increased pressure on the natural resource base?*
- *lead to major conflicts with regard to existing land use and ownership of land?*
- *obstruct, or lead to substantial changes in, the local population's exploitation or use of natural resources other than those directly affected by the project?*

Source: NORAD, 1989

10.4. Environmental Monitoring and Auditing

Monitoring is necessary for several reasons. For example, it is necessary to have baseline information about environmental quality before operations begin, and to monitor periodically the impact of the operation on water quality (surface and groundwater), on native species, on chemical contamination of soils and on human health.

Ongoing monitoring of the operation itself can pinpoint vulnerable aspects of the operation e.g. unsafe chemical storage, unsafe waste disposal, poor performance of treatment plant, poor maintenance of safety equipment.

Monitoring not only serves environmental ends. Excessive contaminants in wastewater may indicate economic loss of raw or refined material, and general operating inefficiencies.

When administrative and managerial factors are also monitored, the process is called environmental auditing. This checks the effectiveness of the environmental control personnel, the adequacy of company policies and directives, the consistency of purchasing procedures, and the efficiency of laboratory services, for example.

An audit gives an overall view of the company's ability and effectiveness in environmental control.

10.5. Environmental Management within a Company

As was indicated in Section 10.1, it is essential to adopt a systematic approach to environmental management if the key impacts are to be effectively minimized. This is greatly assisted by a formal environmental policy which guides both the environmental and the production personnel.

It is important for the company to set formal line responsibility for achieving environmental goals, and of keeping within regulatory standards. Such responsibility should rest with senior personnel and be, if possible, separated from day to day supervision of production. Personnel should have environmental expertise and skill. Regular reporting should occur to top management, and periodic audits carried out. There should be adequate finance and personnel to carry out the necessary actions.

The establishment of effective monitoring and reporting systems is one of the first tasks for an environmental manager. This will involve both equipment and personnel. Interpretation of monitoring data may require specialist staff if large numbers of samples, or critical parameters, are involved.

Effective collaboration with production personnel will always be required to ensure that performance norms are known and respected, and that appropriate operational measures are taken to avoid or reduce environmental impact. It is to facilitate such collaboration that an explicit company policy on environment is useful.

Communication will also be required with the public and with government agencies. Many companies have incorporated the modalities of such communication into their policy.

10.6. Emergency Planning

Mining operations rarely generate major accidents which endanger local populations. Such is not always the case in regards to waste storage concentrator tailings disposal facilities in particular. Many old disposal sites were not built with a high safety factor in mind. Some old disposal schemes continue to operate even if the mine is upgraded.

Tailings disposal particularly may be hazardous in some circumstances, mainly in high seismicity or precipitation areas. It is recommended to establish, in such cases, emergency plans complementary to general emergency planning for natural and technological accidents which exist in all countries. These emergency plans should be elaborated by the specific mining industry, in co-operation with government administration and the local community.

The UNEP Industry and Environment Programme Activity Centre has developed a Handbook on Awareness and Preparedness for Emergencies at the Local Level (APELL), to which one may refer (61).

Environmental Assessments Should Address the Issues Below

Natural hazards. *Is the proposed project likely to be affected by natural hazards, such as earthquakes, floods, or volcanic activity? If so, what specific measures will be taken?*

Biological diversity. *Will the project further threaten endangered plant and animal species, critical habitats, or protected areas?*

Tropical forests. *Will the project have a negative impact on tropical forests? Will the project design include arrangements to protect and manage wildlands, or make arrangements for compensatory measures?*

Wetlands. *Will the project have an impact on wetlands, including estuaries, lakes, mangrove and other swamps, or marshes?*

Coastal and marine resources management. *Has the project design included the protection of coastal resources, including coral reefs, mangroves, and wetlands?*

Watersheds. *If the project involves dams, reservoirs, or irrigations systems, will it promote the protection and management of watersheds?*

Dams and reservoirs. *Has the project addressed the specific environmental issues involved in planning, implementing, and operating dam and reservoir projects?*

Land settlement. *Have analysts reviewed the complex physical biological, socio-economic, and cultural aspects involved in land settlement?*

Agronomical. *Has the project adequately addressed the selection and use of fertilizers, herbicides, insecticides, fungicides, and nematicides, including application and disposal procedures and effects on surface and groundwater?*

Industrial hazards. *Does the project design include measures for the prevention and management of industrial hazards?*

Hazardous and toxic materials. *Does the project propose to use, transport, store, and dispose of hazardous and toxic materials in a safe manner?*

Cultural properties. *Is the project committed to protecting archaeological sites, historical monuments, and historic settlements?*

Tribal peoples. *Does the project affect the rights of tribal peoples, including traditional land and water rights? Are induced development and other sociological aspects important? Will the project result in induced development (secondary growth of settlements and of demand for infrastructure)?*

Transboundary impacts. *Does the project have any potential transboundary impacts, for example, on clean air and water?*

International treaties and agreements on the environment and natural resources. *Will the project be subject to current and pending treaties and agreements on the environment and natural resources?*

International waterways. *Will the quality or quantity of water flows change?*

Adapted from: The World Bank

Sample Outline of an Environmental Assessment Report

Environmental assessment reports should be concise, limited to significant environmental issues, and aimed at project designers, and project decision-makers, including financiers. The level of detail should be commensurate with the degree of potential impacts. The report should include the following sections:

1. Executive summary. A summary of significant findings and recommended actions.

2. Environmental regulations. The policy, legal, and administrative framework related to the project. This is especially important in the case of co-financed projects when the requirements of many organizations must be accommodated.

3. Project description. A detailed description of the project, including its technical, geographic, ecological, economic, social and temporal context. Include any off-site investments required as part of the project, for example, pipelines, roads, power plants, water supply, housing, storage facilities.

4. Baseline data. The study area's dimensions and a description of relevant physical, biological, and socio-economic conditions, including any changes anticipated before the project commences.

5. Analysis of alternatives. Alternatives to the proposed project, including the "no action" option. This section examines the potential environmental impacts, capital and recurrent costs, institutional capacities, training, and monitoring requirements for all design, site, technology, and operational alternatives.

6. Environmental impacts. The positive and negative impacts likely to result from the proposed project, and comparison with alternatives. This section reviews the extent and quality of available data, identifies key gaps in data, estimates uncertainties associated with predictions, and specifies topics that do not require further attention.

7. Mitigation plan. Feasible, cost-effective mitigation measures that may reduce adverse impacts on the environment to acceptable levels. The plan should consider compensatory measures if mitigation cannot be implemented effectively.

8. Monitoring plan. This section recommends a monitoring plan, its implementation, by a designated monitoring agency or individual, and includes cost estimates and other pertinant information such as training.

9. Appendices.

- *Personnel and organizations involved in the environmental assessment.*
- *Persons and organizations contacted, including addresses and telephone numbers.*
- *References. Written materials used in study preparation. This is especially important given the large amount of unpublished documentation often used.*
- *Record of interagency/forum meetings. This includes lists of both those invited and those that actually attended, as well as a summary of the discussions.*

Adapted from: The World Bank

Table 18 - Impact Matrix for Mining

Environmental Effects / Development		Exploration Prospecting - Surveys - Drilling - Sampling	Opencast Mining - Overburden stripping - Blasting - Dewatering - Crushing Undergroup Mining - Methods used - Ventilation system - Dewatering Dredging - Floating plant - Pond formation	Ore Processing - Water supply - Washing plant - Process used - Stockpiling - Wastewater treatment - Wastewater disposal	Tailings - Tailings dam - Run-off control	Rehabilitation - Contour shaping - Planting - Overburden use	General - Surface infrastructure - Access roads - Energy source
BIOLOGICAL ENVIRONMENT	Forest Shrubland Grassland Herbfield (alpine) Sand/Shingle/Rock Cropland Urban land Lakes Rivers Estuaries Inter-tidal Marine Wetlands						
PHYSICAL ENVIRONMENT	River regime Erosion/Land stability Sedimentation Surface water Ground water Agricultural soil Foundation materials Climate/Atmosphere Nuisance (noise, dust, smell) Landform						
SOCIAL ENVIRONMENT	Public Participation Employment Settlement Land value Existing land uses Risks and anxieties Personal and social values Historical/Cultural Landscape/Visual Recreation						

Source : (62)

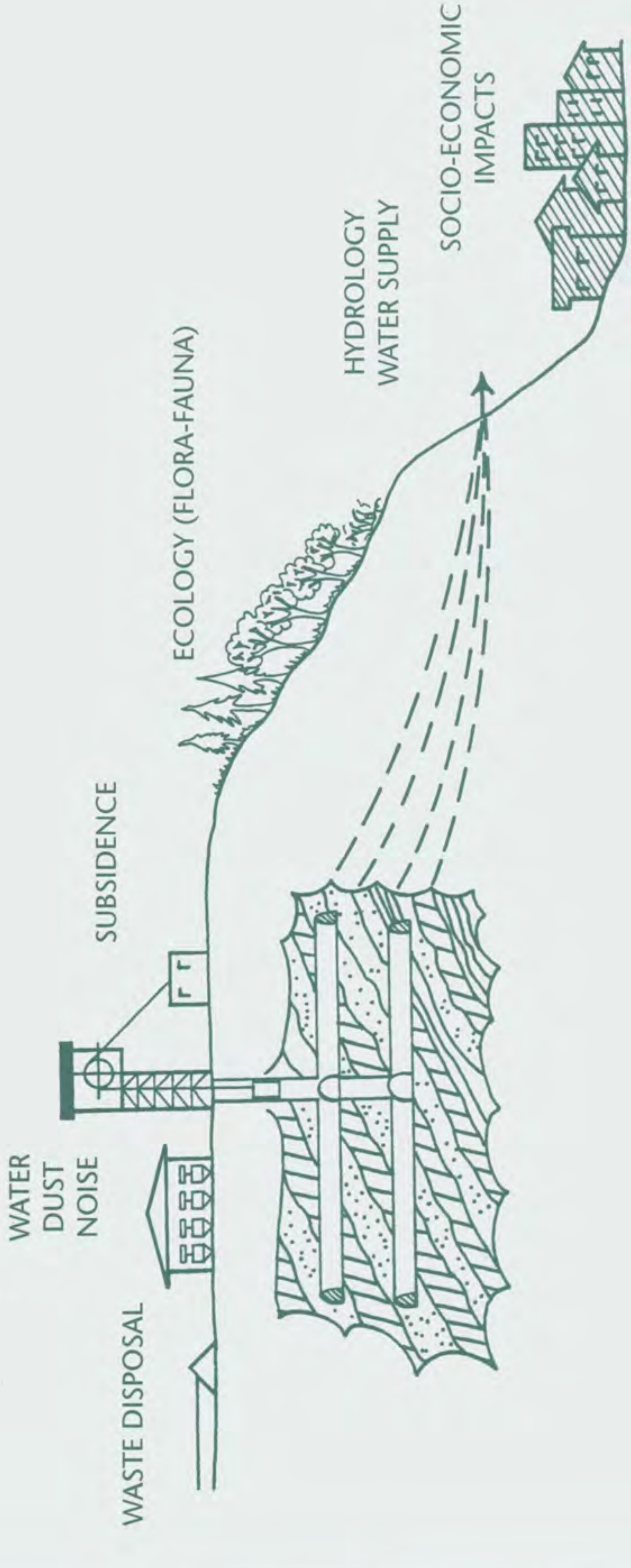


Figure 15 Mining project - main environmental aspects

APPENDIX I

FURTHER READING

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APPENDIX II

EXAMPLES OF ENVIRONMENTAL REGULATIONS

Two specific United States Environmental Protection Agency (EPA) regulations which apply the United States mining industry, and one Canada Government regulation are given here. They are related to base metal mine waste effluents and air particulate contaminants in metallic mineral processing plants.

