COST EFFECTIVE CLOSURE PLAN MANAGEMENT FOR METAL MINES

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High closure costs have been incurred by some mines because of the failure to identify and mitigate conditions which require costly remediation on mine closure. Contaminant leaching, commonly acid rock drainage (ARD), is often a major cause of high closure costs. Planning for closure allows the remediation requirements to be anticipated sufficiently early so that the most cost effective measures can be designed and incorporated into the mine plan. Furthermore, the current regulatory trend is to bring closure costs into the operating period of a mine through some type of financial assurance or bonding requirement. The most cost effective closure plan will be the one which provides the lowest net present value of closure costs which achieves the required level of site rehabilitation on closure. This paper describes an approach to developing a cost effective mine development and closure plan. A summary of the current thinking on the main issues and control technologies for mine closure is presented.

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INTRODUCTION

The challenge facing all industries throughout the world is the concept of "sustainable development", which requires balancing the protection of human health and safety and the natural environment with the need for both sustained economic activity and growth. In the mining industry, waste products are generated in larger volumes than other industries, and mine wastes are primarily disposed of on land. In general, mine wastes are classified as not hazardous, although they sometimes may pose significant health and environmental risks. Significant progress has been made in the past twenty years, and particularly in the last ten years in North America, in developing solutions for constructing, operating and reclaiming mine sites in an environmentally acceptable manner.

This paper describes an approach to developing a cost effective mine development and closure plan. A summary of the current thinking on the main issues and control technologies for mine closure is presented. This paper is based in part on the Ontario Ministry Of Northern Development And Mines publication, "Rehabilitation Of Mines - Guidelines For Proponents" (Steffen Robertson and Kirsten (SRK) et al, 1991).

The essence of a good closure plan is that it is cost effective in achieving the required level of environmental protection. High closure costs have been incurred by some mines because of the failure to identify and mitigate conditions which require costly remediation on closure. Contaminant leaching, commonly acid rock drainage (ARD), is often a major cause of high closure costs. Planning for closure allows the remediation requirements to be anticipated sufficiently early so that the most cost effective measures can be designed and incorporated into the mine plan. Furthermore, the current regulatory trend is to bring closure costs into the operating period of a mine through some type of financial assurance or bonding requirement. With strict financial assurance requirements the costs of the anticipated closure measures are funded up front and hence provide further need for accurate and minimized costs. The most cost effective closure plan will be the one which provides the lowest net present value of closure costs which achieve the required level of site rehabilitation on closure.

Mining is a temporary use of the land. At closure, a mine site and the land affected by the mining operations should to be reclaimed with the following objectives; in order of priority:

- protect public health and safety;
- reduce or prevent environmental degradation; and
- allow a productive land use of the mine site; either its original use or an acceptable alternative.

It is in the interest of all mines, both operating and proposed, that they develop closure plans to meet the above objectives, and where practicable carry out reclamation activities during mining operations in order to reduce the closure costs. In some instances it may be beneficial to modify the mine plan or mine development in order to achieve a closure plan that is more economical and meets the above objectives. Failure to do so may result in inappropriate site development; resulting in conditions at closure, which are difficult to reclaim or require costly reclamation measures.

The closure plan for any mine is site specific. In general, the closure plan consists of ensuring that the physical structures that remain after mine closure do not impose a long-term hazard to public health and safety and the environment, which includes ensuring that the land and watercourses are returned to a safe and environmentally sound state and to an acceptable end use.

The work required to reclaim a specific mine site will depend upon the structures, including mine rock and tailings deposits, that remain after the closure of the mine. It is convenient, therefore, to separate mining activities into components and to design and plan the reclamation work required for each component. Mining activities can generally be divided into the eight main components, namely:

- underground mine workings;
- open pit mine workings;
- rock and overburden piles;
- water management and treatment facilities;
- tailings impoundment;
- buildings and equipment;
- land fills and other waste deposits; and
- infrastructure development.

RECLAMATION OBJECTIVES

Broad Objectives for Post Closure Mine Components

In developing the post closure design for a mine component, the assessment of the rehabilitation objectives, should be made in three broad categories (SRK et al, 1991) as follows:

- Physical stability,
- Chemical stability,
- Land use and aesthetics.

