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Report on the Cleanup of Abandoned Tailings Through Reprocessing Operations

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REPORT ON THE CLEANUP OF ABANDONED TAILINGS THROUGH REPROCESSING OPERATIONS

BY THE

INTERGOVERNMENTAL WORKING GROUP
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FOREWORD

This discussion paper has been prepared by the Intergovernmental Working Group on the Mineral Industry (IGWG) in response to a commitment made at the 1990 Mines Ministers' Conference to "examine a broad range of measures including research and development to encourage the cleanup of abandoned tailings through reprocessing operations."

Traditionally, tailings reprocessing projects have been driven by the profit motive and the opportunities created by improvements in mineral processing technology or by increased prices for mineral products. More recently, tailings reprocessing projects have been instigated or proposed as a cost effective technique for the remediation of pollution problems such as acid drainage, toxic metal and salt contamination.

This report reviews tailings reprocessing practices, problems and potential throughout Canada, and also includes some examples of foreign tailings reprocessing practices and policies.

EXECUTIVE SUMMARY

Problems Associated With Mine Waste Products

The mining industry in Canada produces nearly 2 million tonnes per day of tailings and other wastes such as overburden, broken rock, smelter slags and fly ash.

The value of these mineral wastes is low. There is usually no possibility of further commercial exploitation of these wastes because they are typically located in areas remote from urban centres.

Environmentally acceptable storage and reclamation of large volumes of mineral waste is expensive, but current mine operators have accepted responsibility for postclosure reclamation of their mine sites.

Many old abandoned mineral wastes are inadequately stored and result in pollution of the surrounding air, water and soil or the possibility of a catastrophic failure.

Practical Aspects of Reprocessing Mine Tailings

Improvements in the technology of mineral extraction or increases in the price of a mineral commodity may make it economically attractive to reprocess some mine tailings or other mine waste dumps. This may provide an opportunity to store the residual waste products in a manner that prevents degradation of the environment.

A review of several recent and proposed mine waste retreatment projects in Canada and elsewhere revealed that:

(a) the reduction of the amount of tailings is generally very small, from 0.0001 percent for gold tailings to 15 percent for the proposed production of magnesium from asbestos tailings;

(b) environmental improvements were generally small;

(c) in some cases environmental degradation has been caused by technical or financial failure of the tailings reprocessing operation; and

(d) because the reduction in quantity of tailings is small, the environmental benefits of tailings reprocessing usually accrue from improved methods of impounding the residual waste products.

A review of the various sectors of the mining industry concludes that tailings reprocessing operations are theoretically possible for every type of mining operation in Canada. Research and development of new processing technologies will enhance the potential for economic reprocessing of mine wastes.

The Role of Government in Tailings Reprocessing

In Canada, jurisdictional authority for the control and management of mineral resources within the provinces resides primarily with the provincial governments. However, the federal government has environmental responsibilities that overlap those of the provinces in the area of controlling discharges from mines into the environment. Within the Yukon Territory and the Northwest Territories, jurisdictional authority for mining and environmental protection rests with the federal government, although it may devolve to the territorial governments at some future date.

For the purposes of the Income Tax Act, tailings are considered to be an inventory of ore from a mineral resource. This means that work done to define the quality and quantity of tailings at a site will not qualify as Canadian exploration expense, but profits from a tailings reprocessing operation will be eligible for the resource allowance.

Some foreign governments offer grants or subsidies for tailings reprocessing projects. A levy on current producers to finance reclamation of abandoned mine sites, such as the Superfund in the United States, is perceived by the mining industry to unfairly penalize current mine operators by forcing them to pay to rectify problems created by the activities of previous generations of miners.

Refinement of the regulations governing mine reclamation, abandonment and performance bonds would probably result in better storage and treatment of tailings and other wastes at existing operations and improved designs for waste handling in future operations.

In the case of abandoned tailings deposits, where the title has reverted to the Crown or the responsible company may not have sufficient assets to finance remediation, the Crown may be responsible for the costs of mine reclamation.

Without mineral processing technologies that offer a significant improvement in recovery compared to the technology utilized in the original rejection of the tailings, there is little or no potential for a commercially viable tailings reprocessing operation. This truism is well recognized by governments and the private sector, and both have actively supported mineral processing research in the form of individual and cooperative projects. The examples presented in section 3.3 suggest that investment in mineral processing research may be the most cost effective of all the initiatives available to governments.

Conclusions

Recent tailings reprocessing operations in Canada and abroad have ranged from brilliant successes, producing significant profits and environmental benefits, to dismal failures causing bankruptcies and additional degradation of the environment.

The quantity of residual tailings that remains to be stored after a tailings reprocessing operation is usually very nearly the same as the quantity of the original tailings deposit.

The reprocessing of an abandoned mine tailings deposit will be of benefit to the environment if it extracts a hazardous component or if the residual tailings are stored in an impoundment that is environmentally superior to the original impoundment.

Tailings reprocessing operations sometimes require toxic chemicals, which were not present in the original tailings, to be added to the residual tailings.

In the case of most of the tailings deposits that currently pose major environmental hazards, it may be more cost effective to undertake remedial work to improve the integrity of the present impoundment and containment structures and to control the release and migration of contaminants rather than to reprocess the tailings.

Successful tailings reprocessing requires mineral processing technology that is significantly more effective and efficient than the technology used when the original tailings were deposited. This means that, in many cases, private sector and government support for mineral processing research and development will provide the most effective encouragement for the reprocessing of abandoned tailings.

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1. INTRODUCTION

1.1 The Problem of Environmentally Hazardous Mine Wastes: A Public Policy Issue Demanding Attention

Any intensive use of the earth's resources carries with it the potential for adverse environmental consequences. Mining is no exception. In Canada, mining and mineral processing operations produce about 650 million tonnes per year of wastes. This amount is added each year to the billions of tonnes of old mining and mineral processing wastes accumulated over the years and scattered around the country.

Adopting a sound regulatory approach to new and operating mines will do much to avoid future reclamation problems. Past practices have left a legacy of abandoned sites that pose serious environmental risks in the form of acid mine drainage that could result in pollution of groundwater and water in nearby lakes and rivers.

In addition, failures of tailings dams could pose serious environmental problems. A spill of gold mine tailings into the Montreal River near Matachewan, Ontario in October 1990 was such an example. Incidents such as these reinforce the public perception that abandoned mine sites and tailings dumps pose serious ecological problems and that they must be rectified.

1.2 Background and Recent Developments

The 1988 "Report on the Economic and Policy Aspects of Acid Discharge" prepared by an IGWG/Industry subcommittee on mine waste concluded that: "There is an urgent need for measures to deal with the reclamation of abandoned mine sites."

Some IGWG members have argued that there could be a case for government incentives for the promotion of tailings reprocessing in the case of abandoned tailings, on the basis that reprocessing operations may lead to improvements in environmental quality.

1.3 Thrust and Organization of the Report

The current report examines the reprocessing potential of abandoned tailings and the extent to which reprocessing is a means to improve environmental quality.

Chapter two of the report broadly describes the generic mine waste problem and the associated environmental hazards.

Chapter three reviews cases of reprocessing projects, both domestic and foreign. It also discusses the potential for reprocessing of tailings resulting from the mining and processing of deposits of base metals, precious metals, industrial minerals (including potash and asbestos), uranium, coal, and oil sands. The extent to which reprocessing promotes environmental enhancement is examined.

Chapter four discusses possible initiatives to encourage reprocessing of mine tailings and considers the legal, fiscal, jurisdictional and economic issues and constraints that must be taken into account.

Finally, Chapter five presents the conclusions and recommendations developed in this report.

2. PROBLEMS ASSOCIATED WITH MINE WASTE PRODUCTS

2.1 Nature and Dimensions of the Mine Waste Problem

During 1990, the mining industry in Canada produced ore at a rate of almost one milion tonnes per day. The amount of tailings resulting from the processing of these ores was only slightly less at about 950 000 tonnes per day. The amount of waste rock produced was also about one million tonnes per day. These wastes are costly to dispose of and to maintain in waste dumps. Furthermore, they can result in pollution of ground-water, surface water, soil and air in the immediate vicinity.

2.1.1 Mining and Mineral Processing Wastes

Mining and mineral processing wastes are composed of several principal types: overburden; waste rock from open pits or from development work in underground mines; coarse mill rejects from screening or heavy media separation processes; and fine rejects or mill tailings from screening, magnetic separation, and flotation processes.

Table 1 presents a simple classification of mineral wastes together with examples showing their current and potential uses.

Although mineral waste varies widely in composition from mine site to mine site, material from any one plant or location normally would have relatively uniform physical and chemical characteristics.

Many waste accumulations have limited value as sources of raw mineral material because of high impurity content, remote location, or both. However, some are favourably located and of interest because of contained metals and minerals or because of inherent physical and chemical characteristics. From the standpoint of reuse, mining wastes may readily be divided into two main categories:

(a) those of interest because of contained minerals or metals that are potentially recoverable, such as copper, gold or silver and,

(b) those of interest as raw material for the manufacture of consumer products or in various applications, for example, for brick and block, as aggregate in concrete, and as soil additives and mineral fillers.

The reuse of wastes in Category 1 depends on the assay values of the copper, gold, or silver and whether or not these metals can be economically recovered.