These regulations are given for purely illustrative purposes and in no way can be considered as universally applicable to the mining industry.

I. USA: EXAMPLE 1

Subpart J-Copper, Lead, Zinc, Gold, Silver and Molybdenum Ores Subcategory

§ 140.100 Applicability: description of the copper, lead, zinc, gold, silver, and molybdenum ores subcategory.

(a) The provisions of this Subpart are applicable to discharges from (1) Mines that produce copper, lead, zinc, gold, silver, or molybdenum bearing ores, or any combination of these ores from open-pit or underground operations other than placer deposits;

(2) Mills that use the froth-flotation process alone or in conjunction with other processes, for the beneficiation of copper, lead, zinc, gold, silver, or molybdenum ores, or any combination of theses ores;

(3) Mines and mills that use dump, heap, in-situ leach, or vat-leach processes to extract copper from ores or ore waste materials; and

(4) Mills that use the cyanidation process to extract gold or silver.

(b) Discharge from mines or mines and mills that use gravity separation methods (including placer or dredge mining or concentrating operations, and hydraulic mining operations) to extract gold ores are regulated under Subpart M.

(c) Discharge from mines (including placer or dredge mining, and hydraulic mining operations) or mines and mills that use gravity separation methods to extract silver from placer ores are not covered under this part.

(d) The provisions of this subpart shall not apply to discharges from the Quartz Hill Molybdenum Project in the Tongass National Forest, Alaska.

§ 440.101 (Reserved)

§ 440.102 Effluent limitations representing the degree of effluent reduction attainable by the application of the best practicable control technology (BPT).

Except as provided in Subpart L of this part and 40 CFR 125.30 through 125.32, any existing point source subject to this subpart must achieve the following effluent limitations representing the degree of effluent reduction attainable by the application of the best practicable control technology currently available (BPT):

(a) The concentration of pollutants discharged in mine drainage from mines operated to obtain copper bearing ores, lead bearing ores, zinc bearing ores, gold bearing ores, or silver bearing ores, or any combination of these ores in open-pit or underground operations other than placer deposits shall not exceed:

Effluent characteristic	Effluent limitations	
	Maximum for any 1 day	Average of daily values for 30 consecutive days
	Milligrams per liter	
TSS	30	20
Cu	30	15
Zn	15	75

Effluent characteristic	Effluent limitations	
	Maximum for any 1 day	Average of daily values for 30 consecutive days
Pb	6	3
Hg	002	001
pH	(*)	(*)

** Within the range 6.0 to 9.0*

(b) The concentration of pollutants discharged from mills which employ the froth flotation process alone or in conjunction with other processes, for the beneficiation of copper ores, lead ores, zinc ores, gold ores, or silver ores, or any combination of these ores shall not exceed:

Effluent characteristic	Effluent limitations	
	Maximum for any 1 day	Average of daily values for 30 consecutive days
	Milligrams per liter	
TSS	30	20
Cu	30	15
Zn	10	5
Pb	6	3
Hg	002	001
Cd	10	05
pH	(*)	(*)

(*) Within the range 6.0 to 9.0

(c)(1) Except as provided in paragraph (c) of this section, there shall be no discharge of process wastewater to navigable water from mines and mills which employ dump, heap, in situ leach or vat leach processes for the extraction of copper from ores or ore waste materials. The Agency recognizes that the elimination of the discharge of pollutants to navigable waters may result in an increase in discharges of some pollutants to other media. The Agency has considered these impacts and has adressed them in the preamble published on December 3, 1982.

(2) In the event that the annual precipitation falling on the treatment facility and the drainage area contributing surface runoff to the treatment facility exceeds the annual evaporation a volume of water equivalent to the difference between annual precipitation falling on the treatment facility and the drainage area contributing surface runoff to the treatment facility and annual evaporation may be discharged subject to the limitations set forth in paragraph (a) of this section.

(d) (1) Except as provided in paragraph (d) of this section, there shall be no discharge of process wastewater to navigable waters from mills which extract gold or silver by use of the cyanidation process. The Agency recognizes that the elimination of the discharge of pollutants to navigable waters may result in an increase in discharges of some pollutants to other media. The Agency has considered these impacts and has adressed them in the preamble published on December 3, 1982.

(2) In the event that the annual precipitation falling on the treatment facility and the drainage area contributing surface runoff to the treatment facility exceeds the annual evaporation, a volume of water equivalent to the difference between annual precipitation falling on the treatment facility and the drainage area contributing surface runoff to the treatment facility and annual evaporation may be discharged subject to the limitations set forth in paragraph (a) of this section.

(e) The concentration of pollutants discharged in mine drainage from mines producing 5,000 metric tons (5,512 short tons) or more of molybdenum bearing ores per year shall not exceed:

Effluent characteristic	Effluent limitations	
	Maximum for any 1 day	Average of daily values for 30 consecutive days
	Milligrams per liter	
TSS	30	20
Cd	10	05
Cu	3	15
Zn	10	5
Pb	6	3
As	10	5
pH	(*)	(*)

(*) Within the range of 6.0 to 9.0

(f) The concentration of pollutants discharged in mine drainage from mines producing less than 5,000 metric tons (5,512 short tons) or discharged from mills processing less thant 5,000 metric tons (5,512 short tons) of molybdenum ores per year by methods other than ore leaching shall not exceed:

Effluent characteristic	Effluent limitations	
	Maximum for any 1 day	Average of daily values for 30 consecutive days
	Milligrams per liter	
TSS	50	30
pH	(*)	(*)

(*) Within the range 6.0 to 9.0

(g) The concentration of pollutants discharged from mills processing 5,000 metric tons (5,512 short tons) or more of molybdenum ores per year by purely physical methods including ore crushing, washing, jigging, heavy media separation shall not exceed:

Effluent characteristic	Effluent limitations	
	Maximum for any 1 day	Average of daily values for 30 consecutive days
	Milligrams per liter	
TSS	30	20
Cd	10	05
Cu	30	15
Zn	10	5
As	10	5
pH	(*)	(*)

(*) Within the range 6.0 to 9.0

(h) The concentration of pollutants discharged from mills processing 5,000 metric tons (5,512 short tons) or more of molybdenum ores per year by froth flotation methods shall not exceed:

Effluent characteristic	Effluent limitations	
	Maximum for any 1 day	Average of daily values for 30 consecutive days
	Milligrams per liter	
TSS	30	20
Cd	10	05
Cu	30	15
Zn	1.0	5
As	1.0	5
pH	(*)	(*)

(*) Within the range 6.0 to 9.0.

§ 440.103 Effluent limitations representing the degree of effluent reduction attainable by the application of the best available technology economically achievable (BAT).

Except as provided in Subpart L of this part and 40 CFR 125.30 through 125.32, any existing point source subject to this subpart must achieve the following effluent limitations representing the degree of effluent reduction attainable by the application of the best available technology economically achievable (BAT):

(a) The concentration of pollutants discharged in mine drainage from mines that produce copper, lead, zinc, gold, silver, or molybdenum bearing ores or any combination of these ores from open-pit or underground operations other than placer deposits shall not exceed:

Effluent characteristic	Effluent limitations	
	Maximum for any 1 day	Average of daily values for 30 consecutive days
	Milligrams per liter	
Cu	030	015
Zn	15	075
Pb	06	03
Hg	0002	000
Cd	010	005

(b) The concentration of pollutants discharged from mills that use the froth-flotation process alone, or in conjunction with other processes, for the beneficiation of copper, lead, zinc gold, silver, or molybdenum ores or any combination of these ores shall not exceed:

Effluent characteristic	Effluent limitations	
	Maximum for any 1 day	Average of daily values for 30 consecutive days
	Milligrams per liter	
Cu	030	015
Zn	10	05
Pb	06	03
Hg	0002	000
Cd	010	005

(c) (1) Except as provided in paragraph (c) of this section, there shall be no discharge of process wastewater to navigable waters from mine areas and mills processes and areas that use dump, heap, in situ leach or vat leach processes to extract copper from ores or ore waste materials. The Agency recognizes that the elimination of the discharge of pollutants to navigable waters may result in an increase in discharges of some pollutants to other media. The Agency has considered these impacts and has adressed them in the preamble published on December 3, 1982.

(2) In the event that the annual precipitation falling on the treatment facility and the drainage area contributing surface runoff to the treatment facility exceeds the annual evaporation, a volume of water equal to the difference between annual precipitation falling on the treatment facility and the drainage area contributing surface runoff to the treatment facility and annual evaporation may be discharged subject to the limitations set forth in paragraph (a) of this section.

(d) (1) Except as provided in paragraph (d) of this section, there shall be no discharge of process wastewater to navigable waters from mills that use the cyanidation process to extract gold or silver. The Agency recognizes that the elimination of the discharge of pollutants to navigable waters may result in an increase in discharges of some pollutants to other media. The Agency has considered these impacts and has adressed them in the preamble published on December 3, 1982.

(2) In the event that the annual precipitation falling on the treatment facility and the drainage area contributing surface runoff to the treatment facility exceeds the annual evaporation, a volume of water equal to the difference between annual precipitation falling on the treatment facility and the drainage area contributing surface runoff to the treatment facility and annual evaporation may be discharged subject to the limitations set forth in paragraph (a) of this section.

(e) Removed and Reserved

§ 440.104 New source performance standards (NSPS).

Except as provided in Subpart L of this part any new source subject to this subsection must achieve the following NSPS representing the degree of effluent reduction attainable by the application of the best available demonstrated technology (BADT):

(a) The concentration of pollutants discharged in mine drainage from mines that produce copper, lead, zinc, gold, silver, or molybdenum bearing ores or any combination of these ores from open-pit or underground operations other than placer deposits shall not exceed:

Effluent characteristic	Effluent limitations	
	Maximum for any 1 day	Average of daily values for 30 consecutive days
	Milligrams per liter	
Cu	030	015
Zn	15	075
Pb	06	03
Hg	0002	0001
Cd	010	005
pH	(*)	(*)
TSS	300	200

(*) Within the range 6.0 to 9.0.