Physical Stability

A mine component that remains after mine closure should be physically stable such that it does not impose a hazard to public health and safety as a result of failure or physical deterioration; and that it continues to perform the function for which it was designed for its design life. It should not erode or move from its intended location under the extreme events or perpetual disruptive forces to which it will be subjected after closure.

Chemical Stability

A mine component, including any impounded waste, that remains after mine closure should preferably be chemically stable and not releasing chemicals (contaminants) into the environment. A less desirable case occurs where there is some chemical instability and leaching of contaminants into the environment, after closure. If this occurs, the resulting water quality should not endanger public health or safety, or result in the exceedance of water quality objectives in downstream waters.

Land Use and Aesthetics

The reclamation required at a mine site shall be determined by considering:

- the naturally occurring physical hazards of the area;
- the level of environmental impact;
- the expected post-operational use of the land;
- and the productivity of the land surrounding the site;

After reclamation is complete, the appearance of a mine component should be compatible with that of the surrounding lands, to the extent possible.

The above objectives are considered to be the "most preferable" in any mine closure plan. Some variation may be considered depending on unique or unusual site-specific conditions. It may not be practicable to achieve these objectives for some existing mines which have been developed with different objectives. In such cases, a "best efforts" approach to mine reclamation may be appropriate. The extent of mine reclamation also depends upon legislated requirements, local public requirements or accepted practice. The balance of this paper assumes the "most preferred" condition will be the objective.

Financial Considerations

Figure 1 illustrates the planned closure cost requirements at any point in time throughout the development, operation, closure and post closure periods of a mine or mine component. At the start of operation period of a mine there is a closure liability equal to the amount G. If there is no progressive reclamation throughout the operation period then the cost to reclaim the site will rise to a value I. If progressive reclamation is conducted during the operation period, represented by the line GH, then the closure cost to reclaim the site will be the amount H. During the closure period, as reclamation work is conducted, the closure liability will reduce to the amount J. In the post-closure period there are two potential scenarios: maintenance and monitoring is required for only a short period to demonstrate that the closure objectives have been met, line JE, or there is a requirement for intermittent or ongoing activity, line JK. These are described further below.

Defined Period Financial Assurance

If the closure plan can demonstrate, with confidence, the close-out date within a few years of the mine closure date then financial assurance is required for a defined period.

Financial assurance provided for defined periods of a few years typically fall within the range of experience of institutions which provide financial assurance products. The basis for financial risk evaluation and funding requirements are reasonably well established for such relatively short defined periods, with the uncertainty increasing as the defined period increases. Where the defined period becomes a number of tens of years the uncertainty passes beyond the typical experience of the financial institutions and the determination of and securing of financial assurance becomes considerably more difficult.

Indefinite Period Financial Assurance

Where it is not possible to demonstrate that close-out can be achieved within a few tens of years after mine closure the financial assurance has to be provided for an indefinite period. The risk of future changes in environmental standards and the potential for changes in closure requirements further adds to the long-term financial risk. Financial assurance provided for indefinite periods do not typically fall within the range of experience of institutions which provide financial assurance products. Third party financial assurance (in the form of bonds or letters of credit) may be difficult or financially onerous to obtain.

Clearly, cost effective closure plan management will aim to reduce or eliminate the requirements for indefinite period financial assurance, or will reduce the requirements for ongoing interaction with the site, and hence the long-term costs, to a very low level.