Reuse of the wastes noted in Category 2, however, to a large degree depends on the inherent physical and chemical characteristics of the waste. The successful use of these wastes for specific applications will depend on established and satisfactory performance or upon their meeting identified physical and performance standards.

Tables 2 to 6 describe current or potential applications for wastes from Canadian mining operations.

TABLE 1. MINERAL WASTE CLASSIFICATION

	Primary Wastes		Secondary Wastes
	Mine Rock	Mill Tailings	Metallurgical Slags and Dusts
Origin and Description	Rock that has been broken and removed to uncover ore for subsequent mining. Accumulations are large, especially at many open-pit mines. Collectively this material is composed of a wide variety of rock types.	Rejects from mineral beneficiation and processing operations. Material from individual operations is usually homogenous in composition and consists of rock forming minerals but may include sulphides, e.g. pyrite and pyrrhotite, and traces of other metallic minerals. Rejects are normally of uniform size. Those from coarse screening or heavy media plant may vary from 10 cm to 1 cm or less in size; flotation tailings are usually minus 150 μm.	Slags, cinders, dusts and sludges from metallurgical plants and from foundries, fly ash and bottom ash from coal-fired power plants, cement and lime kiln dusts. Material from individual operations is usually uniform in composition and size. Size of separate waste types varies widely, from 30 cm or more down to dust.
Examples	Granite, trap rock, syenite, limestone from open-pit iron ore mines.	Pyrrhotite-feldspar-quartz mill tailings from nickel-copper flotation, quartz-feldspar tailings from gold ore processing, serpentine tailings from asbestos mills, carbonate-silicate tailings from niobium oxide recovery plants, salt from potash recovery operations.	Blast and steel furnace slags, copper-nickel slags, fly ash, cement and lime dusts.
Current or Potential Use	Mine backfill, roadfill, landscaping, for production of railroad ballast and construction aggregate.	Potential source of additional metals and minerals, and of raw material for the manufacture of bricks and blocks, for production of thermal insulation, as a soil additive and as a mineral filler in various products. Some tailings are used in mine backfill operations.	Some wastes are suitable as road base material, as aggregate in asphalt pavement, as light- and heavy-weight aggregate in concrete, as pozzolanic additives in concrete and as a soil additive.

TABLE 2. APPLICATIONS FOR WASTES FROM NONFERROUS BASE-METAL MINING OPERATIONS

Company	Metal	Waste - Current or Potential Use
General	copper, lead, zinc, nickel	rock: variable size and composition tailings: finely ground, 75% minus 150 µm, wide variety of rock forming minerals, usually with significant amounts of metallic sulphides (pyrite, pyrrhotite, and others)
Newfoundland Zinc Mines Ltd. Daniel's Harbour, Nfld.	zinc	tailings: chiefly dolomite; have been used experimentally to reduce soil acidity
Concolidated Durham Mines Ltd., Prince William, N.B.	antimony	tailings: chiefly quartz; potential use as sandblast and foundry molding sand
Inco Metals Co., Thompson, Man.	nickel, copper	rock: chiefly quartzite, some use as railroad ballast
Tantalum Mining Corp. of Canada Ltd., Bernic Lake, Man.	tantalum, cesium, lithium	rock: chiefly quartz, mica, feldspar; minor use as a decorative stone for landscaping tailings: chiefly feldspar, quartz, mica; potential source of high-quality feldspar for ceramics
Cominco Ltd., Kimberley, B.C.	zinc, lead	rock: chiefly siliceous argillite; float from sink-plant is used as railroad ballast, (350 000 tonnes per year, plus 20 mm), and for road construction
Princeton Mining Corp. Princeton, B.C.	copper	rock: chiefly volcanics; dense, homogenous with fine-grained sulphides; used locally by Dept. of Highways in road construction; of potential use in building products and as oil absorbent

TABLE 3. APPLICATIONS FOR WASTES FROM PRECIOUS-METAL MINING OPERATIONS

Company	Metal	Waste - Current or Potential Use
General	gold, silver	rock: variable size and composition tailings: finely ground, 80% minus 150 µm, usually with high percentage of quartz, with other silicates, carbonates, and so on; low metallic sulphide content (pyrite, pyrrhotite)
Agnico-Eagle Mines Ltd., Cobalt, Ont.	silver	rock: intermediate volcanics or sediments that have undergone a degree of change in mineral or chemical composition through metamorphism; chiefly used as landfill and as railroad ballast
Dome Mines Ltd., South Porcupine, Ont.	gold	tailings: chiefly quartz and feldspar; possible use in brick and block manufacture

TABLE 4. APPLICATIONS FOR WASTES FROM IRON MINING OPERATIONS

Company	Waste - Current or Potential Use
General	rock: variable size and composition tailings: usually finely ground, 60 to 90% minus 150 µm, but may be coarser depending on processing; wide variety of rock-forming minerals including significant amounts of metallic oxides and sulphides
Hilton Mines Ltd., Shawville, Que.	rock: chiefly granites; used as railroad ballast (500 000 tonnes per year, minus 40 to plus 20 mm) as aggregate in concrete, and in general construction applications; a study of the use of minus 20 mm rock and tailings in concrete railroad ties is in progress tailings: chiefly actinolite and calcite; studies by CANMET indicate that this material is satisfactory for dry-pressed, fired-brick manufacture
Iron Ore Company of Canada, Schefferville and Seven Islands, Que.	rock: low-grade iron formation (40% iron, 30% silica); used as railroad ballast tailings: chiefly quartz and clay; potentially of interest as paint pigment and in the manufacture of ceramics
Quebec Cartier Mining Co., Seven Islands, Que.	tailings: chiefly quartz (88%) and hematite (11%); minor use as aggregate in concrete and asphalt
Quebec Iron and Titanium Corp., Tracy, Que.	tailings: chiefly plagioclase and ilmenite; current source of roofing granule material remainder useful as aggregate or filler in asphalt and concrete
Cliffs of Canada Ltd., Temagami, Ont.	rock: chiefly iron silicates, feldspar, mica; bulk is used in road and dike construction, possible use as railroad ballast
Marmoraton Mining Co., Marmora, Ont.	rock: chiefly limestone, syenite, traprock; traprock is used as aggregate in asphalt mixes, possible use of separate rock types as construction aggregate and as aggregate in concrete tailings: chiefly limestone and syenite (40% calcium oxide, 40% silica); possible use in the manufacture of dry-pressed, fired brick

TABLE 5. APPLICATIONS FOR WASTES FROM INDUSTRIAL MINERAL MINING OPERATIONS

Company	Mineral	Waste - Current or Potential Use
General		rock: variable size and composition tailings: most industrial mineral mines do not produce large amounts of tailings (exceptions are potash and asbestos); where produced, tailings usually are finely divided, of uniform composition and substantially free of metallic sulphides
Asbestos mines, Eastern Townships, Que.	asbestos	tailings: chiefly nonfibrous serpentine and associated minerals (40% magnesia, 40% silica); currently used as road fill and in asphalt, potentially useful for the manufacture of brick, mineral wool and in fertilizer
Baker Talc Ltd., South Bolton, Que.	talc	tailings: chiefly ferruginous magnesite and talc; potentially useful as inert mineral filler, as a coating on fertilizer prills to prevent sticking and to add magnesium to soil
St. Lawrence Columbium and Metals Corp., Oka, Que.	columbium oxide	tailings: chiefly calcite and quartz; potentially useful as mineral filler, as soil additive and neutralizer, and as neutralizer for acid effluents
Indusmin Ltd., Midland, Ont.	silica	tailings: quartz (99% silica); used as additive in autoclave concrete block, potential use as filler in paint and plastics and in sand-lime-brick manufacture
Minnesota Minerals Ltd., Havelock, Ont.	traprock	tailings: chiefly trap rock (45% silica, 22% alumina); potential use as filler in asphalt and for mineral wool manufacture
Baroid of Canada Ltd., Spillimacheen, B.C.	barite	tailings: chiefly shale and dolomite; suitable as fill in road construction and maintenance
Ideal Basic Industries, Vananda, B.C.	limestone	waste rock: chiefly dike rock from limestone quarry, also process rock waste from previous iron mining operation; markets include road fill, riprap, and aggregate uses, 100 000 tonnes per year
Sherbrooke University, Sherbrooke, Que.	dolomitic limestone	tailings: screenings from aggregate plant at St. Eustache; used in asphalt and as landfill, current studies on use in high-strength concrete

TABLE 6. APPLICATIONS FOR WASTES FROM COAL MINING OPERATIONS

Company	Waste - Current or Potential Use
General	rock/tailings: rejects vary in size from 100 mm or larger to very fine material, high percentage of clay and shale with variable amounts of coal
Cape Breton Development Corp., Victoria Junction plant, Sydney, N.S.	rock: shale, sandstone pyrite; small amounts have been used in portland cement and, experimentally, for lightweight aggregate manufacture
Coleman Collieries Ltd., Coleman, Alta.	tailings: chiefly shale; rejects from wash plant useful as roadbed material and in dam construction
Fording Coal Ltd., Elkford, B.C.	rock: sandstone, siltstone, mudstone; used in road and dike construction, of potential interest for manufacture of lightweight aggregate tailings: potential feedstock for thermal electricity generating station

2.1.2 Waste Rock

Waste rock is extensively used locally as mine or open-pit backfill, in road construction and maintenance, and on occasion, as aggregate in concrete and as railroad ballast. Local use by a mining company seldom requires that the waste meet specific standards but rather is based largely on satisfactory in-service performance. However, if sold to a contractor for use in the construction of major highways or as railroad ballast on major lines, then the material undoubtedly would be subject to established physical and chemical specifications.