(b) (1) Except as provided in paragraph (b) of this section, there shall be no discharge of process wastewater to navigable waters from mills that use the froth-flotation process alone, or in conjunction with other processes, for the beneficiation of copper, lead, zinc, gold, silver, or molybdenum ores or any combination of these ores. The Agency recognizes that the elimination of the discharge of pollutants to navigable waters may result in an increase in discharges of some pollutants to other media. The Agency has considered these impacts and has addressed them in the preamble published on December 3, 1982.

(2) (i) In the event that the annual precipitation falling on the treatment facility and the drainage area contributing surface runoff to the treatment facility exceeds the annual evaporation, a volume of water equal to the difference between annual precipitation falling on the treatment facility and the drainage area contributing surface runoff to the treatment facility and annual evaporation may be discharged subject to the limitations set forth in paragraph (a) of this section.

(ii) In the event there is a build up of contaminants in the recycle water which significantly interferes with the ore recovery process and this interference can not be eliminated through appropriate treatment of the recycle water, the permitting authority may allow a discharge of process wastewater in an amount necessary to correct the interference problem after installation of appropriate treatment. This discharge shall be subject to the limitations of paragraph (a) of this section. The facility shall have the burden of demonstrating to the permitting authority that the discharge is necessary to eliminate interference in the ore recovery process and that the interference could not be eliminated through appropriate treatment of the recycle water.

(c) (1) Except as provided in paragraph (c) of this section, there shall be no discharge of process wastewater to navigable waters from mine areas and mills processes and areas that use dump, heap, in-situ leach or vat-leach processes to extract copper from ores or ore waste materials. The Agency recognizes that the elimination of the discharge of pollutants to navigable waters may result in an increase in discharges of some pollutants to other media. The Agency has considered these impacts and has adressed them in the preamble published on December 3, 1982.

(2) In the event that the annual precipitation falling on the treatment facility and the drainage area contributing surface runoff to the treatment facility exceeds the annual evaporation, a volume of water equal to the difference between annual precipitation falling on the treatment facility and the drainage area contributing surface runoff to the treatment facility and annual evaporation may be discharged subject to the limitations set forth in paragraph (a) of this section.

(d) (1) Except as provided in paragraph (d) of this section, there shall be no discharge of process wastewater to navigable waters from mills that use the cyanidation process to extract gold or silver. The Agency recognizes that the elimination of the discharge of pollutants to navigable waters may result in an increase in discharges of some pollutants to other media. The Agency has considered these impacts and has addressed them in the preamble published on December 3, 1982.

(2) In the event that the annual precipitation falling on the treatment facility and the drainage area contributing surface runoff to the treatment facility exceeds the annual evaporation, a volume of water equal to the difference between annual precipitation falling on the treatment facility and the drainage area contributing surface runoff to the treatment facility and annual evaporation may be discharged subject to the limitations set forth in paragraph (a) of this section.

(e) Removed and Reserved

EDITORIAL NOTE: Paragraph (b) (2) (ii) of § 440.104 published at 47 FR 54609, Dec. 3, 1982, contains information collection requirements which will not become effective until OMB approval has been obtained.

§ 440.105 Effluent limitations representing the degree of effluent reduction attainable by the application of the best conventional pollutant control technology (BCT). (Reserved).

USA: EXAMPLE 2.

Subpart LL - Standards of Performance for Metallic Mineral Processing plants

Source: 49 FR 6464. Feb. 21, 1984, unless otherwise noted.

§ 60.380 Applicability and designation of affected facility.

(a) The provisions of this subpart are applicable to the following affected facilities in metallic mineral processing plants: Each crusher and screen in open-pit mines; each crusher, screen, bucket elevator, conveyor belt transfer point, thermal dryer, product packaging station, storage bin, enclosed storage area, truck loading station, truck unloading station, railcar loading station, and railcar unloading station at the mill or concentrator with the following exceptions. All facilities located in underground mines are exempted from the provisions of this subpart. At uranium ore processing plants, all facilities subsequent to and including the beneficiation of uranium ore are exempted from the provisions of this subpart.

(b) An affected facility under paragraph (a) of this section that commences construction or modification after August 24, 1982, is subject to the requirements of this part.

§ 60.381 Definitions.

All terms used in this subpart, but not specifically defined in this section, shall have the meaning given them in the Act and in Subpart A of this part.

"Bucket elevator" means a conveying device for metallic minerals consisting of a head and foot assembly that supports and drives an endless single or double strand chain or belt to which buckets are attached.

"Capture system" means the equipment used to capture and transport particulate matter generated by one or more affected facilities to a control device.

"Control device" means the air pollution control equipment used to reduce particulate matter emissions released to the atmosphere from one or more affected facilities at a metallic mineral processing plant.

"Conveyor belt transfer point" means a point in the conveying operation where the metallic mineral or metallic mineral concentrate is transferred to or from a conveyor belt except where the metallic mineral is being transferred to a stockpile.

"Crusher" means a machine used to crush any metallic mineral and includes feeders or conveyors located immediately below the crushing surfaces. Crushers include, but are not limited to, the following types: jaw, gyratory, cone, and hammermill.

"Enclosed storage area" means any area covered by a roof under which metallic

minerals are stored prior to further processing or loading.

"Metallic mineral concentrate" means a material containing metallic compounds in concentrations higher than naturally occurring in ore but requiring additional processing if pure metal is to be isolated. A metallic mineral concentrate contains at least one of the following metals in any of its oxidation states and at a concentration that contributes to the concentrate's commercial value: Aluminium, copper, gold, iron, lead, molybdenum, silver, titanium, tungsten, uranium, zinc, and zirconium. This definition shall not be construed as requiring that material containing metallic compounds be refined to a pure metal in order for the material to be considered a metallic mineral concentrate to be covered by the standards.

"Metallic mineral processing plant" means any combination of equipment that produces metallic mineral concentrates from ore. Metallic mineral processing commences with the mining of ore and includes all operations either up to and including the loading of wet or dry concentrates or solutions of metallic minerals for transfer to facilities at non-adjacent locations that will subsequently process metallic concentrates into purified metals (or other products), or up to and including all material transfer and storage operations that precede the operations that produce refined metals (or other products) from metallic mineral concentrates at facilities adjacent to the metallic mineral processing plant. This definition shall not be construed as requiring that mining of ore be conducted in order for the combination of equipment to be considered a metallic mineral processing plant. (See also the definition of "metallic mineral concentrate.")

"Process fugitive emissions" means particulate matter emissions from an affected facility that are not collected by a capture system.

"Product packaging station" means the equipment used to fill containers with metallic compounds or metallic mineral concentrates.

"Railcar loading station" means that portion of a metallic mineral processing plant where metallic minerals or metallic mineral concentrates are loaded by a conveying system into railcars.

"Railcar unloading station" means that portion of a metallic mineral processing from a railcar into a hopper, screen, or crusher.

"Screen" means a device for separating material according to size by passing undersize material through one or more mesh surfaces (screens) in series and retaining oversize material on the mesh surfaces (screens).

"Stack emissions" means the particulate matter captured and released to the atmosphere through a stack, chimney, or flue.

"Storage bin" means a facility for storage (including surge bins and hoppers) or metallic minerals prior to further processing or loading.

"Surface moisture" means water that is not chemically bound to a metallic mineral or metallic mineral concentrate.

"Thermal dryer" means a unit in which the surface moisture content of a metallic mineral or a metallic mineral concentrate is reduced by direct or indirect contact with a heated gas stream.

"Truck loading station" means that portion of a metallic mineral processing plant where metallic minerals or metallic mineral concentrates are loaded by a conveying system into trucks.

"Truck unloading station" means that portion of a metallic mineral processing plant where metallic ore is unloaded from a truck into a hopper, screen, or crusher.

§ 60.382 Standard for particulate matter.

(a) On and after the date on which the performance test required to be conducted by § 60.8 is completed, no owner or operator subject to the provisions of this subpart shall cause to be discharged into the atmosphere from an affected facility any stack emissions that:

(1) Contain particulate matter in excess of

0.05 grams per dry standard cubic meter.
(2) Exhibit greater than 7 percent opacity, unless the stack emissions are discharged from an affected facility using a wet scrubbing emission control device.
(b) On and after the sixtieth day after achieving the maximum production rate at which the affected facility will be operated, but not later than 180 days after initial startup, no owner or operator subject to the provisions of this subpart shall cause to be discharged into the atmosphere from an affected facility any process fugitive emissions that exhibit greater than 10 percent opacity.

§ 60.383 Reconstruction.

(a) The cost of replacement of ore-contact surfaces on processing equipment shall not be considered in calculating either the "fixed capital cost of the new components" or the "fixed capital cost that would be required to construct a comparable new facility" under § 60.15. Ore-contact surfaces are: Crushing surfaces; screen meshes, bars, and plates; conveyor belts; elevator buckets; and pan feeders.
(b) Under § 60.15, the "fixed capital cost of the new components" includes the fixed capital cost of all depreciable components (except components specified in paragraph (a) of this section) that are or will be replaced pursuant to all continuous programs of component replacement commenced within any 2-year period following August 24, 1982.

§ 60.384 Monitoring of operations.

(a) The owner or operator subject to the provisions of this subpart shall install, calibrate, maintain, and operate a monitoring device for the continuous measurement of the change in pressure of the gas stream through the scrubber for any affected facility using a wet scrubbing emission control device. The monitoring device must be certified by the manufacturer to be accurate within ± 250 pascals (± 1 inch water) gauge pressure and must be calibrated on an annual basis in accordance with manufacturer's instructions.
(b) The owner or operator subject to the provisions of this subpart shall install, calibrate, maintain, and operate a monitoring device for the continuous measurement of the scrubbing liquid flow rate to a wet scrubber for any affected facility using any type of wet scrubbing emission control device. The monitoring device must be certified by the manufacturer to be accurate within ± 5 percent of design scrubbing liquid flow rate and must be calibrated on at least an annual basis in accordance with manufacturer's instructions.

§ 60.385 Recordkeeping and reporting requirements.

(a) The owner or operator subject to the provisions of this subpart shall conduct a performance test and submit to the Administrator a written report of the results of the test as specified in § 60.8 (a).
(b) During the initial performance test of a wet scrubber, and at least weekly there after, the owner or operator shall record the measurements of both the change in pressure of the gas stream across the scrubber and the scrubbing liquid flow rate.
(c) After the initial performance test of a wet scrubber, the owner or operator shall submit semiannual reports to the Administrator of occurrences when the measurements of the scrubber pressure loss (or gain) and liquid flow rate differ by more than ± 30 percent from the average obtained during the most recent performance test.
(d) The reports required under paragraph (c) shall be postmarked within 30 days following the end of the second and fourth calendar quarters.
(e) The requirements of this subsection remain in force until and unless the Agency, in delegating enforcement authority to a State under section 111 (c) of the Act. approves reporting requirements or an alternative means of compliance surveillance adopted by such States. In that event, affected sources within the

State will be relieved of the obligation to comply with this subsection, provided that they comply with requirements established by the State.