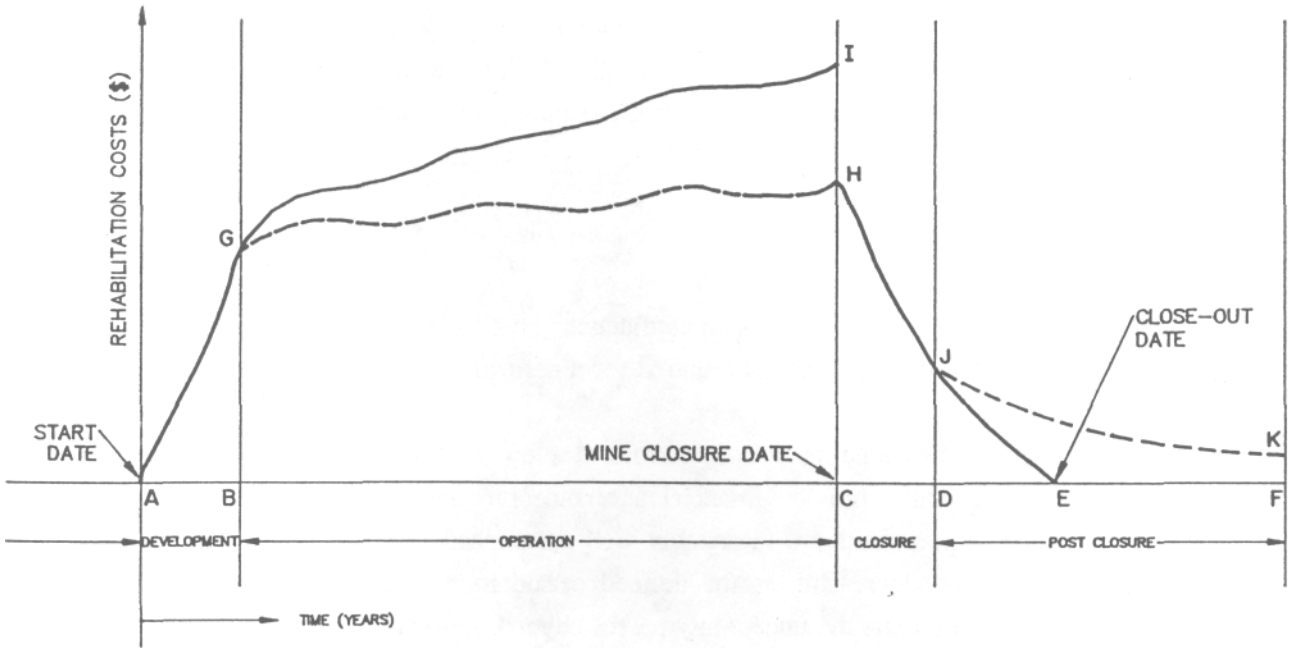

Figure 1 Graph of Mine Reclamation Costs

Design for Closure

The concept of designing for closure merges two separate objectives: the requirement that the closed out mine components meet the reclamation objectives and that reclamation measures be optimized with regard to cost by being incorporated into the initial mine design and, where practicable, implemented during the development or operation of the mine component rather than delayed until closure. It is also necessary to ensure that the reclamation and closure measures are effective over the long-term. This requires that the mine operator look well into the future, possibly in the order of several decades and possibly centuries, and identifies those processes and forces which will come to act upon the mine components which will remain after closure. The operator must then design and implement the closure plan so that the long-term risk of failure of components is minimized or eliminated. Where deterioration is inevitable, the operator should identify and provide for the necessary long-term maintenance. Wherever practicable, there should be no ongoing intervention or operating activities other than periodic inspections and minimal maintenance after closure. Closure of a mine component has occurred at the time when a condition is reached where reclamation objectives are met and all requirements for operations and ongoing reclamation activities have ceased.

The design of post-closure mine components should be based upon utilization of the best available technology economically achievable, BATEA. Economically achievable implies the selection of demonstrated control technology for which the incremental cost of application is justifiable by the resulting increase in environmental protection; and does not imply the limit of, nor should it be limited by, the economic capability of the proponent.

Closure Plan Categories

There are three general closure plan categories for a reclaimed mine site, namely:

Walk-Away Closure Plan

A walk-away closure plan is one where, following the end of all reclamation activities, there is no monitoring or maintenance required. This is an ideal closure plan and can often be achieved for some components of a mine site but not always for an entire site. A walk-away plan may include short-term monitoring to ensure that the reclamation objectives have been met and components will remain stable. After a finite period of monitoring, of a few years, to demonstrate that the closure objectives have been met, a walk-away condition is achieved.