2.1.3 Mill Tailings

As Tables 2 to 6 indicate, there are a number of current or potential commercial applications for Canadian mill tailings.

Mill tailings may be used locally as backfill in mines and in construction. With increasing interest in the potential use of mill tailings in applications such as brick and block manufacture, soil additive, and mineral filler material, the need for standards to govern the use of these materials is becoming increasingly evident.

2.1.4 Smelter Slags

Annual production of nonferrous smelter slags in Canada is estimated at 8 million tonnes. Most of it is derived from copper, nickel, zinc, or lead smelters at Murdochville and Rouyn-Noranda in Quebec, Sudbury, Falconbridge and Timmins in Ontario, Flin Flon and Thompson in Manitoba, and Trail in British Columbia.

These slags are normally disposed of as landfill, although nickel slag from the Sudbury area has been used for over 25 years as railroad ballast material. Copper slag from the Noranda and Flin Flon smelters has also been used for railroad ballast.

Dicalcium silicate slags resulting from the production of magnesium metal by the Pigeon process at Haley Station, Ontario have been studied as raw material for building products manufacture. Good quality building brick was produced by an autoclave process developed at CANMET.

Nonferrous slags also have been used as road base and fill material and as cemented backfill in underground mines.

2.1.5 Fly Ash

Fly ash is produced by the burning of coal to generate electricity at plants in Nova Scotia, New Brunswick, Ontario, Manitoba, Saskatchewan and Alberta.

Chemically, fly ash is a heterogeneous mixture of crystalline and amorphous compounds of silica, alumina and iron oxide with varying proportions of calcium oxide and other minor components. The composition of a particular ash is largely determined by the composition of the inorganic portion of the coal from which it is derived. Physically, fly ash particles are mostly spherical in shape and range in diameter from 1 to 150 µm.

Annual production of fly ash is in the order of 2 million tonnes, of which about 5 percent is used as a pozzolanic additive in concrete to replace part of the portland cement. Although use of fly ash in concrete is increasing, total consumption for this purpose probably does not exceed 10 percent of the production of fly ash in any regional market.

Other uses of fly ash, including its application in the manufacture of lightweight aggregate and as a soil cement in highway construction, are being gradually developed.

The recovery of vanadium (1.4 percent) and nickel (0.7 percent) from fly ash resulting from the burning of coke recovered from the bitumen portion of the tar sands at Fort McMurray in Alberta has also been studied.

2.1.6 Dimensions of the Reclamation Problem

For policy purposes, reclamation problems can be divided into two categories:

(a) traditional or normal reclamation, where the waste and tailings are not reactive; and

(b) situations where waste materials contain sulphide mineralization and cause acid mine drainage (AMD).

Traditional or normal reclamation involves removal of all buildings, utilities and equipment, sealing of all openings, recontouring of excavations and spoil piles with appropriate drainage facilities and establishing a self-sustaining vegetation cover to prevent erosion and dust problems. Some of this work can be performed while the mine is operating with the balance after the close. Postclosure reclamation will generally be of short duration, say one to four years. Most of these activities are mining or civil engineering operations and their costs can be estimated quite accurately.

In the second case, reclamation is much more difficult and costly. It may require, in addition to the foregoing, the building of a system to contain or capture the AMD effluent and treat it. These facilities, when well operated and maintained, are generally sufficient to prevent harmful environmental impact downstream. However, acid generation may persist for hundreds of years following mine closure. The operation of treatment plants for such long periods of time is costly and clearly not desirable. To estimate the operating costs of these operations for such long periods of time with any degree of accuracy is, to say the least, difficult.

Therefore, alternative new technologies are needed to find permanent and economic solutions to the AMD problem. Recognizing this need, Canadian governments and industry set up a joint project, the Mine Environment Neutral Drainage (MEND), to coordinate research efforts in this area. The B.C. Acid Mine Drainage Task Force is another group coordinating research into the problems of acid drainage specific to British Columbia.

It has been estimated that acid generating wastes cover 15 000 hectares of land in Canada. In Ontario, 100 major abandoned mine sites were identified of which 20 pose an AMD problem. These 20 sites are estimated to contain 55 million tonnes of reactive sulphide tailings and cover a surface area of 830 hectares.

In Quebec, there are about 107 major abandoned mine sites and 21 of these sites, covering an estimated area of 4500 hectares, have been classified as hazardous waste sites because of acid drainage. The province of British Columbia has about 72 million tonnes of acid generating tailings, or about 4 percent of the total in Canada. However, there are also about 250 million tonnes of acid generating waste rock (80 percent of the Canadian total) which is increasing by about 25 million tonnes per year.

2.1.7 The MEND Program

The MEND program was established in 1988 to develop technologies to prevent and control AMD. This means researching the processes responsible for generating acidic drainage and determining techniques for controlling it. The Canada Centre for Mineral and Energy Technology (CANMET) is a major participant in the five-year, $12.5 million project, which also involves the Canadian mining industry, Environment Canada, Indian and Northern Affairs Canada, and the provinces of British Columbia, Manitoba, Ontario, Quebec and New Brunswick, where most of Canada's sulphide minerals are mined. MEND research activities focus on prediction, prevention and control, treatment, monitoring, technology transfer and international liaison. Activities include:

(a) the development of improved methods for predicting and modelling acid generation from wastes containing sulphides;

(b) the evaluation of various technologies to reduce or prevent the weathering of tailings; and

(c) the application of chemical, biological and other processes for treating AMD, capturing heavy metals and stabilizing sludges from existing lime plants.

2.1.8 Potential and Prospects

Although virtually all of Canada's mineral wastes will never have commercial value, there are some that could have value as alternate or supplemental sources of mineral raw material, particularly in traditional nonmetallic or industrial mineral markets. Interest in such wastes is growing and will continue to grow as higher quality and more readily accessible mineral deposits are mined to exhaustion or where, as in some urban centres, quarrying is restricted by local regulations.

Waste utilization is an attractive alternative to disposal in that disposal costs and potential pollution problems are reduced or even eliminated and resources are conserved. Technical and economic constraints severely limit the use of some mineral wastes. Distance from potential markets, quantity and quality of material available, ease of recovery, transportation costs, market demand and specifications all influence whether or not waste materials will be recovered and reused.

Energy considerations must also be taken into account and may be a positive factor in that these wastes are already mined and partially processed. In some instances it may be feasible to arrange low-cost bulk shipment of waste by boat or barge or, perhaps, to obtain more favourable rail rates through use of unit trains or backhaul arrangements.

Market specifications may require that the physical nature of the material (particle size or size distribution) be altered to meet a potential use or application, whereas chemical specifications for raw material for a particular use may be unnecessarily stringent. Thus, the producer may be obliged to undertake further processing, or the consumer may have to alter specifications to permit use of a particular waste material.

Most of the successful reprocessing projects recover only a small proportion of the total waste volume and therefore still have the problem of disposal of the remaining waste material. Because current regulations governing the disposal of mine wastes are generally more stringent than those that applied at the time that the wastes were originally accumulated, there is an environmental benefit realized when these wastes are reprocessed, stored and reclaimed to modern standards of environmental protection. (Section 3.1).

Although interest in mineral waste is growing, such interest is tempered by the fact that there is little published information on the basic nature of these wastes or on their availability and potential utility. Specifications that could encourage a wider use of such wastes are lacking. A number of domestic and foreign organizations are promoting activities designed to fill this information gap: the Mineral Waste Utilization Symposia sponsored by the U.S. Bureau of Mines/Illinois Institute of Technology Research in Chicago; Ontario Research's Canadian Waste Materials Exchange; and CANMET's Mineral Waste report series.

2.2 Environmental Hazards Associated with Mine Wastes

2.2.1 Air Pollution

Wind blown dust from mine waste dumps and tailings deposits may contaminate the region immediately downwind (up to several kilometres) from the mine site. The composition of the dust will be site specific depending upon the geology and extraction processes utilized at the mine site, but it may contain elements that have been shown to be toxic in plants or humans such as Al, As, Be, Ca, Cd, Cr, Co, Cu, Fe, Pb, Mn, Hg, Mo, Ni, Th, W, V and Zn.

Waste gases from sulphide ore smelting operations contain sulphur oxides that, in the Sudbury and Wawa regions of Ontario, have been shown to affect vegetation as far as 30 kilometres away from the smelter site.

2.2.2 Water Pollution

As discussed above, mine waste dumps that expose sulphide minerals to air and water may generate acidic solutions containing heavy metals that are extremely toxic. If not contained or neutralized, these AMD solutions may contaminate the surface waters and groundwaters in the vicinity of the mine site. Waters draining from mine tailings deposits may be acidic, or contain toxic metals, or contain residues of process chemicals. If these waters are released into the environment without adequate treatment, they may cause widespread damage to aquatic flora and fauna.