(Approved by the Office of Management and Budget under the control number 2060-0016).

§ 60.386 Test methods and procedures.

(a) In conducting the performance tests required in § 60.8, the owner or operator shall use as reference methods and procedures the test methods in Appendix A of this part or other methods and procedures as specified in this section, except as provided in § 60.8 (b).

(b) The owner or operator shall determine compliance with the particulate matter standards § 60.382 as follows:

(1) Method 5 or 17 shall be used to determine the particulate matter concentration. The sample volume for each run shall be at least 1.70 dscm (60 dscf). The sampling probe and filter holder of Method 5 may be operated without heaters if the gas stream being sampled is at ambient temperature. For gas streams above ambient temperature, the Method 5 sampling train shall be operated with a probe and filter temperature slightly above the effluent temperature (up to a maximum filter temperature of 121 °C (250 °F)) in order to prevent water condensation on the filter.

(2) Method 9 and the procedures in § 60.11 shall be used to determine opacity from stack emissions and process fugitive emissions. The observer shall read opacity only when emissions are clearly identified as emanating solely from the affected facility being observed.

(c) To comply with § 60.385 (c), the owner or operator shall use the monitoring devices in § 60.3284 (a) and (b) to determine the pressure loss of the gas stream through the scrubber and scrubbing liquid flow rate at any time during each particulate matter run, and the average of the three determinations shall be computed.

II. CANADA: EXAMPLE 1

REGISTRATION
SOR/77-178 25 February, 1977

FISHERIES ACT

Metal Mining Liquid Effluent Regulations

P.C. 1977-388 24 February, 1977

His Excellency the Governor General in Council, on the recommendation of the Minister of Fisheries and the Environment, pursuant to sections 33 and 34 of the Fisheries Act, is pleased hereby to make the annexed Regulations respecting deleterious substances in liquid effluents from metal mines.

REGULATIONS RESPECTING DELETERIOUS SUBSTANCES IN LIQUID EFFLUENTS FROM METAL MINES

Short Title

1. These Regulations may be cited as the *Metal Mining Liquid Effluent Regulations.*

Interpretation

2. In these Regulations,

"Act" means the *Fisheries Act; (Loi)*

"arithmetic mean" means the average value of the concentrations in composite or grab samples collected over the time period required by section 7; *(moyenne arithmétique)*

"composite sample" means

(a) a quantity of undiluted effluent consisting of a minimum of three equal volumes of effluent or three volumes proportionate to flow that have been collected at approximately equal time intervals over a sampling period of not less than 7 hours and not more than 24 hours, or

(b) a quantity of undiluted effluent collected continually at an equal rate or at a rate proportionate to flow over a sampling period of not less than 7 hours and not more than 24 hours; (échantillon composite)

"deposit" means to deposit or permit into water frequented by fish; *(rejeter)*

"effluent" includes mine water effluent, mill process effluent, tailings impoundment area effluent, treatment facility effluent, seepage and surface drainage; *(effluent)*

"existing mine" means a mine that came into commercial production before the date of coming into force of these Regulations and that operated on a commercial basis for at least two months in the twelve months immediately prior to that date; *(mine existante)*

"expanded mine" means an existing mine that has increased its production rate, *(mine à production accrue)*

ENREGISTREMENT
DORS/77-178 25 février 1977

LOI SUR LES PÊCHERIES

Règlement sur les effluents liquides des mines de métaux

C.P. 1977-388 24 février 1977

Sur avis conforme du ministre des Pêcheries et de l'Environnement et en vertu des articles 33 et 34 de la Loi sur les pêcheries, il plaît à Son Excellence le Gouverneur général en conseil d'établir le Règlement relatif aux substances nocives présentes dans les effluents des mines de métaux, ci-après.

REGLEMENT RELATIF AUX SUBSTANCES NOCIVES PRÉSENTES DANS LES EFFLUENTS DES MINES DE MÉTAUX

Titre abrégé

1. Ce règlement peut s'intituler: *Règlement sur les effluents liquides des mines de métaux.*

Interprétation

2. Dans ce règlement,

"chantier" comprend tout le terrain et tous les travaux servant ou ayant servi à l'exploitation minière ou à la préparation du minerai et comprend, sans limiter le sens général de ce qui précède, les mines souterraines ou à ciel ouvert, les bâtiments, les aires de stockage du minerai, les terrils, les dépôts de stériles et les étangs de traitement, abandonnés ou non, les secteurs dégagés ou perturbés adjacents à ces endroits, les fossés et les cours d'eau ou plans d'eau, dont la qualité a été modifiée par l'exploitation minière; *(operation area)*

"dépôt de stériles" désigne une aire de décharge, de superficie limitée, circonscrite par une formation naturelle ou un ouvrage artificiel ou les deux à la fois; *(tailings impoundment area)*

"eau de drainage superficiel" comprend toute eau de ruissellement qui coule sur un chantier minier ou en provient et qui de ce fait est contaminée; *(surface drainage)*

"échantillon composite" désigne

a) un volume d'effluent non dilué composé d'au moins trois portions égales d'effluent ou de trois portions proportionnelles au débit, recueillies à des intervalles de temps sensiblement égaux, pendant une période d'échantillonnage d'au moins 7 heures et d'au plus 24 heures, ou

b) un volume d'effluent non dilué prélevé de façon continue à un débit constant ou à un débit proportionnel à celui de l'effluent, pendant une période d'échantillonage d'au moins 7 heures et d'au plus 24 heures;
(composite sample)

"final discharge point" means the point beyond which the operator of a mine exercises no further control over an effluent; *(point de rejet final)*

"gold mine" means a mine where the gold produced from the mine is recovered in the operation area by the process of cyanidation and accounts for more than 50% of the value of the output of the mine; *(mine d'or)*

"grab sample" means a quantity of undiluted effluent collected at any given time; *(échantillon pris au hasard)*

"metal" includes antimony, bismuth, cadmium, cobalt, copper, chromium, gold, iron, lead, magnesium, mercury, molybdenum, nickel, niobium, silver, tantalum, tin, thorium, titanium, tungsten, uranium and zinc, *(métal)*

"mill process effluent" includes tailing slurries and all other effluent discharged from a milling operation; *(effluents des installations de préparation du minerai)*

"mine" includes all metal mining and facilities that are used to produce a metal concentrate may be produced and all associated smelters, pelletizing plants, sintering plants, refineries, acid plants, and any similar operation where any effluent from such operation is combined with the effluents from mining and milling; *(mine)*

"mine water effluent" means water pumped or flowing out of any undergroud workings or open pit; *(effluents d'eau minière)*

"Minister" means Minister of the Environment; *(Ministre)*

"new mine" means a mine that did not start commercial production prior to the date of coming into force of these Regulations and that commences commercial production on or after that date; *(mine nouvelle)*

"operation area" includes all the land and works that are used or have been used in conjonction with mining or milling activity and, without limiting the generality of the foregoing, includes open pits, undergroud mines, buildings, or storage areas, active and abandoned waste rock dumps, active and abandoned tailings impoudment areas and treatment ponds, cleared or disturbed areas adjacent to those places, structures or areas and ditches, watercourses or water bodies the character of which have been altered by mining activity; *(chantier)*

"reference mine production rate" means the greater of the design rated capacity and the maximum average annual production rate ever achieved during the operating life of a mine prior to the date of coming into force of these Regulations; *(rythme de production de référence)*

"reopened mine" means a mine that resumes production on or after the date of coming into

"échantillon pris au hasard" désigne un volume d'effluent non dilué recueilli à un moment quelconque; *(grab sample)*

"effluent" comprend les effluents d'eau minière, les effluents des installations de préparation du minerai, les effluents des dépôts de stériles, les effluents des étangs ou des installations de traitement et les eaux d'infiltration ou de drainage superficiel; *(effluent)*

"effluents d'eau minière" désigne les eaux pompées ou rejetées par une mine souterraine ou à ciel ouvert: *(mine water effluent)*

"effluents des installations de préparation du minerai" comprend les boues stériles et tout autre effluent, rejetés à la suite de la préparation du minerai: *(mill process effluent)*

"étang de traitement" désigne un étang, une lagune ou toute autre étendue fermée autre qu'un dépôt de stériles et servant au traitement d'un effluent: *(treatment pond)*

"Loi" désigne la Loi sur les pêcheries: *(Act)*

"matière totale en suspension" désigne un résidu non filtré provenant de l'exploitation d'une mine et contenu dans un effluent liquide de la mine; *(total suspended matter)*

"métal" comprend l'antimoine, le bismuth, le cadmium, le cobalt, le cuivre, le chrome, l'or, le fer, le plomb, le magnésium, le mercure, le molybdène, le nickel, le niobium, l'argent, le tantale, le tin, le thorium, le titane, le tungstène, l'uranium et le zinc: *(métal)*

"mine" comprend l'ensemble des installations d'extraction et de préparation du minerai, produisant un concentré métallique, ou un minerai à partir duquel on peut obtenir le métal ou un concentré et toutes les installations connexes, fonderies, ateliers de bouletage ou de frittage, raffineries, fabriques d'acide et autres du même genre, dont les effluents se combinent à ceux des installations d'extraction et de préparation du minerai: *(mine)*

"mine à production accrue" désigne une mine existante dont la productivité a été accrue de plus de 30% par rapport à son rythme de production de référence; *(expanded mine)*

"mine d'or" désigne une mine où l'or produit est récupéré sur le chantier par cyanuration et constitue plus de la moitié de la valeur de la production; *(gold mine)*

"mine existante" désigne une mine dont la production industrielle a débuté avant la date d'entrée en vigueur de ce règlement et a été maintenue pendant au moins deux mois au cours des douze mois ayant précédé immédiatement cette date; *(existing mine)*

"mine nouvelle" désigne une mine dont la production industrielle a débuté à ou après la date d'entrée en vigueur de ce règlement; *(new mine)* force of these Regulations and that had not been in operation for more than two months in the twelve month period immediately prior to the date of coming into force of these Regulations; *(mine remise en exploitation)*

"surface drainage" includes all surface run-off that flows over, through or out the operation area of a mine and that is contaminated as a result of flowing over, through or out of that area, *(eau de drainage superficiel)*

"tailings impoudment area" means a limited disposal area that is confined by man-made or natural structures or by both; *(dépôt de stériles)*

"total suspended matter" means the non-filterable residue that results from the operation of a mine, that is contained in liquid effluent from the mine; *(matière total en suspension)*

"treatment pond" means a pond, lagoon or other confined area, other than a tailings impoudment area, used to treat an effluent; *(étang de traitement)*

"undiluted" means not having water added primarily for the purposes of meeting the limits of authorized deposits prescribed by section 5. *(non dilué)*

Application

3. These Regulations apply to every new mine, expanded mine and reopened mine, other than a gold mine.

Substances Prescribed as Deleterious Substances

4. For the purposes of paragraph (c) of the definition "deleterious substance" in subsection 33(11) of the Act, the following substances from the operations or processes of a mine to which these Regulations apply are hereby prescribed as deleterious substances;
(a) arsenic;
(b) copper;
(c) lead;
(d) nickel;
(e) zinc;
(f) total suspended matter; and
(g) radium 226.