Passive Care Closure Plan

A passive care closure plan is one where, following the end of reclamation activities, there is only a requirement for occasional monitoring and infrequent maintenance. A walk-away closure plan can not be achieved for some mines or mine components, such as tailings embankments with on-going operating spillways, and passive care is required. Passive care is achieved only if the requirement for on-going monitoring and maintenance is infrequent, of low cost, and with a low risk of failure such that the potential long-term burden on future generations is small. In these cases, where monitoring shows that the closure objectives have been met then transfer of monitoring and maintenance responsibility, along with financial support, from the mine operator to government agencies may occur. This creates a walk-away solution from the mine operator's perspective.

Active Care Closure Plan

An active care closure plan is one where, following the end of primary reclamation activities, there is still an on-going requirement for continual or regular operation, maintenance or monitoring. This occurs when, for example, there is a requirement for water treatment of acidic drainage. An active care closure plan is rarely acceptable for a new mine, although it may be the only economic and therefore the best option for some abandoned or operating mines. For active care sites, government agencies may not be prepared to accept responsibility for ongoing activity, even with financial assurance, and the mine operator may have to provide on-going care and bear the associated long-term liability.

Developing the Closure Plan

Preparing an acceptable closure plan, prior to the development of a mine is known as "designing for closure". In reality, however, the closure plan submitted at the time of permit application is an interim plan. The plan is based upon projected conditions, such as the expected life of the mine and environmental protection standards that will be applicable at the time of mine closure. The life or operation of a mine may change and we have experienced the "changing goal posts" of progressive environmental legislation and standards over recent years. Hence, the closure plan should be re-evaluated on a regular basis as the mine progresses.

The closure plan must consider the long-term physical and chemical stability and land use issues associated with the components left behind after operations cease, such as: underground mining and open pit excavations, rock and overburden piles, tailings impoundments, water management and water treatment facilities, buildings and equipment and the infrastructure.

The recommended design process for developing a closure plan is illustrated on Figure 2. All closure plans should commence with Step 1, a description of the pre-development environment. Such a description is essential in order to understand the impact of project development, the effectiveness of reclamation and the success of the closure plan in achieving the reclamation objectives.

During mine planning, or when developing a closure plan for an existing mine, an inventory and description of the facilities and components that have or will be developed and operated for the project should be prepared, Step 2. A brief description of each component should be prepared which indicates its physical and chemical characteristics.

Following definition of the mine development, the operator should describe the proposed reclamation measures that will be implemented to achieve close out, Step 3. This should include a description of the progressive reclamation measures as well as the reclamation measures that will be implemented on closure. In Step 4, an impact assessment is made of the proposed development and reclamation measures. If the predicted long-term physical and chemical effects and anticipated land uses do not meet the objectives for the site, then alternative reclamation measures will have to be considered (Loop a). If the mine operator evaluates a number of alternative reclamation measures and finds that they all result in unacceptable impacts, then it may be necessary to consider an alternative form of mine development (Loop b).

The monitoring and maintenance requirements can be defined once a development and reclamation design has been attained, which results in an acceptable impact, Step 5. In Step 6 the construction schedule can be prepared and the project costs, including closure costs, can be estimated. If the project costs are excessive, then consideration may be given to alternative mine development scenarios (Loop c). Once a project has been optimized to achieve both acceptable environmental impact and project costs, it is necessary to develop and describe the form of financial assurance which will be provided to ensure that the closure plan can be implemented (Step 7). Only after Step 7 is complete can the project proceed to permitting and implementation.

The content of a closure plan is directly related to the environmental impact risks. A small mine, which has the potential to endanger public health and safety or cause substantial environmental damage after closure, may require comprehensive pre-development data collection, design and study of alternative facilities and environmental impact assessment. Similarly, a large mine which will leave physically and chemically stable waste products with little risk to the public or the environment, may require a relatively simple closure plan.