2.2.3 Radioactive Emissions

Waste dumps, tailings deposits and ore stockpiles at uranium mines may be sources of radioactive emissions.

2.2.4 Failure Hazards

Failures of mine waste dumps may cause catastrophic deaths as in the 1966 coal mine waste dump failure at Aberfan, Wales, that inundated a primary school. The recent failure of a tailings dam near Matachewan, Ontario released sand and silt containing heavy metals into the Montreal River.

2.3 Abandoned Tailings Sites

The term "abandoned tailings site" is applied to any deposit of mine tailings that is no longer being actively worked. The tailings site may or may not have been subject to reclamation work prior to being abandoned. The abandoned tailings site may still be owned by an active mining company, or the property may have reverted to the Crown.

Ideally, an abandoned tailings site will have been reclaimed to an environmentally benign state prior to being abandoned. Unfortunately, many abandoned tailings sites have not been adequately reclaimed, and they are currently creating some or all of the environmental hazards described in Section 2.2 above.

The reclamation of an environmentally hazardous abandoned tailings site may be a large, difficult and expensive operation. In some cases reprocessing of the abandoned tailings has been proposed as a source of revenue, a portion of which would be used to pay for the expense of reclaiming the tailings to an environmentally benign condition.

It is estimated that there are more than 6000 abandoned tailings sites in Canada. At present we do not know what quantity of material is stored in these abandoned tailings sites or the degree to which they may be environmentally hazardous.

3. PRACTICAL ASPECTS OF REPROCESSING MINE TAILINGS

The purpose of this section is to consider the economic feasibility of reprocessing mine tailings.

3.1 Recent Canadian Examples of Actual or Proposed Tailings Reprocessing Projects

Table 7 presents data on eleven tailings reprocessing projects that were either placed into production or have been proposed for production within Canada in recent years.

Seven of these eleven projects were designed to recover gold, one to recover iron ore (magnetite), one to recover asbestos, one to recover lead and zinc and one to recover magnesium metal from asbestos tailings. Ten of these projects were designed to generate a profit, with environmental cleanup a secondary consideration. Four of the projects have been profitable, four are not yet into production, one is said to have covered operating costs only during its last year of operation, and two were commercial and environmental failures. The capital costs of these projects range from less than $1 million to more than $400 million.

Tailings reprocessing does not generally result in a major reduction in the quantity of tailings to be disposed of. In the case of gold mine tailings, the amount of material extracted (gold) in the reprocessing operation is approximately 0.0001 percent of the total weight of the tailings. The other 99.9999 percent of the tailings deposit remains as a potential environmental problem. However, if the reprocessed tailings are stored in an impoundment that is environmentally superior to the original tailings impoundment, then there will be some benefit to the environment.

The proposed Magnola project (Table 7d) is remarkable for the fact that it will reduce the quantity of waste material by about 15 percent.

The Eastmaque gold tailings reprocessing project (Table 7b) extracts gold by producing a flotation concentrate that is largely pyrite containing most of the gold values. This pyrite concentrate is trucked to the Horne smelter at Noranda. In this case, the removal of some of the potentially acid generating pyrite from the tailings impoundment at Eastmaque does in fact produce an environmental benefit.

A successful base-metal tailings reprocessing operation existed at the Craigmont copper mine at Merritt, B.C. from 1969 to 1983 (Table 7c). Magnetite (iron ore) was recovered from the copper mine tailings and sold to coal washing plants, which used the magnetite in heavy media sink/float separation techniques. One million tonnes of magnetite were recovered from approximately 35 million tonnes of tailings.

The proposal by Curragh Resources Inc. (Table 7d) to reprocess the tailings stored in the Rose Creek Valley at the Faro lead zinc mine has been submitted as part of the abandonment plan required as a condition of the water licence issued by the Minister of Indian and Northern Affairs. Approximately 40 million tonnes of tailings are estimated to contain lead, zinc and silver with a gross value of about $1.5 billion. These tailings are potentially acid generating and the cost of preventing AMD problems in the Rose Creek Valley has been estimated at about $29 million. The reprocessing of these tailings is part of a plan to move the tailings from the Rose Creek Valley, where they are deemed to pose an AMD problem, and to place them into the old Faro open pit where they will be stored underwater in an environmentally benign condition. The reprocessing is not expected to be profitable, but it is expected to generate sufficient revenue to cover the operating costs. To the extent that the project may serve to significantly reduce the ultimate cost of Curragh's remediation obligations it could be regarded as an economically viable proposal.

The addition of process chemicals to old tailings deposits may cause environmental degradation if not properly managed. Sumac Ventures Inc. (Table 7b) extracted gold by heap leaching old mine tailings. The operation was closed when waste management inspectors detected traces of cyanide leaking into peripheral test wells.

The reprocessing of old tailings deposits that had already been reclaimed and revegetated causes a temporary (i.e. several years) degradation of the environment. If the reprocessing operation is financially unsuccessful, as in the case of ERG Resources Inc. (Table 7a), and the necessary reclamation funds are not in place, there may be many years of dispute and litigation before the tailings deposit is restored to the same conditions that existed before the start of the reprocessing operation.

3.1.1 Recent Foreign Examples of Actual or Proposed Tailings Reprocessing Projects

Table 8 provides a partial listing of some 30 foreign tailings reprocessing operations that are currently in production. Eleven of these are in South Africa and nine are in Australia, both recovering gold. Lead and silver are recovered in Spain, copper, gold and silver are recovered in the United States and copper is recovered in Zambia.

The largest and most profitable tailings reprocessing operation in the world is probably that of East Rand Gold (ERGO) in South Africa. ERGO began treating old tailings from gold mines close to Johannesburg in 1976 and extracts gold, silver, uranium and pyrite. The pyrite is made into sulphuric acid that is sold. This reduces the potential for the generation of acid drainage from the tailings. The current impoundment area for the residual tailings is claimed to reduce the dust problem and to ensure that cyanide from the reprocessing solutions does not enter the streams and rivers.

TABLE 7A. TAILINGS REPROCESSING PROJECTS IN CANADA

Company	ERG Resources Inc.	Giant Yellowknife Mines Limited	Lac Minerals Ltd.
Project	Old tailings ponds in Timmins area	Tailings retreatment	Lake Shore tailings
Location	Timmins, Ont.	Yellowknife, N.W.T.	Kirkland Lake, Ont.
Commodity	Gold	Gold	Gold
Capacity		10 000 tonnes per day	750 tonnes per day
Reserves	170 million tonnes @ 0.432 g Au/tonne	7 million tonnes @ 2.3 g Au/tonne	3.3 million tonnes @ 2.6 g Au/tonne
Started	October 1988	May 1988	January 1989
Ended	Fall 1989	October 1990	
Current Status	Care and maintenance since April 1990	Ceased	Current operation
Capital Cost	$78 million	$25.5 million	$11 million
Operating Cost	Projected @ US$5.63 per g gold	Predicted $5.78/tonne, reported $8.03 per g in 1988	Budgeted @ $4.50 per g
Mining Method	Water monitors	Summer operation only	Dredge
Milling Process	Flotation, regrind, cyanidation, carbon-in-pulp	Carbon-in-pulp	Macassa mill
Production	Est. 529 kg Au in 1988	687 kg Au in 1989	
Profitable?	No	Broke even during last year	Presumed profitable
Remarks	Financial and environmental disaster due to short falls in feed grade, throughput and metallurgical recovery		

TABLE 7B. TAILINGS REPROCESSING PROJECTS IN CANADA

Company	Eastmaque Gold Mines Ltd.	Candorado Mines Ltd. and Cantrell Resources Ltd.	Sikaman Gold Resources Ltd.
Project		Nickel plate tailings	High River Gold Mines project
Location	Kirkland Lake, Ont.	Hedley, B.C.	Snow Lake, Man.
Commodity	Gold	Gold	Gold
Capacity	2270 tonnes/day upgraded to 2500 tonnes/day		
Reserves	7 million tonnes @ 1.3 g Au/tonne	1.5 million tonnes @ 1.4 g Au/tonne	274 000 tonnes @ 12.9 g Au/tonne
Started	December 1987	November 1988	Proposed for 1991
Ended	? 1999		
Current Status	Current operation	Current operation	Seeking financing
Capital Cost	$10.5 million	$3.2 million	$17 million
Operating Cost	US$7.07/g Au		$42.86 per tonne
Mining Method	Dredging year round		
Milling Process	Flotation	Heap leach	Arseno process and cyanidation
Production	56 kg Au per month	25 kg of gold in 1989	
Profitable?	$865 000 operating profit for first four months	Presumably	Hopefully
Remarks	Removal of pyrite from the tailings is an environmental benefit		Will improve environment by curtailing arsenic leachate from the present tailings

