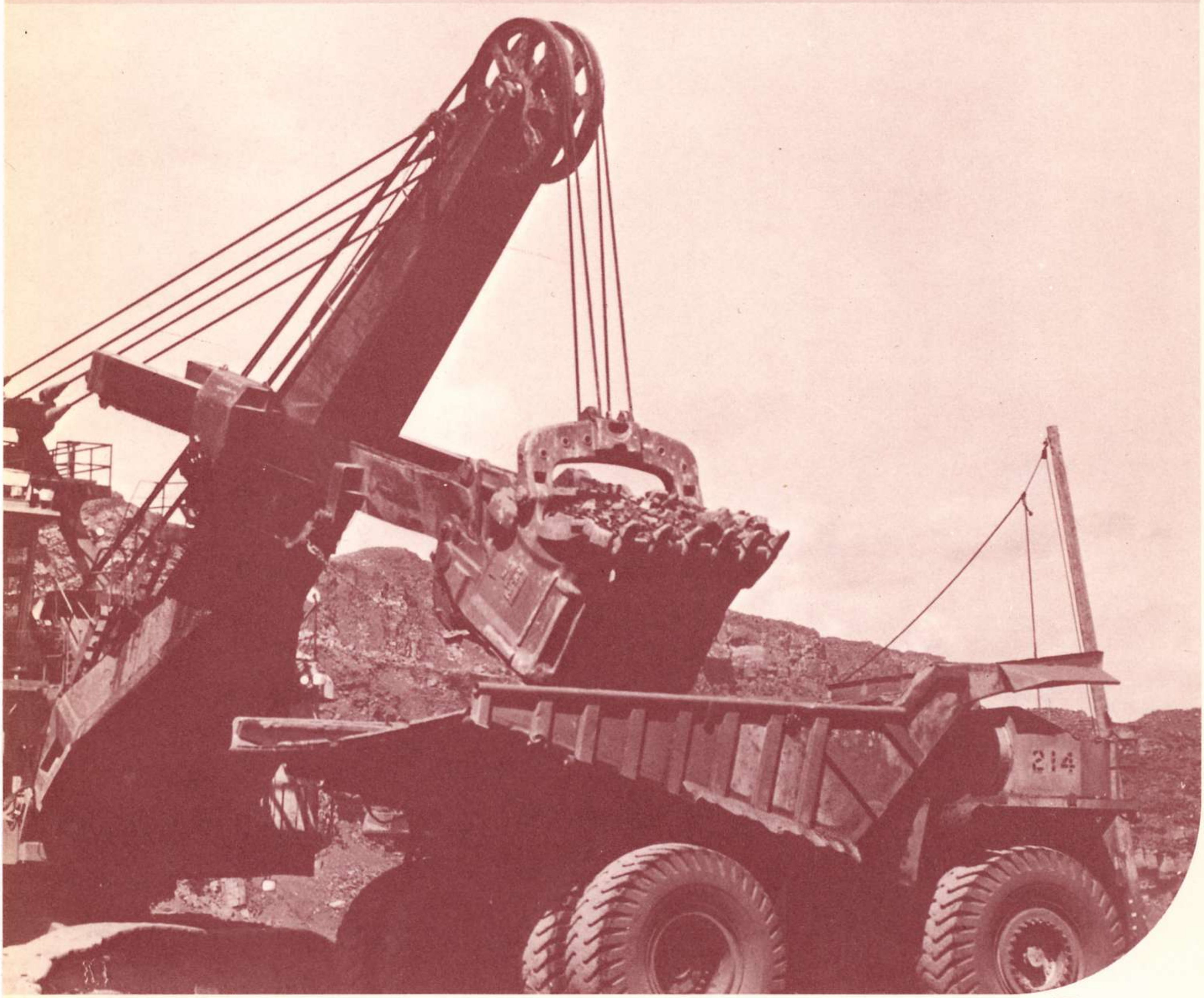
# A Brief Submitted to the Royal Commission of Inquiry

## Health and Environmental Protection Uranium Mining

September, 1979

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Waste Disposal

BY THE INSPECTION AND
ENGINEERING DIVISION
MINERAL RESOURCES BRANCH



Province of British Columbia
Ministry of Energy, Mines and Petroleum Resources

# SUBMISSION OF MINISTRY OF ENERGY MINES AND PETROLEUM RESOURCES TO ROYAL COMMISSION ON HEALTH AND ENVIRONMENTAL PROTECTION – URANIUM MINING

## PHASE V – WASTE DISPOSAL

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## SUMMARY

- The major waste materials involved in metal mining operations are tailings, waste rock, and overburden.

- Provincial statutes which may govern waste disposal are the *Mines Regulation Act, Pollution Control Act, Health Act, Forest Act, Land Act,* and *Water Act.*

- Federal legislation which may govern waste disposal are the *Atomic Energy Control Act* and the *Fisheries Act.*

- Tailings dams are regulated by both the Ministry of Energy, Mines and Petroleum Resources and the Pollution Control Branch and approvals are required before proceeding with construction of any tailings impoundment.

- The Ministry of Energy, Mines and Petroleum Resources has published *Guidelines for the Design, Construction, Operation, and Abandonment of Tailings Impoundments.* These guidelines were prepared for existing coal and metal mines and were not intended to regulate the disposal of radioactive materials.

- When a tailings impoundment is being designed, the Chief Inspector has the power to request an engineering report [*Mines Regulation Act,* section 7(3)], signed by a professional engineer registered in the Province of British Columbia.