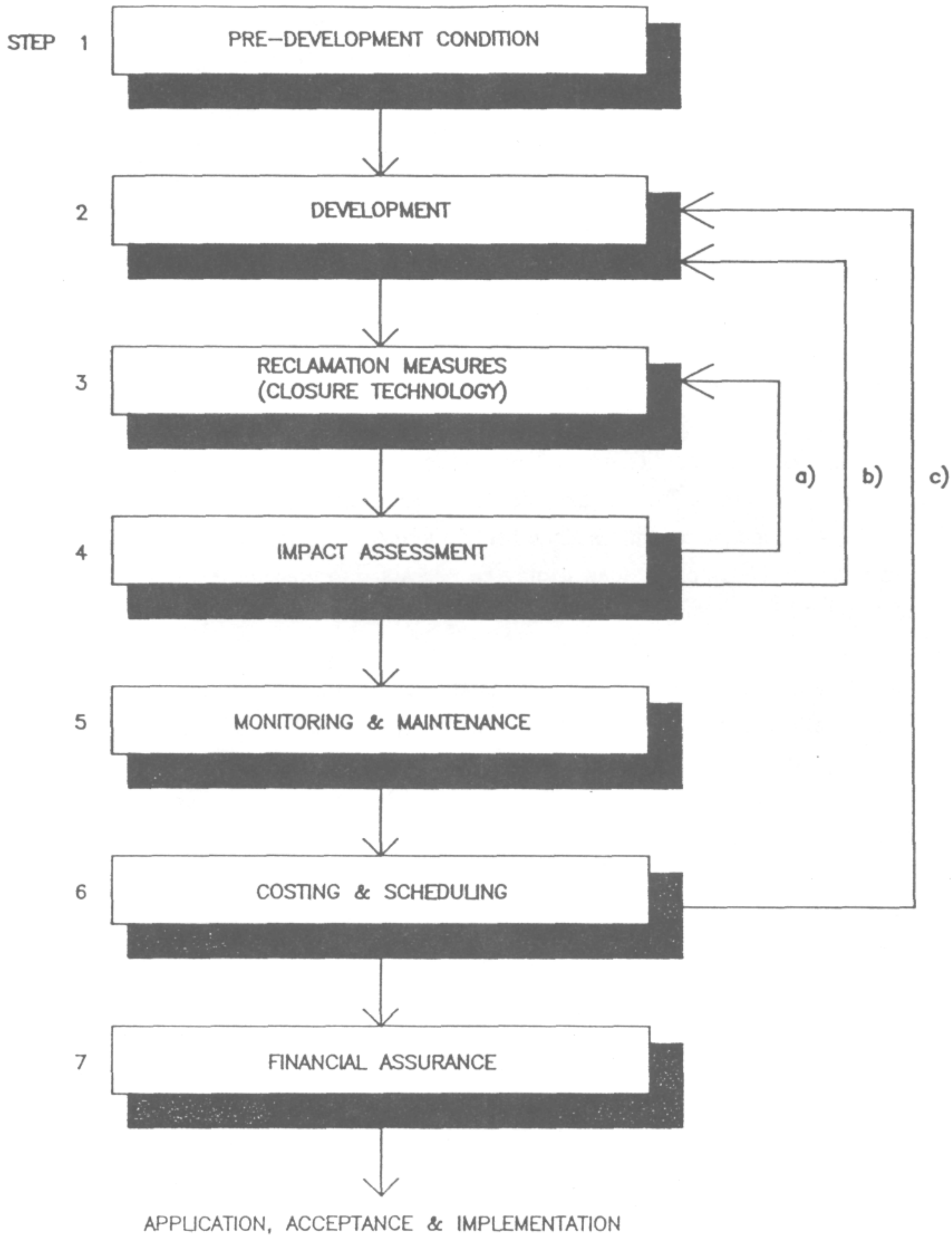

Figure 2 Closure Plan Development

Should site specific circumstances, safety or environmental protection objectives or applicable technology change prior to implementation of the closure plan to any site or sub-site, then the plan should be revised to reflect the changes, including changes in the financial assurance.

An approach and spreadsheet for estimating the cost of mine reclamation is described in SRK 1992a.

ISSUES AND CONTROL TECHNOLOGY FOR MINE CLOSURE

General

Early mine reclamation requirements (1950's to 1970's) related mainly to measures for the protection of public safety and to ensure the physical stability of a mine site and to the re-establishment of vegetation. Thus the construction of stable tailings embankments and spillways, removal of derelict or deteriorating buildings, prevention of public access to unstable slopes and subsidence zones and revegetation programs have long been rehabilitation requirements. More recently, there has been an increased recognition of the potential for chemical instability resulting in the leaching of contaminants from the mine components and their entry into the downstream environment. The need to demonstrate chemical stability, or sufficiently low release rates so as not to affect downstream environments, is now apparent. Finally, a reclaimed site, which is both physically and chemically stable, should preferably achieve a land use with an equivalent productivity to that applicable pre-mine development. It is convenient to group closure technology into the three broad categories of: physical stability, chemical stability and land use.