TABLE 7C. TAILINGS REPROCESSING PROJECTS IN CANADA

Company	Sumac Ventures Inc.	Craigmont Mines Limited	Baie Verte Reprocessing Inc.
Project	Old Union project		Wet milling project
Location	Grand Forks, B.C.	Merritt, B.C.	Baie Verte, Nfld.
Commodity	Gold	Magnetite (iron ore)	Chrysotile asbestos
Capacity	91 000 tonnes @ 1.7 g Au/tonne	136 tonnes per day of tailings	
Reserves			
Started	1988	November 1969	August 1990
Ended	June 1989	November 1982	? 2010
Current Status	Closed	Possible recommencement in 1992	Operations suspended due to a dispute between the owners
Capital Cost			$22 million
Operating Cost			
Mining Method			
Milling Process		Magnetic separation	
Production		One million tonnes of magnetite concentrate (1969-82)	
Profitable?		Presumed profitable	Not known
Remarks	Closed after waste management inspector detected cyanide in test wells		

TABLE 7D. TAILINGS REPROCESSING PROJECTS IN CANADA

Company	Noranda Minerals and Lavalin Inc.	Curragh Resources Inc.
Project	Magnola project	Rose Creek tailings deposit
Location	Thetford Mines, Que.	Faro, Yukon
Commodity	Magnesium	Zinc, lead, silver
Capacity	50 000 tonnes/year of magnesium	
Reserves		? 40 million tonnes @ 3% Pb-Zn
Started	Mid-1990s	? 2006
Ended		?
Current Status	Process testing	Proposed in abandonment plan
Capital Cost	$400 million	$5.4 million
Operating Cost		$6.50/tonne
Mining Method		Hydraulic monitor and slurry pump
Milling Process		Grind and flotation
Production		
Profitable?		Expected to break even
Remarks		Potentially acid generating tailings will be placed into Faro Pit and stored underwater to prevent acid drainage

TABLE 8. A PARTIAL LISTING OF FOREIGN TAILINGS REPROCESSING OPERATIONS

Country	Project Name	Location	Commodity Extracted
Australia	Buniyong	Victoria	Gold
	Charters Towers	Queensland	Gold
	Cobar Tailings	New South Wales	Gold
	Gwalia Tailings	Western Australia	Gold
	Kalgoorlie Tailings	Western Australia	Gold
	Mount Morgan	Queensland	Gold
	Sunburst	Queensland	Gold
	Trafalgar and Lancefield	Western Australia	Gold, silver
	Warrego	Northern Territories	Copper, gold, bismuth
Chile	Punitaq		Copper
South Africa	Daggafontein	Transvaal	Gold, silver
	ERGO	Transvaal	Gold, silver, uranium
	Freegold	Orange Free State	Gold, uranium
	Gazankulu	Transvaal	Gold
	Knights	Transvaal	Gold
	Nigel	Transvaal	Gold
	Nugo; Rand Mines Milling and Mining	Transvaal	Gold
	Sallies	Transvaal	Gold
	Simmergo	Transvaal	Gold, silver
	Village Main Reef	Transvaal	Gold
	Waverly	Transvaal	Gold
Spain	Santa Elvira	Jaen	Lead, silver
United States	Gooseberry	Nevada	Silver, gold
	Cripple Creek	Colorado	Gold
	Eldorado Canyon	Nevada	Gold, silver
	Silver City	Utah	Gold
	Magma Copper	Arizona	Copper
Venezuela	Mocupia Gorge	Bolivar	Gold
Zimbabwe	Cam and Motor	Eiffel Flats	Gold
Zambia	ZCCM	Nchanga Tailings	Copper

At Miami, Arizona in the United States, the Magma Copper Co. began to reprocess tailings from the old Miami Copper Mine in April 1989. These tailings consist of 34.5 million tonnes with an average grade of 0.33 percent copper that were dumped during the period 1911 to 1932. Magma reprocesses 10 900 tonnes of tailings per day. Capital cost of the project was estimated at US$19.6 million and operating costs are about US$2.50 per tonne. The project produces a major environmental benefit in that it removes the tailings from a watercourse close to the town of Miami and places the residual tailings in an abandoned open pit, underwater and isolated from the regional water-table, to eliminate the environmental risk of AMD.

3.2 The Potential for Reprocessing of Mine Tailings

3.2.1 Base Metal Mines

Tailings from base metal mines generally contain very little potential for commercial reprocessing operations. As discussed earlier, sulphide minerals, such as pyrite and pyrrhotite, commonly contained in base-metal tailings are an environmental liability because they constitute a potential source of acid drainage.

There have been examples of successful Canadian reprocessing of base-metal tailings however. There is the notable project of Craigmont discussed in 3.1 above. There is also the example of Cominco's Sullivan lead-zinc mine at Kimberley, B.C., where pyrite and pyrrhotite are recovered from the tailings stream within the mill and converted into sulphuric acid, which is used with phosphate rock to make fertilizer. The principal waste product from this process is gypsum, which is much more benign and easy to store than pyrite and pyrrhotite.

In New Brunswick there are large base-metal tailings deposits containing very high amounts of sulphide minerals that are potential sources of sulphur, sulphuric acid and by-product metals. The Canada-New Brunswick Mineral Development Agreement contains provisions for a research project to tackle this problem.

CANMET has developed a ferric chloride leach process that could improve the metal recovery from New Brunswick complex sulphide deposits by 28 percent to 37 percent of the ore value. Moreover, this process is potentially applicable to the reprocessing of tailings. CANMET is currently seeking industry partners to build and operate a demonstration plant to prove the process on a commercial scale.

The MEND program is considering potential new uses for pyrrhotite and pyrite concentrates. At Sudbury, Ont., Falconbridge and Inco are storing high sulphide tailings separate from low sulphide tailings so that if a new process is developed for the reprocessing of high sulphide tailings, the high sulphide tailings will be readily available.

Finally, tailings at the Newfoundland Zinc Mine operation at Daniel's Harbour, Nfld., which consist largely of the mineral dolomite, have been used experimentally as a soil conditioner.

3.2.2 Coal Mines

Coal is known to occur in all Canadian provinces and territories except Quebec and Prince Edward Island. It is mined extensively in the provinces of Nova Scotia and New Brunswick in the east and Saskatchewan, Alberta and British Columbia in the west.

In Nova Scotia and New Brunswick the bituminous metallurgical and thermal coals contain 2 percent to over 8 percent sulphur. Consequently the coals and even some of the overburden have the potential to generate AMD.

Production and accumulation of waste material in New Brunswick is confined to the Minto-Chipman region of Queens County. It has produced over 38 million tonnes of coal and its current production is approximately 500 000 - 550 000 tonnes per year.

In Nova Scotia coal mine waste material has been accumulating over a period of more than 100 years. An estimated 54 million tonnes of coal mine waste material is to be found in old dumps, most of which are located close to existing communities. No washing was practised in the early years of operation. High ash coal particles were sorted by hand and the high ash fine coal fraction was sometimes removed by screening and then discarded. Later on, partial washing of the coarse fractions resulted in high losses of useable fine coal.

The presence of coal in these dumps creates both environmental and safety hazards. Environmental hazards are dependent on the nature of tailings material and by-products that eventually leak to water streams or end up in the atmosphere. In addition to AMD hazards, there is the risk of spontaneous combustion. The emission of smoke containing sulphur dioxide from spontaneous combustion of coal has been a constant source of complaint in some of the communities in Nova Scotia.

Currently, about 94 percent of the coal in Canada is produced in the west, mostly by open-pit and strip mining methods. Large quantities of waste material have been accumulating near processing plants in Alberta and British Columbia over the last 20 years. In western Canada, the losses of fine coal to tailings are magnified by the high proportion of fines in run-of-mine coals and occasionally by the presence of partly oxidized coal. The fine cleaning circuits are usually the least efficient operations in coal preparation plants. In addition, during the early operations of new plants, and before the implementation of changes to improve fine coal recovery, considerable amounts of fine saleable coal were lost to tailings ponds. Over the years, large tonnages have accumulated causing shortages of space near preparation plants, particularly in the mountain region. This has created a potential environmental hazard. As in the case of the eastern Canadian fields, the presence of coal in these dumps also creates the risk of spontaneous combustion. On the other hand, the western Canadian coals are low in sulphur and therefore acid drainage from waste dumps is generally not a major problem.

The problem of tailings with substantial coal content is not unique to Canada. For example, in the United States it is estimated that 100 million tonnes of tailings are added every year to the many hundreds of millions of tonnes of coal wastes currently on the ground.

Reprocessing of coal tailings where possible (fines fraction is generally more suitable) to recover saleable coal can serve both economic and environmental objectives. The recovery of coal from tailings requires minimal mining cost and therefore the margin of profit per tonne may be substantial. The removal of coal particles would minimize the above mentioned risks of spontaneous combustion and the release of pollutants into water streams. Also, it would reduce the necessity to find more space for tailings ponds near the preparation plants.

Private entrepreneurs have been recovering thermal coal from abandoned waste coal dumps in Nova Scotia over the last several years at a rate of 50 000 - 150 000 tonnes per year. The Cape Breton Development Corporation in Sydney selectively mines waste dumps for preparation plant feed.

Fording Coal in British Columbia is believed to mine some old fine tailings that it either ships directly as thermal coal or mixes with other coal products. The company has also reportedly investigated the feasibility of using it as feed for an on-site thermal power generating plant.