Authorized Deposit of deleterious Substances

5. (1) Subject to these Regulations, the operator of a mine may deposit a deleterious substance prescribed by section 4 if
(a) the monthly arithmetic mean of the concentration in each undiluted effluent of that substance described in an item of Part 1 of Schedule 1 does not exceed the concentration

"mine remise en exploitation" désigne une mine dont la production a repris à ou après la date d'entrée en vigueur de ce règlement et qui n'a pas été exploitée pendant plus de deux mois au cours des douze mois avant précédé immédiatement cette date: *(reopened mine)*

"Ministre" désigne le ministre de l'Environnement: *(Minister)*

"moyenne arithmétique" désigne la valeur moyenne des concentrations dans les échantillons, composites ou pris au hasard, recueillis durant la période de temps indiquée à l'article 7: *(arithmetic mean)*

"non dilué" qualifie un effluent auquel aucune addition d'eau n'a été faite principalement afin de satisfaire aux limites prescrites à l'article 5 au sujet des rejets autorisés: *(undiluted)*

"point de rejet final" désigne le point au-delà duquel l'exploitant d'une mine n'exerce plus aucune influence sur la qualité d'un effluent: *(final discharge point)*

"rejeter" signifie déposer ou permettre que soit déposée une substance dans des eaux poissonneuses: *(deposit)*

"rythme de production de référence" désigne le rythme maximal de production théorique ou, s'il est plus élevé, le rythme moyen maximal de production annuelle obtenu au cours de la durée d'exploitation d'une mine, avant la date d'entrée en vigueur de ce règlement. *(reference mine production rate)*

Application

3. Ce règlement s'applique à toutes les mines nouvelles, remises en exploitation et à production accrue, sauf les mines d'or.

Substances déclarées nocives

4. Aux fins de l'alinéa c) de la définition de "substance nocive", au paragraphe 33(11) de la Loi, les substances énumérées ci-après provenant des opérations ou des procédés d'une mine visée par ce règlement sont déclarées nocives:
a) l'arsenic:
b) le cuivre:
c) le plomb:
d) le nickel:
e) le zinc:
f) les matières totales en suspensions: et
g) le radium 226.

Rejet autorisé de substances nocives

5. (1) Sous réserve de ce règlement, l'exploitant d'une mine peut rejeter les substances déclarées nocives à l'article 4, à condition que
a) la moyenne arithmétique mensuelle de la concentration dans chaque effluent non dilué de chacune des substances visées dans un article de la partie 1 de l'annexe 1 ne dépasse

in column 1 of that item and the monthly arithmétic mean pH of that effluent is not less than the value set out in column 1 of Part 2 of that schedule;

(b) the concentration in a composite sample of each undiluted effluent of that substance described in an item of Part I of Schedule I does not exceed the concentration in column II of that item and the pH of the composite sample is not less than the value set out in column II of Part 2 of that schedule; and

(c) the concentration in a grab sample of each undiluted effluent of that substance described in an item of Part 1 of Schedule 1 does not exceed the concentration in column III of that item and the pH of the grab sample is not less than the value set out in column III of Part 2 of that schedule.

(2) Notwithstanding subsection (1), the operator of a mine may deposit the deleterious substances prescribed by section 4 in any quantity or concentration into a tailings impoudment area designated in writing by the Minister.

ADDITIONAL CONDITIONS OF AUTHORIZATION

General

6. An operator of a mine shall

(a) install and maintain facilities of such type as the Minister may in writing approve for sampling and analysing effluents for the purpose of enabling the Minister to determine whether the operator is complying with the limits of authorized deposits prescribed by section 5;

(b) taxe grab or composite samples of each undiluted effluent at its final discharge point on the regular basis prescribed by section 7;

(c) analyse the samples referred to in paragraph (b) on the regular basis prescribed by section 7;

(d) where possible measure or in any other case estimate the volume of each undiluted effluent deposited per month at its final discharge point on the regular basis prescribed by section 9; and

(e) within 30 days after the end of each month, send to the Minister a report, in such form as the Minister may in writing approve, containing the information prescribed by section 10.

Frequency of Sampling and Analysis

7. (1) Subject to subsection (2), the sampling and analysis referred to in paragraphs 6 (b) and (c) shall be made

(a) once a week, where the arithmetic mean of

pas la concentration indiquée par cet article dans la colonne I, et que la moyenne arithmétique mensuelle du pH de cet effluent ne soit pas inférieure à la valeur indiquée à la colonne I de la partie 2 de l'annexe:

b) la concentration de chacune des substances visées dans un article de la partie 1 de l'annexe 1, dans un échantillon composite de chaque effluent non dilué ne dépasse pas la concentration indiquée par cet article dans la colonne II, et que le pH de l'échantillon composite ne soit inférieur à la valeur indiquée à la colonne II de la partie 2 de l'annexe: et

c) la concentration de chacune des substances visées dans un article de la partie I de l'annexe I, dans un échantillon pris au hasard de chaque effluent non dilué ne dépasse pas la concentration indiquée par cet article dans la colonne III, et que le pH de cet échantillon ne soit pas inférieur à la valeur indiquée à la colonne III de la partie 2 de l'annexe.

(2) Nonobstant le paragraphe (1), l'exploitant d'une mine peut rejeter n'importe quelle quantité ou concentration de substances nocives, visées à l'article 4, dans un dépôt de stériles que le Ministre a désigné par écrit.

CONDITIONS SUPPLEMENTAIRES D'AUTORISATION

Disposition générale

6. l'exploitant d'une mine

a) installe et entretient les appareils d'échantillonnage et d'analyse des effluents que le Ministre a approuvés par écrit et qui permettent à celui-ci de juger si les limites de rejet prescrites à l'article 5 sont respectées:

b) prélève des échantillons composites ou pris au hasard de chacun des effluents non dilués à leur point de rejet final aux fréquences indiquées à l'article 7:

c) analyse les échantillons visés à l'alinéa b) aux fréquences indiquées à l'article 7:

d) lorsque c'est possible, mesure ou, dans tous les autres cas, évalue aux fréquences indiquées à l'article 9 le volume des rejets mensuels de chaque effluent à son point de rejet final: et

e) dans les 30 jours de la fin de chaque mois, envoie au Ministre un rapport, établi suivant un modèle que celui-ci a approuvé par écrit, contenant les renseignements prévus à l'article 10.

Fréquence d'échantillonnage et analyse

7. (1) Sous réserve du paragraphe (2), l'échantillonnage et l'analyse visés aux alinéas 6(b) et c) ont lieu

a) chaque semaine, si la moyenne arithmétique the concentration in undiluted effluent of a substance described in an item of Schedule 2 in the immediately preceding six months was equal to or greater than the arithmetic mean set out in column I of that item;

(b) once every two weeks, where the arithmetic mean of the concentration in undiluted effluent of a substance described in an item of Schedule 2 in the immediately preceding six months was equal to or greater than the arithmetic mean set out in column II of that item but less than that set out in column I of that item;

(c) once a month, where the arithmetic mean of the concentration in undiluted effluent of a substance described in an item of Schedule 2 in the immediately preceding six months was equal to or greater than the arithmetic mean set out in column III of that item but less than that set out in column II of that item;

(a) once every six months, where the arithmetic mean of the concentration in undiluted effluent of a substance described in an item of Schedule 2 in the immediately preceding six months was less than the arithmetic mean set out in column III of that item; and

(e) once a week for the first six months of operation of a mine.

(2) The sampling and analysis of undiluted effluent to determine its pH level shall be made

(a) once a week, where the pH of the undiluted effluent was less than 5.0 at any time in the immediately preceding six months;

(b) once every two weeks, where the pH of the undiluted effluent was between 5.0 and 5.5 at any time in the immediately preceding six months;

(c) once a month, where paragraph (a) or (b) does not apply; or

(d) once a week for the first six months of operation of a mine.

Analytical Test Methods

8. (1) For the purposes of section 5, the concentration in undiluted effluent of a substance described in column I of an item of Schedule 3 shall be determined using

(a) the test method referred to in column II of that item as modified by the directions in columns III and IV for procedure and sample preservation respectively; or

(b) any other method, approved in writing by the Minister, the results of which can be confirmed by the method referred to in paragraph (a).

(2) For the purposes of section 5, the pH of undiluted effluent shall be determined using

(a) the test method prescribed by section 221 of the publication "Standard Methods for the Examination of Water and Waste Water", 13 th Edition (1971), published jointly by the

des concentrations dans l'effluent non dilué de l'une des substances indiquées à l'annexe 2 a été égale ou supérieure, au cours des six mois précédents, à celle de la colonne I:

b) toutes les deux semaines, si la moyenne arithmétique des concentrations dans l'effluent non dilué de l'une des substances indiquées à l'annexe 2 a été égale ou supérieure, au cours des six mois précédents, à celle de la colonne II mais inférieure à celle de la colonne I:

c) chaque mois, si la moyenne arithmétique des concentrations dans l'effluent non dilué de l'une des substances indiquées à l'annexe 2 a été égale ou supérieure, au cours des six mois précédents, à celle de la colonne III mais inférieure à celle de la colonne II:

d) tous les six mois, si la moyenne arithmétique des concentrations dans l'effluent non dilué de l'une des substances indiquées à l'annexe 2 a été inférieure, au cours des six mois précédents, à celle de la colonne III: et

e) chaque semaine au cours des six premiers mois d'exploitation d'une mine.

(2) L'analyse et l'échantillonnage d'un effluent non dilué pour déterminer son niveau pH ont lieu

a) chaque semaine, s'il a été inférieur à 5.0 à un moment quelconque durant les six mois précédents:

b) toutes les deux semaines, s'il a été entre 5.0 et 5.5 à un moment quelconque durant les six mois précédents:

c) chaque mois, lorsque les alinéas a) ou b) ne s'appliquent pas: ou

d) chaque semaine au cours des six premiers mois d'exploitation d'une mine.

Méthodes d'essai analytiques

8. (1) Aux fins de l'article 5, la concentration dans l'effluent non dilué d'une des substances visées à la colonne I de l'annexe 3 se détermine

a) par la méthode d'essai visée à la colonne II, modifiée par les indications inscrites aux colonnes III et IV, relativement au mode opératoire et à la concervation des échantillons: ou

b) par toute autre méthode, approuvée par écrit par le Ministre, dont les résultats peuvent être vérifiés par la méthode visée à l'alinéa a).