Physical Stability

In order to evaluate the physical stability of mine components there are a number of factors that must be characterized. These include material properties, geometry and construction method. Material properties control the strength and durability of a mine component Its geometry influences its stability and reclamation options. Construction method may influence related stability parameters such as the position of the phreatic surface in tailings embankments and rock piles, or the potential for subsidence over underground mines.

Design for mine operating conditions usually aims at minimizing production costs. Thus pit slope angles should, in theory, be as steep as possible to minimize excavation costs, consistent with extracting the last bit of ore before mining ceases. If slopes collapse, subsequently, the operator may not be concerned since he is no longer in the pit. Similar arguments apply to underground workings even though, in the long-term, surface subsidence could take place. Backfilling of old abandoned shallow coal mine workings has been required in numerous locations (Britain and Colorado are examples) to prevent damage to surface developments. Clearly, the design for closure needs to anticipate what impact post mining ground movement would have on the adjacent or surrounding physical environment.

Stability analyses can be used to assess the effectiveness of remedial actions implemented for long-term stability. Slope stabilization measures might involve unloading the crest of the slope, overall slope flattening or constructing toe berms. The analyses may well show that such measures are of questionable environmental or land use benefit and not cost beneficial. If they are not cost beneficial, they do not represent BATEA. In many cases, particularly in pit slopes, it is economically preferable to accept the risk of failure and make allowance for the consequences by, for example, preventing access to the pit area. The same methods of stability analyses can be used to estimate safe setback distances from the crest of a slope. The acceptability of such alternative strategies should be established at the permitting stage, as re-sloping or backfilling a pit after the fact represents a large closure cost. Further details on stability of dumps and pit slope can be found in Piteau Assoc. 1991, Klohn Leonoff, 1991, HBT AGRA Ltd, 1992 and Canmet, 1977.

Tailings dams need careful consideration for longevity. Often they are constructed of highly credible materials such as tailings sands. Although immediate static conditions may be satisfactory, long-term dynamic forces may suggest the need for extensive protective measures. Since gradual deterioration of some construction materials takes place with time, conservative values of strength properties should be selected. If sealing is contemplated, design parameters should be selected accordingly. The other major parameters in the static stability of tailings piles are the influence of pore water pressures and the location of the phreatic surface. If base drainage is utilized in the design, consideration should be given to the effect of clogging in drains with time, thus leading to rise in water pressures and reduction in stability. Again, conservative assumptions need to be made in estimating the position of phreatic surfaces. Further information on the stability of tailings and embankments can be found in Vick, 1990 and SRK et al, 1987.

Measures for improving the stability of slopes are described in SRK et al, 1991, and 1992a.

Extreme Events

Because of the long period of interest, the likelihood of extreme events is proportionately large. This likelihood is determined from probabilityifrequency relationships based on the historical record of events. In many remote regions of Canada, this record is relatively short, generally not more than a few tens of years, and the extrapolation for 1000 to 2000 years is of uncertain accuracy. Therefore, conservative assumptions should be used in predicting the magnitude of the extreme events described below.

Large precipitation events represent one of the most likely causes of failure of mine components, particularly tailings impoundments. Failure during such events may result in large losses of tailings to the environment. Methods for the estimation of high precipitation events, and for the calculation of the resulting flood flows are well developed for dam design purposes.

Dynamic loads, due to earthquakes, may result in the liquefaction of low density saturated tailings or uncompacted, saturated portions of granular embankments or embankment foundation materials. Failure of the El Cobre tailings dam in Chile and the Mochi Koshi tailings dam in 1980 in Japan are ample demonstration. New dams should be designed and constructed to appropriate standards.

During cyclic accelerations, occurring during earthquakes, the side slopes of drained rock piles constructed at their angle of repose may slump with displacements occurring during each cycle. At the end of the earthquake, the slope will again be marginally stable in its slumped location. Such slump displacements can be determined using Newmark's method, and may not be sufficient to pose a significant hazard to public health or safety. Near populated areas, consideration may need to be given to the potential for large rock blocks on the slope to dislodge and roll down to and beyond the slope toe.