Westar Mining has investigated the reprocessing potential of their tailings to recover thermal coal in a pilot plant study with CANMET. Westar is currently looking into the feasibility of setting up a commercial processing plant. The Smoky River Mine near Grande Cache, Alta. dries and ships its tailings to a nearby power station of Alberta Power under a long-term contract for the cost of drying, handling and shipping the tailings. The company is required to manage the disposal of fly ash from the power station. The quantity of fly ash is much less than the quantity of tailings.

In the United States, The Public Utility Regulatory Policies Act established incentives for private sector initiatives in electrical energy power generation. A qualifying facility can contract with a public utility to sell electricity at the utility's "avoided cost." The Federal Energy Regulatory Commission recognizes coal wastes to be a qualified waste fuel for small power production facilities. It is believed that through application of fluidized bed combustion technology, abandoned coal waste piles can be successfully reclaimed as materials are excavated and used as fuel in new power generating plants. The impact of these type of projects on abandoned mine land reclamation is expected to be significant.

3.2.3 Precious Metal Mines

In 1989, 55 primary gold mines in Canada processed over 26 million tonnes of ore and produced about 136 tonnes of gold. Because the gold content is only a small fraction (average 5-6 ppm) of the ore processed, most of the ore ends up as tailings. This amount is added each year to the many millions of tonnes already accumulated over the years in many parts of the country. Gold tailings are usually finely ground (80 percent minus 150 µm) material containing a high percentage of quartz, other silicates, carbonates and some metallic sulphides (pyrite, pyrrhotite).

The gold tailings can be reprocessed either to recover some of the gold left by the previous operator or for other applications. The other applications could be in land fill and in brick and block manufacturing. However, these applications are rather limited by their locations remote from potential markets for these products.

In recent years, there has been a significant increase in the number of projects in Canada to reprocess tailings of gold mines. Depending on the grade of the original ore and the year that it was processed, the quantity of gold left in the tailings could be sufficient for economic reprocessing by the private sector without any government assistance. This potential is evidenced by the fact that during the last several years the majority of all the reprocessing projects in Canada, which were either in operation or were contemplated, were those of gold tailings. This is due substantially to relatively higher gold prices as well as improvements in processing technology.

The reprocessing of gold tailings to recover the gold left by the previous operation has only a very marginal effect on the environment since most of the successful projects recover only a very small fraction of the total waste volume. These projects still have the problem of disposal of the remaining waste material. However, as the current regulations governing the disposition of mine wastes are generally more stringent than those that applied at the time that these reprocessed wastes were originally accumulated, there is an environmental benefit realized when these wastes are reprocessed, stored and reclaimed to modern standards of environmental protection. Additionally, if another mineral like pyrite is extracted during the reprocessing of the tailings, as in the case of the Eastmaque operation, it will improve the environment considerably by reducing the acid mine drainage potential of the tailings. The use of new technology to reprocess tailings can result in environmental benefits such as in the case of Snow Lake Gold Project where the process will convert the arsenopyrite mineral into environmentally stable ferric arsenate.

3.2.4 Uranium Mines

Table 9 provides a listing of all the mine tailings deposits of active and inactive uranium mines in Canada. There are two uranium tailings deposits in the Northwest Territories, six in Saskatchewan and fourteen in Ontario.

Uranium mine tailings may possess any or all of the problems posed by other kinds of tailings, plus the additional hazard of radioactivity. The radioactivity in uranium mine tailings is caused partly by residual uranium, which the uranium extraction plant failed to recover, but principally by the thorium^{230}-radium^{226}-radon^{222} decay series that is present in all uranium ores but is not usually recovered in the uranium extraction process. Radium^{226} is soluble in water and radon^{222} is a gas. All of these radioactive products present health hazards by varying degrees.

Uranium tailings contain small amounts of gold, nickel, titanium, thorium and rare earths. At the Cluff Lake mine in Saskatchewan, tailings from the D Zone were reprocessed to extract economic concentrations of gold. The feasibility of extracting nickel from the Key Lake tailings and of extracting titanium, thorium and rare earths from the Elliott Lake tailings has been studied but found to be uneconomic.

3.2.5 Oil Sands

Slightly less than half of the world's heavy oil deposits (estimated at 10^{12} m^3) are located in Alberta. The majority of heavy oil deposits are relatively deep and not suitable for surface mining. However, in the Athabaska area of Alberta, there are several major oil sand orebodies that are amenable to open-pit exploitation. Syncrude Canada Ltd. (Syncrude) and Suncor Inc. (Suncor) operate the only two commercial oil sands plants in the world near Fort McMurray, Alberta. The Suncor plant, which was brought on stream in 1967, has a current processing capacity of 40 million tonnes per year of oil sands. The Syncrude plant, completed in 1978 at a cost of $2.1 billion, has a current processing capacity of 100 million tonnes per year of oil sands. Suncor produces about 60 000 barrels per day of synthetic crude, and Syncrude produces about 130 000 barrels per day.

Both Syncrude and Suncor use the Clark caustic-hot-water process to extract bitumen from the oil sands. In the production of synthetic crude oil from oil sands by this process, large quantities of water (about 15 m^3 per 1 m^3 of synthetic crude oil) are used. Because only about three quarters of process-affected waters is available for recirculation, large quantities of wastes in the form of sludge are produced. These fluid wastes are stored in a tailings pond, enclosed by dikes and beaches composed of compacted tailings sand.

Currently, the two Alberta oil sands plants are storing some 200 million m^3 of fines in various tailings ponds, the volume of which is increasing at a rate of about 30 million m^3 per year.

The above mentioned sludge discharge contains a mixture of bitumen (2-5 percent), minerals (25-40 percent) and water (55-70 percent). The higher range of bitumen in the sludge is generally the

TABLE 9. URANIUM TAILINGS IN CANADA

Site/ Location	Operator/ Years	Mine Status	Volume (million tonnes)
Port Radium/N.W.T.	Eldorado/1933-60	Inactive	0.9
Rayrock/N.W.T.	Rayrock/1957-59	Inactive	0.1
Lorado/Saskatchewan	Lorado/1957-60	Inactive	0.6
Gunnar/Saskatchewan	Gunnar/1955-64	Inactive	4
Beaverlodge/Saskatchewan	Eldorado/1953-82	Inactive	6
Dyno/Ontario	Canadian Dyno/1958-60	Inactive	0.4
Bicroft/Ontario	Bicroft/1958-63	Inactive	2
Faraday/Ontario	Faraday/1957-64	Inactive	2
Madawaska/Ontario	Madawaska/1976-82	Inactive	2
Nordic/Ontario	Rio Algom/1957-68	Inactive	13
Lacnor/Ontario	Northspan/1957-60	Inactive	3
Stanrock-CanMet/Ontario	Stanrock-CanMet/1957-64	Inactive	7.5
Spanish American/Ontario	Northspan/1957-60	Inactive	0.5
Pronto/Ontario	Pronto/1955-60	Inactive	5
Agnew Lake/Ontario	Agnew Lake/1977-83	Inactive	2.5
Panel/Ontario	Rio Algom/1958-61 and 1978-90	Inactive	14
Quirke/Ontario	Rio Algom/1956-61 and 1968-90	Inactive	42
Denison/Ontario	Denison/1957-59 and 1960-	Active	54
Stanleigh/Ontario	Rio Algom/1958-64 and 1983-	Active	15
Cluff Lake/Saskatchewan	Amok/1980-	Active	0.9
Rabbit Lake/Ontario	Cameco/1975-	Active	Pond 6 Pit 0.3
Key Lake/Saskatchewan	Cameco/1983-	Active	2

case at Suncor. The terminal sludge is a gel-like material containing at least 30 percent solids. The solids content precludes the survival of fish and other aquatic life and yet is too easily fluidized to support traffic. The tailings water, which comprises 70 percent of sludge, is acutely toxic to fish.

The 2-5 percent bitumen in sludge with 70 percent water becomes 7-16 percent bitumen in dewatered sludge. Therefore, any plan calling for the transfer of sludge from the tailings ponds to a permanent disposal site would technically present opportunities to extract residual bitumen in the sludge.

Vanadium and carbon were recovered from fly ash at Suncor by Carbovan Inc. However, a combination of low vanadium prices coupled with operating, engineering and mechanical problems caused the operation to be suspended in May 1991.

The primary tailings from the tar sand extraction plants consist largely of silica sand and they have been considered as a source of glass sand. Beneficiation using specialized magnetic, attrition and gravity separation techniques resulted in glass sand suitable only for the manufacture of bottles, plate glass, window glass and coloured ware. It was not suitable for fine tableware or optical glass. While the tailings sand appears suitable for glassmaking, the cost of preparing the sand and the failure to achieve a high quality glass sand limits its commercial attractiveness.

Suncor is currently planning an extensive sampling of its tailings to evaluate their mineral content in order to determine their economic potential.

3.2.6 Iron Ore Mines

Canadian examples of iron ore tailings reprocessing are not available. On the other hand, CANMET research studies have shown that some iron ore tailings (Marmoraton, Hilton) could be made into dry-pressed fired bricks for construction use. However, these same CANMET studies also showed that the expected profit margins were too small to attract investment into the projects.

Tailings from the iron ore mines near Schefferville, Quebec contain principally quartz and clay, which have been recognized as potential raw materials for the manufacture of paint and ceramics.

One recently closed iron ore mine (Adams mine at Kirkland Lake, Ontario) has been considered as a dump site for garbage from the Toronto region.