(2) Aux fins de l'article 5, le pH de l'effluent non dilué se détermine

a) par la méthode d'essai prescrite à la section 221 du recueil "Standard Methods for the Examination of water and Waste Water", 13e édition (1971), publié conjointement par

American Public Health Association, American Water Works Association and the Water Pollution Control Federation; or
(b) any other method, approved in writing by the Minister, the results of which can be confirmed by the method referred to in paragraph (a).

Flow Measurement

9. The measurement or estimation of volume of undiluted effluent referred to in paragraph 6(d) shall be made monthly, unless the lowest frequency of sampling and analysis prescribed by subsection 7(1) is every six months, in which case the measurement or estimation shall be made every six months.

Reporting

10. A report referred to in paragraph 6(e) shall contain the following information respecting the month in respect of wich the report is made:
(a) the arithmetic mean concentrations (in milligrams per liter or picocuries per liter) of the deleterious substances in each undiluted effluent deposited and the arithmetic mean pH of undiluted effluents deposited;
(b) the concentrations of deleterious substances in all samples used to determine the arithmetic mean concentrations referred to in paragraph (a);
(c) the pH of all samples used to determine the arithmetic mean pH referred to in paragraph (a);
(d) the volume (in Imperial gallons per month) of each undiluted effluent deposited; and
(e) the type of sample collection (composite or grab) used for each effluent deposited.

Permitted Variations in Additional Conditions

11. Where the operator of a mine establishes to the satisfaction of the Minister that for scientific and technical reasons a scheme of sampling and analysis, measurement or estimation or reporting referred to in sections 7, 8, 9 and 10 other than at the regular time interval frequencies required by those sections, is sufficient to enable the Minister to determine whether the operator is complying with the limits of authorized deposits prescribed by section 5, the Minister may, in writing, permit the operator to
(a) take and analyse samples of each undiluted effluent in accordance with the scheme on a regular basis specified in the permit,
(b) measure or estimate the volume of each effluent in accordance with the scheme on a regular basis specified in the permit, or
(c) report to the Minister in accordance with the scheme on a regular basis specified in the permit,
and sections 7, 8, 9 and 10 do not apply to the operator if he complies with the scheme on the regular basis specified in the permit.

l'American Public Health Association, l'American Water Works Association et la Water Pollution Control Federation: ou
b) par toute autre méthode, approuvée par écrit par le Ministre, dont les résultats peuvent être vérifiés par la méthode visée à l'alinéa a).

Mesures du débit

9.Les mesures ou les évaluations du volume d'effluent non dilué visé à l'alinéa 6d) se font mensuellement à moins que la fréquence minimale des échantillonnages et des analyses prescrits au paragraphe 7(1) ne soit tous les six mois, auquel cas, elles sont effectuées à cette fréquence.

Rapport

10.Le rapport visé à l'alinéa 6e) contient les renseignements suivants pour le mois auquel il se rapporte:
a) la moyenne arithmétique des concentrations (en milligrammes ou en picocuries par litre) des substances nocives dans chaque effluent non dilué rejeté, et la moyenne arithmétique du pH de chaque effluent non dilué rejeté:
b) les concentrations de substances nocives dans tous les échantillons ayant servi au calcul de la moyenne arithmétique des concentrations visée à l'alinéa a);
c) le pH de tous les échantillons ayant servi au calcul de la moyenne arithmétique du pH visée à l'alinéa a);
d) le volume (en gallons impériaux par mois) de chaque effluent non dilué rejeté; et
e) le type d'échantillon (composite ou pris au hasard) utilisé pour chaque effluent rejeté.

Dérogations aux conditions supplémentaires

11.Lorsque l'exploitant d'une mine établit à la satisfaction du Ministre que, pour des raisons scientifiques et techniques, un mode d'échantillonnage et d'analyse, de mesures ou d'évaluations, ou de présentation de rapports à une fréquence différente de celle visée aux articles 7, 8, 9 et 10 suffit pour permettre au Ministre de juger si les limites de rejet prescrites à l'article 5 sont respectées, ce dernier peut autoriser l'exploitant par écrit.
a) à prélever et à analyser les échantillons de chaque effluent non dilué, selon le mode et aux fréquences indiqués sur le permis,
b) à mesurer ou à évaluer le volume de chaque effluent, selon le mode et aux fréquences indiqués sur le permis, ou
c) à envoyer le rapport au Ministre, selon le mode et aux fréquences indiqués sur le permis,
et les articles 7, 8, 9 et 10 ne s'appliquent pas à l'exploitant s'il se conforme aux permis.

SCHEDULE 1
PART 1
AUTHORIZED LEVELS OF SUBSTANCES

Item	Substance	Column I Maximum Authorized Monthly Arithmetic Mean Concentration	Column II Maximum Authorized Concentration in a Composite Sample	Column III Maximum Authorized Concentration in a Grab Sample
1.	Arsenic	0.5 mg/l	0.75 mg/l	1.0 mg/l
2.	Copper	0.3 mg/l	0.45 mg/l	0.6 mg/l
3.	Lead	0.2 mg/l	0.3 mg/l	0.4 mg/l
4.	Nickel	0.5 mg/l	0.75 mg/l	1.0 mg/l
5.	Zinc	0.5 mg/l	0.75 mg/l	1.0 mg/l
6.	Total Suspended Matter	25.0 mg/l	37.5 mg/l	50.0 mg/l
7.	Radium 226	10.0 pCi/l	20.0 pCi/l	30.0 pCi/l

NOTE : The concentrations are given as total values with the exception of Radium 226 which is a dissolved value after filtration of the sample through a 3 micron filter.

PART 2
AUTHORIZED LEVELS OF pH

Parameter	Column I Minimum Authorized Monthly Arithmetic Mean pH	Column II Minimum Authorized pH in a Composite Sample	Column III Minimum Authorized pH in a Grab Sample
pH	6.0	5.5	5.0

SCHEDULE 2
DETERMINATION OF FREQUENCY WITH WHICH UNDILUTED EFFLUENTS ARE TO BE SAMPLED AND ANALYSED FOR PARTICULAR SUBSTANCES

Item	Substance	Column I At Least Weekly if Concentration is Equal to or Greater than	Column II At Least Every Two Weeks if Concentration is Equal to or Greater than	Column III At Least Monthly if Concentration is Equal to or Greater than
1.	Arsenic	0.5 mg/l	0.2 mg/l	0.10 mg/l
2.	Copper	0.3 mg/l	0.1 mg/l	0.05 mg/l
3.	Lead	0.2 mg/l	0.1 mg/l	0.05 mg/l
4.	Nickel	0.5 mg/l	0.2 mg/l	0.10 mg/l
5.	Zinc	0.5 mg/l	0.2 mg/l	0.10 mg/l
6.	Total Suspended Matter	25.0 mg/l	20.0 mg/l	15.0 mg/l
7.	Radium 226	10.0 pCi/l	5.0 pCi/l	2.5 pCi/l

NOTE : All concentrations given are total values with the exception of Radium 226 which is a dissolved value after filtering the sample through a 3 micron filter. Radium 226 need be measured in only which there is radioactive ore.

ANNEXE 1
PARTIE 1
CONCENTRATIONS AUTORISEES DES SUBSTANCES

Article	Substance	Colonne I Concentration maximale autorisée (moyenne atithmétique mensuelle)	Colonne II Concentration maximale autorisée dans un échantillon composite	Colonne III Concentration maximale autorisée dans un échantillon pris au hasard
1.	Arsenic	0.5 mg/l	0.75 mg/l	1.0 mg/l
2.	Cuivre	0.3 mg/l	0.45 mg/l	0.6 mg/l
3.	Plomb	0.2 mg/l	0.3 mg/l	0.4 mg/l
4.	Nickel	0.5 mg/l	0.75 mg/l	1.0 mg/l
5.	Zinc	0.5 mg/l	0.75 mg/l	1.0 mg/l
6.	Matière totale en suspension	25.0 mg/l	37.5 mg/l	50.0 mg/l
7.	Radium 226	10.0 pCi/l	20.0 pCi/l	30.0 pCi/l

REMARQUE : Ces concentrations représentent des valeurs totales, sauf pour le Radium 226 où l'échantillon ayant traversé un filtre à pores de 3 microns d'ouverture est ensuite dissous.

PARTIE 2
CONCENTRATIONS pH AUTORISEES

Parameter	Colonne I pH minimal autorisé (moyenne arithmétique mensuelle	Colonne II pH minimal autorisé dans un échantillon composite	Colonne III pH minimal autorisé dans un échantillon pris au hasard
pH	6.0	5.5	5.0

ANNEXE 2
FREQUENCE D'ECHANTILLONNAGE D'UN EFFLUENT FINAL NON DILUE ET DU DOSAGE DE CERTAINES SUBSTANCES

Article	Substance	Colonne I Au moins toutes les semaines, si la concentration est égale ou supérieure à	Colonne II Au moins toutes les deux semaines, si la concentration est égale ou supérieure à	Colonne III Au moins tous les mois, si la concentration est égale ou supérieure à
1.	Arsenic	0.5 mg/l	0.2 mg/l	0.10 mg/l
2.	Cuivre	0.3 mg/l	0.1 mg/l	0.05 mg/l
3.	Plomb	0.2 mg/l	0.1 mg/l	0.05 mg/l
4.	Nickel	0.5 mg/l	0.2 mg/l	0.10 mg/l
5.	Zinc	0.5 mg/l	0.2 mg/l	0.10 mg/l
6.	Matière totale en suspension	25.0 mg/l	20 mg/l	15 mg/l
7.	Radium 226	10.0 pCi/l	5.0 pCi/l	2.5 pCi/l

REMARQUE : Ces concentrations représentent des valeurs totales, sauf pour le Radium 226 où l'échantillon ayant traversé un filtre à pores de 3 microns d'ouverture est ensuite dissous. Le Radium 226 est mesuré dans les mines à minerais radio-actifs seulement.