Forest fires are expected to occur relatively frequently in the 1000 to 2000 year period of interest. Of themselves, they do not pose a significant threat to the stability of rehabilitated mine components. However, loss of vegetation cover may lead to accelerated erosion by wind and water, or development of oxygen or water pathways along root holes through soil covers.

Droughts, like fires, are expected to occur at irregular intervals with consequences essentially similar to those for fires.

Perpetual Disruptive Forces

Perpetual disruptive forces include: wind and water erosion, sedimentation, frost action, ice and debris accumulations, slaking and leaching of rocks, and biological activities such as beaver dams, burrowing animals and root penetration. Measures to control these processes range from establishing rip rap and insulating layers to providing regular maintenance for the removal of beaver dams and ice and debris accumulations. These are described further in SRK 1992a.

CHEMICAL STABILITY

Chemical stability issues include: acid rock drainage (ARD), leaching of metals, and flushing of mill reagents or other chemicals. Potential control technologies for chemical stability are summarized in

Table 1. Generally, control measures must be specific to the type and source of contaminant. Prediction of the type, concentration and volume of an effluent is essential to identifying the most effective and economical control method. Prediction methods are described in SRK et al, 1989 and SRK, 1992b.

TABLE 1

CHEMICAL STABILITY - POTENTIAL CONTROL TECHNOLOGIES

CONTROL OF REACTIONS

CONTROL TECHNOLOGY	ARD	METAL LEACHING	MILL REAGENTS
Conditioning of waste/ removal of deleterious mineral.	Yes	Yes	
Covers and seals for exclusion of water.	Yes	Yes	
Covers and seals for exclusion of oxygen.	Yes		
Blending/ base addition.	Yes		
Bactericides (short term only)	Yes		
Change mill process, change reagents.			Yes
Change mill process, add fixing or neutralizing agents.			Yes

CONTROL OF MIGRATION

CONTROL TECHNOLOGY	ARD	METAL LEACHING	MILL REAGENTS
Covers & seals to reduce infiltration.	Yes	Yes	Yes
Controlled placement to reduce infiltration.	Yes	Yes	Yes
Diversion of surface water.	Yes	Yes	Yes
Interception of groundwater.	Yes	Yes	Yes

COLLECTION & TREATMENT

CONTROL TECHNOLOGY	ARD	METAL LEACHING	MILL REAGENTS
Active treatment in chemical/physical treatment plant.	Yes	Yes	Yes
Passive treatment using wetland.	Yes	Yes	Yes
Passive treatment using alkaline trench.	Yes		
Passive treatment using retention pond.			Yes

LAND USE

Reclamation, in the context of land use, means measures taken so that the use or conditions of the land or lands is:

- restored to its former use or condition, or
- made suitable for an acceptable alternative use.

Generally, a closure plan should include information on the expected conditions and uses of a mine site after the mining has ceased and all reclamation measures have been completed.

The return of the land or lands to the original mix of uses implies an understanding of the conditions that existed prior to project development, including the level of productivity. For existing mines this information may not be available or obtainable by direct survey or measurement. In such circumstances, the original conditions must be inferred from undisturbed adjacent similar lands. The inferred original condition includes four main components:

- the ambient or background level of contamination in the local area;
- the natural topographic features of the region;
- use of the surrounding area including level of population, frequency of travel through, and the degree of isolation; and
- the natural vegetation, habitat and productivity.

Original uses include natural vegetation, wildlife, recreation, sport or cultural uses, subsistence farming or hunting, surface and groundwater uses and any commercial uses. Since mineral resource recovery is an original use, reclamation activities should not unreasonably prevent the future exploitation of any remaining mineral resources that may occur on the site.

The reclaimed site should not contain any hazards that are greater than the hazards typical of the area prior to project development. Thus, the reclamation of dump slopes in steep mountainous terrain need not be flattened to slopes flatter than the steep slopes typical of adjacent areas. It is, however, desirable that any hazards which do remain are minimized to the extent achievable with BATEA.

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