3.2.7 Asbestos Mines

Asbestos has been produced in the Yukon, British Columbia, Quebec and Newfoundland. Large quantities of tailings have been accumulated over the years, particularly in Quebec. These tailings are composed mainly of magnesium oxide and silica. The tailings piles could be reprocessed to recover either the remaining chrysotile fibre left by the original ore treatment or magnesium metal.

The recovery of short chrysotile fibre left in the tailings piles is now possible because of a technological improvement in the ore processing technique. In particular, a new wet process was developed and effectively implemented in Newfoundland and in British Columbia. The federal government was involved during the development phase of the project and during the construction of the Newfoundland wet mill. Initially, the wet mill was using rejects from the dry mill as primary feed, with a view to begin processing old tailings when the open-pit mine closed in February 1991. Operations are currently suspended due to a legal dispute between the owners.

The other possibility for reprocessing asbestos tailings is to recover the magnesium metal. There are different technologies available to achieve this goal. The Magnola Project in Quebec is reaching the pilot plant testing stage and a commitment to go ahead with the construction of a commercial plant is anticipated. Both levels of government are partners with the private sector in this project, which will require a substantial investment.

The recovery of shorter fibre from the tailings of the dry process will not result in an improved environment unless the reject from the wet process is discharged into the abandoned open pit. On the other hand, the extraction of the magnesium from asbestos tailings could reduce the quantity of material by some 10 to 15 percent.

3.2.8 Potash Mines

The ten potash mines in Saskatchewan and the two in New Brunswick produce over 20 million tonnes per year of solid salt wastes. This amount is added each year to the more than 300 million tonnes of solid salt wastes that are stored on surface, mainly in Saskatchewan. These waste piles occupy about 1700 hectares of land. The total area of land occupied by potash mining in Saskatchewan is about 3500 hectares and the underground mined area is about 39 000 hectares. Waste brine and brine produced by precipitation runoff from the salt piles are stored in large ponds for evaporation or deep well injection. In Saskatchewan, from 25 to 55 percent of the brine is injected into saline aquifers several hundred metres below the orebody. The Potacan mine in New Brunswick discharges brine into the ocean. Potash Corporation of America, at the Penobsquis mine near Sussex, New Brunswick, disposes of most of its tailings underground by using them as stope fill.

The main environmental threat with salt tailings is that the brine may escape containment facilities and contaminate the surface soils and the groundwater table. Brine may also find its way into fresh groundwater when surplus brine is injected into aquifers. However, this appears to be a remote possibility in Saskatchewan because the aquifers in question are deep and below the potash beds. Sub-surface migration of brine is known to have occurred at all of Saskatchewan's potash mines and in some cases brine has migrated up to two kilometres in the surficial aquifer.

While a mine is active, various mitigative methods can contain the brine and prevent unacceptable contamination of surface and ground water. However, no satisfactory method has yet been found to permit abandonment of potash tailings piles. It has been predicted that, by the time all economically recoverable potash has been mined in Saskatchewan and if methods of managing wastes do not change, over 200 waste piles, containing 20 billion tonnes of salt waste and covering some 1600 square kilometres, will ultimately be generated. However, methods of managing waste are changing. The Saskatchewan Department of the Environment and Public Safety has stated that no additional land beyond that presently allocated will be approved for tailings containment.

Wastes produced by the refining of potash in Saskatchewan range from 60 to 70 percent of the ore. As discussed above, sodium chloride or salt is the major component and accounts for about 90 percent of the waste. Potassium chloride accounts for another 5 percent. The insolubles (slimes) comprised of minerals such as dolomite, anhydrite, gypsum and clays typically make up to 5-10 percent of the waste. Numerous other minerals are present in trace quantities.

At first glance, reprocessing potash tailings to produce and market salt appears to be an ideal solution since the production costs are estimated to be relatively low. However, most road salt in the prairie region is already supplied by the potash industry and high transportation costs to other markets make it uneconomical.

International Minerals and Chemicals Corporation (Canada) Limited supplies by-product rock salt from its potash operation at Esterhazy (capacity 120 000 tonnes per year). Sifto Canada Inc. produces 20 000 - 30 000 tonnes per year of fine salt by processing salt tailings from a nearby potash operation at Patience Lake. The Canadian Salt Company Limited at Belle-Plaine produces 100 000 - 110 000 tonnes per year of table salt from by-product brine from the potash solution mine operated by Kalium Canada Ltd. The Rocanville Division of Potash Corporation of Saskatchewan produces commercial salt by screening. In New Brunswick, Potash Company of America extracts salt directly and also as a by-product at its potash mine near Sussex at a rate of 400 000 - 500 000 tonnes per year. This salt is sold mainly to companies in the eastern United States.

While the Saskatchewan potash industry will likely continue to supply the prairies with a large portion of its salt products, the chances of breaking into other salt markets in North America or offshore do not appear to be promising because of the high transportation costs.

Marketing of other minerals, especially metals, contained in potash tailings is a possibility that has not, as yet, been seriously explored. Their removal would not result in a significant reduction in waste because they represent such a small portion of the total waste produced. However, the generation of brine from the separation process would reduce costs of disposal of tailings by well injection since the cost of dissolution would be associated with the mineral extraction.

The use of salt tailings for backstowing underground to support the workings and enhance potash recovery is an attractive option. In fact, it is being practised at the New Brunswick potash mines. Also, the beneficiation of ore underground using electrostatic separation will reduce haulage costs and could facilitate storage underground.

In Saskatchewan, old mined out areas have collapsed leaving no space for tailings presently stored on surface. Existing salt piles could be dissolved and deep well injected over the remaining life of the mine. The cost of injection could be reduced somewhat by using gravity and nonpotable water.

3.2.9 Other Industrial Minerals

Barite has been recovered by reprocessing of tailings at the Mineral King mine and the Silver Giant mine in southeastern British Columbia, and from the Buchans mine in Newfoundland.

The tailings deposits of some gypsum mines in Nova Scotia contain anhydrite that potentially could be recovered for use in cement manufacture or as a fertilizer for peanut crops.

Mica occurs in the tailings deposits of many metal mines in Canada. The Hemlo gold mine tailings and the Highland Valley Copper mine tailings have both been studied with a view to the production of mica. To date, the low unit value of mica has thwarted these plans to produce mica from mine tailings.

Feldspar recovery from the tailings of TANCO's spodumene mine at Bernic Lake, Manitoba has been proposed but was put on hold in 1989 due to unfavourable market conditions.

3.3 Research and Development Initiatives

Tailings are reprocessed either to recover the contained mineral or metal values such as gold, silver and copper or for other applications such as landfill, brick and block manufacturing, and backstowing underground to support roof. Alternatively, they may be reprocessed to make them environmentally benign.

The challenge of reprocessing abandoned tailings for the recovery of contained minerals or metals is analogous to extraction and recovery of values from low-grade ores. Mine and mill rejects are wastes because they could not economically be processed to recover residual metals with the technology available at the time. Therefore either a significant change for the better in the economics of metal values or advances in extractive and/or process technology, or both, is a prerequisite for successful reprocessing.

Research and development are the keys to advances in process technology and for finding new and improved uses for mine and mineral processing wastes. Moreover, modified or new technologies can be introduced into process streams to reduce the volume and toxicity of the wastes generated in the future. There are examples of successes both in the private and public sectors.

Sikaman Gold Resources Ltd.'s Snow Lake Gold Project (Section 3.1) is a good example. The project proposes to use a newly developed and patented Arseno Process to process arsenical gold tailings (12.9 g Au/tonne) that were set aside during a mining operation between 1949 and 1958. The process not only recovers 90 percent of the gold content of the tailings but it also converts the arsenopyrite mineral into an environmentally stable ferric arsenate compound. The process was developed by a private company with government assistance.

Another example of private research is Syncrude's Tails Oil Recovery System which increased bitumen recovery from 91 percent to 95 percent. However, there is a continued need for research in finding ways of handling the existing tailings ponds sludge and reducing the toxicity of ponds.

As mentioned above, recovery of nickel and vanadium from Athabasca tar sands fly ash was investigated by the Mines Branch of the Department of Energy, Mines and Resources (EMR) in the 1970s. Recently a company named Carbovan has been recovering vanadium and carbon from fly ash at Suncor.

CANMET, the main research and development arm of EMR has been active in mine waste research for many years. CANMET involves industrial clients in its research projects from the outset and works closely with other research and development organizations. The following is a brief description of a few of these recent initiatives.

Cooperative Study for Disposal of Tar Sands Sludge

CANMET was a founding partner in a government-industry project to assess ways of disposing of waste from tar sands. The aim of the research is to investigate efficient and environmentally sound solutions to the problem of tar sands sludge. The five-year project, which has a budget of $5 million, involves CANMET, the Alberta Oil Sands Technology and Research Authority, Syncrude Canada Ltd., Suncor Inc., the National Research Council of Canada, the Alberta Research Council and Alberta Energy.

International Study on Mine Backfill

CANMET, the U.S. Bureau of Mines and the Ontario Ministry of Labour signed a Memorandum of Understanding to assess the use of agglomerated tailings for mine backfill. The joint study will evaluate the properties and behaviour of agglomerated backfill and address specific problems associated with the use of agglomerated materials. CANMET and the Ontario Ministry of Labour are contributing one half of the $50 000 project costs, while the U.S. Bureau of Mines is providing the remaining funds.