SCHEDULE 3

ANALYTICAL TEST METHODS FOR DETERMINING CONCENTRATION OF SUBSTANCES IN LIQUID EFFLUENTS

Item	Column I Substance	Column II Test Method	Column III Procedure	Column IV Sample preservation	Column V * References
1.	Arsenic	Colorimetric	HNO - H_4SO_4 digestion followed by A_5H_3 reaction with silver diethyldithiocarbamate	To pH 1 with $HN0_3$	1
2.	Copper	Atomic absorption Spectrophotometry	Sampie is digested with HC1-$HN0_3$ before analysis	To pH 1 with $HN0_3$	2, 3, 4
3.	Lead	"	"	"	2, 3, 4
4.	Nickel	"	"	"	2, 3, 4
5.	Zinc	"	"	"	2, 3, 4
6.	Radium 226	Radon Emanation	counting for Ra 222		5
7.	Total Suspended Matter	Gravimetric	Filter through Whatman GF/C or equivalent Oven dry at 105°C. to no further weight loss		1

*1. *American Public Health Association (APHA), "Standard Methods for the Examination of Water and Wasterwater". 13th Edition (1971).*
2. *Methods in Geochemistry and Geophysics: Atomic Absorption Spectrophotometry in Geology. E.A. Angino and G. Billings, American Elsevier Publishing Company Inc. 1967.*
3. *Atomic Absorption Spectrophotometry, 2nd Edition W.T. Elwell and J.A.F. Gidley, Pergammon Press 1966.*
4. *Atomic Absorption Spectroscopy, Walter Slavia, John Wiley & Sons Inc. 1968.*
5. *Lucas H.F. Review of Scientific Instruments 28 page 680 (1957).*

ANNEXE 3

METHODES DE DOSAGE DES SUBSTANCES DANS LES EFFLUENTS LIQUIDES

Article	Colonne I Substance	Colonne II Méthode d'essai	Colonne III Mode opératoire	Colonne IV Conservation des échantillons	Colonne V * References
1.	Arsenic	Colorimetrie	Minéralisation dans HNO_3 - H_4SO_4 suivie de la réaction de AsH_3 avec le diéthyldithiocarbamate d'argent	Ajuster le pH à 1 avec $HN0_3$	1
2.	Cuivre	Absorption atomique Spectrophotométrie	Minéralisation de l'échantillon dans HC1-HNO_3 avant l'analyse	Ajuster le pH à 1 avec $HN0_3$	2, 3, 4
3.	Plomb	"	"	"	2, 3, 4
4.	Nickel	"	"	"	2, 3, 4
5.	Zinc	"	"	"	2, 3, 4
6.	Radium 226	Emanation de radon	Comptage de la radio-activité or du Ra 222		5
7.	Matière totale en suspension	Gravimetrie	Filtration au Whatman GF/C ou l'équivalent. Séchage à l'étuve à 105°C jusqu'à poids stable		1

*1. *American Public Health Association (APHA), "Standard Methods for the Examination of Water and Wasterwater". 13^e Edition (1971).*
2. *E.A. Angino et G. Billings, Methods in Geochemistry and Geophysics: Atomic Absorption Spectrophotométry in Geology. American Elsevier Publishing Company Inc. 1967.*
3. *W.T. Elwell and J.A.F. Gidley, Atomic Absorption Spectrophotometry, 2^e Edition Pergammon Press 1966.*
4. *Walter Slavia, Atomic Absorption Spectroscopy, John Wiley & Sons Inc. 1968.*
5. *Lucas H.F. Review of Scientific Instruments 28 page 680 (1957).*

CANADA : EXAMPLE 2.

DEPARTMENT OF THE ENVIRONMENT

The following guidelines are issued under the authority of the Minister of Fisheries and the Environment. The intent of these guidelines is to control the discharge of liquid effluents from existing base metal, uranium and iron ore mines in a manner similar to the "Metal Mining Liquid Effluent Regulations", SOR/77-178, which apply to new, expanded and reopened base metal, uranium and iron ore mines, as published in Part II of the March 9 issue of the Canada Gazette.

GUIDELINES FOR THE MEASUREMENT OF ACUTE LETHALITY IN LIQUID EFFLUENTS FROM METAL MINES

Introduction

1. These Guidelines may be referred to as the Guidelines for the Measurement of Acute Lethality in Liquid Effluents from Metal Mines.
These Guidelines are not to be construed as regulations made under the authority of Section 33 of the Fisheries Act.

Interpretation

2. In these Guidelines, "Composite Sample", "Effluent", "Deposit", "Gold Mine", "Metal", "Mine", "Minister", and "Undiluted" have the meaning defined in the "Metal Mining Liquid Effluent Regulations".

Application

3. These Guidelines apply to every Metal Mine except gold mines.

Objective

4. For the purposes of these Guidelines, the objective for each undiluted effluent deposited is that no more than 50% of the fish die in a composite sample within 96 hours when tested according to the procedure described as the Final Evaluation Test Procedure for Acute Lethality (Flow Through Test) set out in Schedule I.

Monitoring

5. A Mine Operator should carry out an acute lethality test on a composite sample of each undiluted effluent deposited, or have these tests carried out on his behalf, in accordance with the test procedure described as Screening Test Procedure for Acute Lethality (Static Test) set out in Schedule II, every three months.

MINISTERE DE L'ENVIRONNEMENT

Les présentes lignes directrices sont publiées avec l'autorisation du ministre des Pêches et de l'Environnement. Elles ont pour objet de limiter les rejets d'effluents par les mines existantes de métaux communs, d'uranium et de fer, de la même façon que le "Règlement sur les effluents liquides des mines de métaux", (DORS/77-178), publié le 9 mars dans la Partie II de la Gazette du Canada, s'applique aux mêmes mines, nouvelles, à production accrue et remises en exploitation.

LIGNES DIRECTRICES CONCERNANT LE CONTRÔLE DE LA LETALITE AIGUE DES EFFLUENTS DES MINES DE METAUX

Introduction

1. Les présentes lignes directrices peuvent être désignées sous le nom de Lignes directrices concernant le contrôle de la létalité aiguë des effluents des mines de métaux.
Elles ne peuvent être interprêtées comme étant un règlement établi aux termes de l'article 33 de la Loi sur les pêcheries.

Interprétation

2. Dans les présentes lignes directrices, les termes "échantillons composite" "effluents", "métal", "mine", "mine d'or", "Ministre", "non dilué", et "rejeter" ont la même définition que dans le Règlement sur les effluents liquides des mines de métaux.

Application

3. Les présentes lignes directrices s'appliquent à toutes les mines de métaux, à l'exception des mines d'or.

Objectif

4. Aux fins des présentes lignes directrices, l'objectif pour chaque effluent rejeté à l'état non dilué est un taux de mortalité des poissons ne dépassant pas 50% après 96 heures, lors d'un contrôle toxicologique réalisé dans des conditions dynamiques selon la méthode indiquée à l'annexe I, Contrôle de la létalité aiguë (d'une durée de 96 heures, dans des conditions dynamiques), à l'aide d'un échantillon composite de l'effluent.

Contrôle

5. L'exploitant d'une mine devrait effectuer ou faire effectuer tous les trois mois un contrôle de la létalité aiguë de chaque effluent rejeté à l'état non dilué, à l'aide d'un échantillon composite, selon la méthode décrite à l'annexe II, Pré-contrôle de la létalité aiguë (d'une durée de 96 heures, dans des conditions statiques).

Reporting

6. A Mine Operator should promply forward to the Minister after the end of every three-month period, a report indicating:

(i) the following results from the acute lethality tests of each effluent deposited:

(a) the date and time period of the composite sample collection:

(b) details on transportation and storage of the sample;

(c) the date and time the test commenced;

(d) the number of dead fish observed in the test and control vessels for the exposure times outlined in the test procedure used:

(e) the percent mortality of fish exposed to the test sample and to the control water at the completion of the test:

(f) any other information the owner may feel is useful in interpreting the result of the test;

(ii) any other information that the Minister may request.

Acceptable Modification of Monitoring and Reporting

7. Where the operator of a mine establishes to the satisfaction of the Minister that for scientific and technical reasons a scheme of sampling and testing, or reporting referred to in sections 5 and 6 other than at the regular time interval frequencies specified in those sections, is sufficient to enable the Minister to determine whether the operator is meeting the objectives outlined in section 4, the Minister may in writing, indicate that it is acceptable for the operator to

(a) take and test samples of each undiluted effluent in accordance with the sheme; or

(b) report to the Minister in accordance with the scheme.

SCHEDULE I

FINAL EVALUATION TEST PROCEDURE FOR ACUTE LETHALITY (96-HOUR FLOW THROUGH TEST)

(Ordinarily carried out by the Minister for the purpose of section 4)

1. For the purpose of this Schedule, the applicable portions of APHA *(Standard Methods for the Examination of Water and Wastewater*, 13th Edition (1971), published jointly by the American Public Health Association, American Water Works Association and the Water Pollution Control Federation), section 231, should be used as a basis for this test procedure except as modified in this schedule.

2. Rainbow trout (Salmo gairdneri Richardson) are to be used as the test species.

Rapports

6. Tous les trois mois l'exploitant d'une mine doit sans délai faire parvenir au Ministre:

(i) un rapport des contrôles de la létalité aiguë de chaque effluent rejeté, comportant les renseignements suivants:

a) la date et l'heure du prélèvement de l'échantillon composite;

b) des détails sur le transport et la conservation de l'échantillon;

c) la date et l'heure du début du contrôle;

d) le nombre de poissons morts dans les solutions contrôlées et dans les solutions témoins après les durées d'exposition indiquées dans le mode opératoire;

e) le pourcentage de poissons morts dans les solutions contrôlées et dans les solutions témoins à la fin de l'épreuve;

f) tout autre renseignement que l'exploitant pourra juger utile à l'interprétation des résultats des contrôles;

(ii) tout autre renseignement que le Ministre pourra demander.

Modification acceptable des modalités de contrôle de présentation des rapports

7. Lorsque l'exploitant d'une mine établit à la satisfaction du Ministre que, pour des raisons scientifiques et techniques, une fréquence d'échantillonnage et d'analyse ou de présentation des rapports, différente de celle dont il est question aux articles 5 et 6, suffit popur permettre au Ministre de juger si les objectifs fixés à l'article 4 sont respectés, ce dernier peut indiquer par écrit à l'exploitant qu'il est acceptable:

a) de prélever et d'analyser les échantillons de chaque effluent non dilué, à la fréquence proposée; ou

b) de faire parvenir les rapports au Ministre à la fréquence proposée.

ANNEXE I

CONTRÔLE FINAL DE LA L´ÉTALITÉ AIGUE (D'UNE DURÉE DE 96 HEURES, DANS DES CONDITIONS DYNAMIQUES)

(Normalement réalisé par le Ministre, aux fins de l'article 4)

1. Aux fins de la présente annexe, utiliser les indications applicables de la section 231 du recueil de l'APHA *(Standard Methods for the Examination of Wastewater,* 13e édition, 1971, publié conjointement par l'American Public Health Association, l'American Water Works Association et la Water Pollution Control Federation), comme fondement opératoire du présent contrôle, à l'exception des modifications précisées ci-après.

2. L'espèce utilisée dans le contrôle est la truite arc-en-ciel *(Salmo gairdneri Richardson).*

3. Only healthy standardized stocks of rainbow trout are to be used.
4. Each test must use 3 test vessels of effluent exposed fish and 3 test vessels of control fish. Thirty fish must be used in each of the effluent exposed and the control groups.
5. A final evaluation for acute lethality is invalid if mortality occurs in the control group during the test. Mortality in the stock of fish used for the test must not exceed one percent per day in the seven days preceding the test.
6. For every one gram of fish, there must be at least two litres of fresh test solution every 24 hours. The minimum water depth in any test vessel must be 10 centimetres. The minimum volume of solution in the test vessel must be 200 cubic centimetres per gram of fish.
7. Flow through acute lethality tests are required. a minimum of 90% molecular replacement of solution in the test vessels is required in each 8-hours period during the test.
8. In any test, individual fish must weigh between 0.5 and 10 grams and the length of the largest fish should not be more than two times the smallest.
9. The test should be conducted at 15 ± 1°C
10. When containers of effluent must be held or transported the containers must be completely filled to eliminate air and kept tightly sealed until the time of testing. An effluent sample may be held for up to 5 days after the time of collection before a test is begun.
11. Only that amount of aeration or oxygenation required to maintain a dissolved oxygen level of 8 mg/l or greater as measured in the effluent and control tanks may be applied. Aeration or oxygenation must be carried out at a point between the test vessels and the buik storage container.
12. Effluent from those operations that discharge only fresh water in their effluents, whether they discharge into inland or marine waters, must be tested with rainbow trout held in fresh water. For effluents containing sea water, the Regulatory Agency will determine an appropriate test species of fish. Any such test fish should be held in sea water of the same salinity as the effluent to be tested. The control solution must have the same salinity as the effluent.
13. Immediately prior to the start of the test the pH of the effluent should be measured. If it is found to be outside the pH range 6-9.5 the pH may be adjusted. Acidic effluents are to be adjusted to an initial pH of 6-7; basic effluents are to be adjusted to an initial pH of 8-9.
14. The effluent samples must be tested at full strength without any dilution.
15. The number of dead fish in each test vessel should be observed and recorded at approximately 1/4, 1/2, 1, 2, 4, 24, 72 and 96 hours after commencement of the bioassay. Fish are conside-

3. N'utiliser que des truites normalisées en bonne santé.
4. Chaque épreuve se fera au moyen de trois groupes de poissons exposés à l'effluent, et d'autant de poissons témoins. Le nombre de poisson dans chaque groupe doit être de 30.
5. Le contrôle est nul si au moins un poisson meurt au cours des essais. Le taux de mortalité des poissons d'essai ne doit pas dépasser 1% par jour, au cours des 7 jours précédant le contrôle.
6. Il doit y avoir au moins deux litres de solution neuve pour chaque période de 24 heures et chaque gramme de poisson. La profondeur minimale de l'eau doit être de 10 centimètres. Le volume minimal de la solution doit être de 200 centimètres cubes par gramme de poisson.
7. Les contrôles doivent être réalisés dans des conditions dynamiques. Un taux de remplacement minimal de 90% de la solution, échelonné sur une période de 8 heures, est exigé pour toute la durée du contrôle.
8. Pour tous les contrôles chaque poissons doit peser entre 0,5 et 10 grammes, et la longueur du plus gros ne doit pas être plus du double de celle du plus petit.
9. Le contrôle doit se faire à 15 ± 1°C.
10. Lorsque les contenants d'effluent doivent être conservés ou déplacés, les remplir à pleine capacité pour en éliminer l'air, et les boucher hermétiquement jusqu'au moment des contrôles. On peut conserver les échantillons d'effluent pendant un maximum de 5 jours après la date du prélèvement, avant les contrôles.
11. Ne réaliser que le taux d'oxygénation ou d'aération nécessaire au maintien d'une teneur en oxygène dissous de 8 mg/1 ou plus, mesurée dans les réservoirs d'effluent et de solution témoin. Loxygénation ou l'aération doit être faite en un point situé entre les bassins et le réservoir les alimentant.
12. Les effluents ne contenant que de l'eau douce, qu'ils soient déversés en eaux douce ou salée, doivent être contrôlés avec de la truite arc-en-ciel gardée dans de l'eau douce. Pour les effluents contenant de l'eau de mer, l'organisme de réglementation déterminera une espèce de poisson appropriée. Cette espèce sera gardée dans de l'eau de mer d'une salinité égale à celle de l'effluent devant être contrôlé. La solution témoin sera de la même salinité.
13. Juste avant le début des contrôles, mesurer le pH de l'effluent. S'il n'est pas dans l'intervalle de 6 à 9.5, l'ajuster entre 6 et 7 si les effluents sont acides, et entre 8 et 9 s'ils sont basiques.
14. Les échantillons d'effluent doivent être contrôlés tels quels, sans dilution.
15. Le nombre de poissons morts dans chaque milieu contrôlé doit être noté aprés environ 1/4, 1/2, 1, 2, 4, 24, 72, et 96 heures. Le poisson est considéré comme mort lorsqu'une légère poussée

red dead when, upon mild mechanical prodding with a glass rod, there is no visible respiration movement or any other overt movement. As soon as the fish is considered dead it should be removed from the test vessel with a dip net.

SCHEDULE II

SCREENING TEST PROCEDURE FOR ACUTE LETHALITY (96-HOUR STATIC TEST)

(To be carried out by, or for, the Mine Operator for the purpose of section 5)

1. For the purpose of this Schedule, the applicable portions of APHA *(Standard Methods for the Examination of Water and Wastewater.* 13th Edition (1971), published jointly by the American Public Health Association, American Water Works Association and the Water Pollution Control Federation), section 231, should be used as a basis for this test procedure except as modified in this Schedule.
2. Rainbow trout *(Salmo gairdneri* Richardson) are recommended as the standard test organism.
3. Only healthy stocks of fish are to be used.
4. Each screening test should use a minimum of ten effluent exposed fish and ten control fish.
5. A screening test is invalid if mortality occurs in the control group during the test. Mortality in the stock of fish used for the test should not exceed one percent per day in the seven days preceding the test.
6. For every one gram of fish, there must be at least two litres of test solution per test. The minimum water depth in any test vessel should be 10 cm.
7. Screening acute lethality tests should be conducted in the static mode. The solution in the effluent and control tanks should not be changed during the course of the test.
8. In any test, individual fish should weigh between 0.5 and 10 grams and the length of the largest fish should not be more than two times the smallest.
9. The test should be conducted at 15 ± 1°C.
10. When containers of effluent must be held or transported the containers should be completely filled to eliminate air and kept tightly sealed until the time of testing. An effluent sample may be held for up to 5 days after the time of collection before a test is begun.
11. Only that amount of oxygenation or aeration required to maintain a dissolved oxygen level of 8 mg/l or greater as measured in the effluent and control tanks should be applied. Aeration or oxygenation may be carried out in the test vessels.
12. Effluent from those operations that discharge into inland or marine water, should be tested with fish held in fresh water. For effluents containing sea water, fish held in sea water of the same salinity

avec une tige de verre ne laisse voir aucun mouvement respiratoire ou autre, sur quoi il doit être immédiatement retiré à l'aide d'une épuisette.

ANNEXE II

PRÉ-CONTRÔLE DE LA LÉTALITÉ AIGUE (D'UNE DUREE DE 96 HEURES, DANS DES CONDITIONS STATIQUES)

(Normalement réalisé par l'exploitant de la mine, ou en son nom, aux fins de l'article 5)

1. Aux fins de la présente annexe, utiliser les indications applicables de la section 231 du recueil de l'APHA (Standard Methods for the Examination of Water and Wastewater, 13e édition, 1971, publié conjointement par l'American Public Health Association, l'American Water Works Association et la Water Pollution Control Federation), comme fondement opératoire du présent contrôle, à l'exception des modifications précisées ci-après.
2. L'espèce recommandée pour ce pré-contrôle est la truite arc-en-ciel (Salmo gairdneri Richardson).
3. N'utilisez que du poisson sain.
4. Chaque pré-contrôle doit porter sur au moins 10 poissons exposés aux exposés aux effluents et 10 poissons témoins.
5. Le pré-contrôle est nul si un seul poisson témoin meurt au cours de l'épreuve. La mortalité des indicateurs ne doit pas dépasser 1% par jour, dans les 7 jours précédant le pré-contrôle.
6. Il doit y avoir au moins deux litres de solution par pré-contrôle et par gramme de poisson. La profondeur minimale de l'eau doit être de 10 cm.
7. Les contrôles se font dans des conditions statiques. Les solutions des réservoirs de l'effluent et du milieu témoins ne doivent pas être renouvelées pendant les épreuves.
8. Dans chaque épreuve, chaque poisson doit peser entre 0.5 et 10 grammes, et la longueur du plus gros ne doit pas être plus du double de celle du plus petit.
9. Le contrôle doit se faire à 15 ± 1° C.
10. Lorsque les contenants d'effluent doivent être conservés ou déplacés, les remplir à pleine capacité pour en éliminer l'air et les boucher hermétiquement jusqu'au moment des contrôles. On peut conserver un échantillon d'effluent pendant un maximum de 5 jours après le prélèvement, avant les contrôles.
11. Ne réaliser que le taux d'oxygénation ou d'aération nécessaire au maintien d'une teneur en oxygène dissous de 8 mg/1 ou plus, mesurée dans les réservoirs d'effluents et de solution témoin. Cette opération peut se faire dans les milieux

should be used for the test. The control solution should have the same salinity should be used for the test. The control solution should have the same salinity as the effluent. The Regulatory Agency should be consulted to determine an appropriate test species of fish for effluents containing sea water.
13.Immediately prior to the start of a test the pH of the effluent should be measured. If it is found to be outside of the pH range 6.0-9.5 two tests should be run; one on the effluent as received and a second with the effluent neutrally adjusted as follows: acidic effluents are to be adjusted to an initial pH of 6-7, basic effluents are to be adjusted to an initial pH of 8-9.
14.The effluent samples should be tested at full strength without any dilution.
15.The number of dead fish in each test vessel should be observed and recorded at approximately 1/4, 1/2, 1, 2, 4, 24, 72 and 96 hours after commencement of the bioassay. Fish are considered dead when upon mild mechanical prodding with a glass rod, there is no visible respiration movement or any other overt movement. As soon as the fish is considered dead it should be removed from the test vessel with a dip net.

mêmes.
12. Les effluents ne contenant que de l'eau douce, qu'ils soient rejetés en eaux douce ou salée, doivent être contrôlés avec du poisson gardé en eau douce. Pour les effluents contenant de l'eau de mer, utiliser du poisson gardé en eau de mer d'une salinité égale à celle de l'effluent. Consulter l'organisme de réglementation pour déterminer l'espèce de poisson qui convient aux contrôles en eau salée.
13. Juste avant le début des épreuves, mesurer le pH de l'effluent. S'il n'est pas dans l'intervalle de 6 à 9.5, faire deux contrôles; le premier avec le pH inchangé, le deuxième avec l'effluent au pH ajusté à une valeur dans l'intervalle de 6 à 7 s'il était acide et de 8 à 9 s'il était basique.
14. Les échantillons d'effluent doivent être étudiés tels quels, sans dilution.
15. Le nombre de poissons morts dans chaque milieu contrôlé doit être noté après environ 1/4, 1/2, 1, 2, 4, 24, 72 et 96 heures. Le poisson est considéré comme mort lorsqu'une légère poussée avec une tige de verre ne laisse voir aucun mouvement respiratoire ou autre, sur quoi il doit être immédiatement retiré à l'aide d'une épuisette.

UNEP INDUSTRY AND ENVIRONMENT PROGRAMME ACTIVITY CENTRE

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