High-Volume Fly Ash Concrete

Pioneering research performed by CANMET has led to the development of high-volume fly ash concrete. CANMET's studies confirm that structural quality, high-volume fly ash concrete can be produced with mechanical properties equivalent to those of conventional concrete at considerable cost savings. These concretes have excellent potential for use in foundations, large retaining walls, piles and large columns. Their toughness and ability to control expansive alkali-aggregate reactions promise to make them serviceable in a wide range of conditions. One of the important aspects of the studies has been the collection of performance data on the use of this concrete in the Canadian climate. Annual use of fly ash in concrete in the Halifax area has increased from almost nil in 1983/84 to a current level of approximately 13 000 tonnes with a market value of about $1 million. CANMET's work was recognized as a breakthrough in the industry at the Third International Conference on Fly Ash, Silica Fume, Slag and Natural Pozzolans in Concrete, held in Trondheim, Norway in June 1989.

3.4 Effectiveness of Tailings Reprocessing as an Environmental Cleanup Measure

Some tailings reprocessing projects, for example Magma Copper in Arizona, are spectacularly successful in that they produce a major improvement in the environmental conditions in the immediate vicinity of the mine site and also produce a handsome profit for the operator. Other tailings reprocessing operations, for example ERG at Timmins, Ontario, are disastrous failures that lose money for the operator and leave the environment in worse condition than before the commencement of reprocessing operations.

As described above, tailings reprocessing operations do not usually recover a large proportion of the volume of the original tailings. Even the Craigmont operation, which recovered one million tonnes of magnetite from copper mine tailings, reduced the volume of tailings by less than 3 percent.

However, a modern tailings reprocessing operation can be expected to produce some environmental benefit simply because it will be subject to modern regulations governing abandonment and reclamation. This environmental benefit will arise because the current abandonment and reclamation requirements are more rigorous than those of previous years. However, these environmental benefits will be realized only if the project is technically and financially successful.

Two of the tailings reprocessing operations listed in Table 7 caused additional degradation of the environment. Sumac Resources Ltd. suffered leakage problems with the solutions utilized to leach the gold and silver from the old Union Mine tailings. This leakage caused the local groundwater to become contaminated with cyanide. ERG Resources Inc. began tailings reprocessing at Timmins without first placing with the municipality an agreed reclamation bond.

When a combination of technical and financial problems prematurely ended the operation, the result was a significant deterioration of the environmental quality.

4. THE ROLE OF GOVERNMENT IN TAILINGS REPROCESSING

In Canada, jurisdictional authority for the control and management of mineral resources within the provinces resides primarily with the provincial governments. However, the federal government has environmental responsibilities that overlap those of the provinces in the area of controlling discharges from mines into the environment. Within the Yukon Territory and the Northwest Territories, jurisdictional authority for mining and environmental protection rests with the federal government, although it may devolve to the individual territorial governments at some future date.

Chapter three presented examples of successful tailings retreatment projects and indicated the potential for additional future reprocessing operations. The examples demonstrate that the Canadian mineral industry is willing, able and eager to commission those tailings retreatment projects that offer a reasonable probability of commercial success.

4.1 Tax Measures

For the purposes of the Income Tax Act, a mine tailings deposit is not considered to be a naturally occurring mineral deposit as contemplated by the definition of "mineral resource" set out in section 248 of the Income Tax Act. Instead, it is regarded as an inventory of "ore from a mineral resource" where the "mineral resource" is the original mineral deposit from which the tailings were derived. As a consequence, tailings reprocessing projects are not eligible for the special tax treatment of mining operations including special treatment of exploration expenses, flow-through share financing and Class 41 accelerated capital cost allowances.

However, pursuant to section 1204 of the Income Tax Regulations, income from "the processing in Canada of...ore...from mineral resources in Canada..." is included in the definition of "resource profits." The result is that the resource allowance is available to mine tailings reprocessing projects. This is appropriate since these projects would normally pay provincial mining taxes that are not deductible. Until it was phased out on January 1, 1990, depletion was also earned by tailings reprocessing projects on machinery and equipment described in subsection 10(k) of Schedule II of the Income Tax Regulations.

4.2 Other Fiscal Measures

In some countries of the world, reprocessing of mine tailings may be supported in part by government grants or subsidies. For example, in the United Kingdom, Derelict Land Grants are available to assist the owners of land which has become derelict as a result of prior industrial use. Several coal mine waste dumps and tailings dumps have been reprocessed with the aid of Derelict Land Grants in projects which have transformed abandoned mine sites into industrial, commercial, residential or agricultural developments.

4.3 Regulations

Legislation exists to enforce compliance with the regulations governing the discharge of effluents from tailings dumps at operating mines. In some provinces regulations are stringent and provide for heavy penalties in the case of violations of the air and water quality standards. In some jurisdictions, a proposed new mining operation and all current mining operations must submit an acceptable plan for decommissioning, reclamation, rehabilitation and abandonment of the mineral property before receiving the licences and permits that authorize the commencement of mining operations. Coordinated action would be desirable to harmonize federal and provincial requirements.

To ensure compliance and implementation of the mine abandonment plan, the mining company may be required to post a performance bond that would be forfeited in the event that the mining company fails to complete the work described in its abandonment plan.

The earlier mentioned proposal by Curragh Resources Inc. to reprocess 40 million tonnes of tailings at the Faro lead-zinc mine (Table 7d) was, in large measure, the result of the legal requirement for an environmentally acceptable abandonment plan as a condition of the water license. Although the tailings retreatment is not expected to be profitable, it is expected to be considerably less expensive than the alternative of rehabilitating the tailings in their present location.

Refinement of the regulations governing mine reclamation, abandonment and performance bonds would probably result in better storage and treatment of tailings and other wastes at existing operations and improved designs for waste handling in future operations.

In the case of abandoned tailings deposits, where the responsible company and its officers no longer exist and the title has returned to the Crown, the responsibility or liability for environmental impacts from abandoned tailings may rest with the Crown. An example of how governments have responded to this type of situation is illustrated by their action at the Deloro gold mine site north of Belleville, Ontario where about 10 000 tonnes of calcium arsenate is stored in piles alongside the Moira River. These arsenate waste piles were created by smelting operations that closed down in 1961. Under a federal-provincial agreement to clean up toxic dumps in Ontario, the senior governments will spend between $5 million and $10 million to rehabilitate this site.

4.4 Levy on Current Producers

The United States government, under the Surface Mining Control and Reclamation Act of 1977, imposes levies of 35 cents per ton for surface mined coal, 15 cents per ton for underground mined coal and 10 cents per ton for lignite coal on all currently operating coal mines. The monies raised by these levies, informally referred to as the Superfund, are used to finance the reclamation and rehabilitation of abandoned coal mine sites.

Arguments have been advanced counter to the Superfund concept to the effect that the imposition of a similar production levy on the Canadian mining industry would be unfair, because it would be forcing the present day mine operators to pay for the rectification of problems created by previous generations of mine operators. In addition, imposition of a levy may impair the competitive position of current Canadian producers.

4.5 Research and Development Assistance

Section 3.3 above shows the importance of the research and development of new or improved mineral processing technology in the context of tailings reprocessing. Without mineral processing technologies that offer a significant improvement in recovery compared to the technology utilized in the original rejection of the tailings, there is little or no potential for a commercially viable tailings reprocessing operation. This truism is well recognized by governments and the private sector, and both have actively supported mineral processing research in the form of individual and cooperative projects. The examples presented in Section 3.3 suggest that investment in mineral processing research may be the most cost effective of all the initiatives available to governments.

4.6 Technology Transfer

The term "technology transfer" refers to the activity of worldwide monitoring of newly-developed technology followed by the dissemination of information about the new technologies to all interested parties within Canada. By this means, information about new technologies applicable to tailings reprocessing are quickly made available to all potential users of the technology.

Through CANMET, the federal government already operates a program of technology transfer covering mining and mineral processing technology.

5. CONCLUSIONS

Recent tailings reprocessing operations in Canada and abroad have ranged from brilliant successes, producing significant profits and environmental benefits, to dismal failures causing bankruptcies and additional degradation of the environment.

The quantity of residual tailings that remains to be stored after a tailings reprocessing operation is usually very nearly the same as the quantity of the original tailings deposit.

The reprocessing of an abandoned mine tailings deposit will be of benefit to the environment if it extracts a hazardous component or if the residual tailings are stored in an impoundment that is environmentally superior to the original impoundment.

Tailings reprocessing operations sometimes cause toxic chemicals, which were not present in the original tailings, to be added to the residual tailings.

In the case of most of the tailings deposits that currently pose major environmental hazards, it may be more cost effective to undertake remedial work to improve the integrity of the present impoundment and containment structures and to control other environmental impacts rather than to reprocess the tailings.

Successful tailings reprocessing requires mineral processing technology that is significantly more effective and efficient than the technology used when the original tailings were deposited. This means that, in many cases, private sector and government support for mineral processing research and development will provide the most effective encouragement for the reprocessing of abandoned tailings.

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