- Control is maintained during the construction of a tailings impoundment by requiring the design consultant to be on site to ensure that the design requirements are being followed.

- Monitoring of the tailings dam and an annual report on its stability is required.

- Tailings structures must, after the cessation of mining operations, have a permanent spillway that will be able to withstand the 200-year flood and must be revegetated.

- Control of effluents into the tailings impoundment and discharge from the impoundment is controlled by the Pollution Control Branch.

- Tailings disposal systems presently used in British Columbia are: the board and batten system, underwater disposal, tailings dam construction, and underground disposal.

- There have been several failures associated with tailings structures in British Columbia during the past decade.

- The deposition of waste rock and overburden is largely under the jurisdiction of the Ministry of Energy, Mines and Petroleum Resources.

• Waste rock and overburden dumps are usually structurally stable in metal mines in British Columbia but legislation is in place to control the design, construction, operation, and abandonment of waste dumps in the same manner as tailings structures.

• Effluent control from waste dumps is the responsibility of the Pollution Control Branch.

• Waste dumps may be required to be designed to ensure that materials, which are either amenable to plant growth or result in accumulation of toxic substances in plant material, are buried. The most favourable growth medium may be required to be stockpiled and placed on the surface.

• There are no operating uranium mines in British Columbia.

• Within the Ministry of Energy, Mines and Petroleum Resources control of uranium mine wastes would be treated in a fashion similar to that applied to metal mines, using the latest technology and regulations for so doing.

• Although there is no specialist in uranium waste disposal within the Ministry of Energy, Mines and Petroleum Resources, members of the Inspection and Engineering Division have gained some experience in methods of waste disposal through attending seminars and visiting several uranium mines.

## I. INTRODUCTION

This portion of the Ministry's submission will describe the current legislative framework that governs disposal of wastes from a metal mine, the procedures which are currently followed to design, construct, and approve waste disposal systems for existing metal mines and some of the present methods used for waste disposal. It will also discuss the special case of uranium mining.

Wastes generated from a mining operation are 'disposed' in a variety of fashions and for a number of reasons. They are often handled and stored so that they may be utilized commercially if economics alter. They are deposited where possible so that the surface can be reclaimed to a useful state. Wastes are also disposed of so that they are contained to minimize any discharge of toxic substances.

The major waste materials involved in metal mining operations are:

(1) Tailings
(2) Waste rock (consolidated material)
  (a) no mineralization
  (b) low-grade mineralized rock, presently not ore
(3) Overburden (unconsolidated material)

## II. LEGISLATIVE BASE

The following provincial and federal statutes may govern waste disposal in mining.

### 2.1 Provincial Legislation

**Mines Regulation Act**

The *Mines Regulation Act* was reviewed in Phase II of the Ministry's submission. The Act gives wide powers to ensure that:

(1) Recovery of the mineral resource is maximized [section 10(5)].
(2) The operation is safe [section 10(5)].
(3) The surface of the land is reclaimed [section 11(1)].

**Pollution Control Act**

The *Pollution Control Act* governs discharges from a mine including:

(1) effluents from a mill (including a tailings pond effluent);
(2) effluent from a minesite;
(3) air emissions;
(4) garbage disposal.

**Health Act**

Section 5(a) of the *Health Act* states 'The Minister (of Health) shall take cognizance of the interests of health and life among the people.'

The Act empowers the Lieutenant Governor in Council to make such regulations as he deems necessary for the prevention, treatment, mitigation, and suppression of disease including the control of radiation and the inspection, regulation, and control of commercial and industrial premises for the purposes of health protection provided in the Act.

The Act also ensures that public water supplies meet all public health requirements.

**Forest Act**

Permits are required for the use and disposal of timber on Crown land.

*Licence to Cut* – is required for major mining activities.
*Special Use Permit* – is required if a mine road is to be built over a Forest Reserve.

**Land Act**

The Lands Department has jurisdiction over Crown land not included within the Forest Reserve and not included on a mineral property. The Lands Department may issue:

*Right of Way* – for roads required to access a mineral property.
*Foreshore Lease* – for use of shoreline areas.

**Water Act**

The Water Rights Branch is responsible for licencing the use of all surface water.

*Water Licence* – is required for any water use, storage, or stream diversion.

## 2.2 Federal Legislation

The major federal statutes which may govern waste disposal are the *Atomic Energy Control Act* and the *Fisheries Act.*

**Atomic Energy Control Act**

The Atomic Energy Control Board makes regulations respecting uranium mining and milling. The Board also regulates the production, import, export, transportation, refining, possession, ownership, use, or sale of anything which may be used for the production, use, or application of atomic energy.

*Licencing Guide 31* (*see* Ministry's submission, Phase II, Appendix 4.1.5, p. 72) contains provisions which apply to waste management.

**Fisheries Act**

The *Fisheries Act* regulates the disposal of deleterious substances into any water containing fish.

## III. TAILINGS

Tailings dams are regulated by both the Ministry of Energy, Mines and Petroleum Resources and the Pollution Control Branch and approvals are required before proceeding with construction of any tailings impoundment. The requirements of the Ministry of Energy, Mines and Petroleum Resources for tailings impoundments are outlined in the *Guidelines for the Design, Construction, Operation, and Abandonment of Tailings Impoundments* issued by the Chief Inspector of Mines on March 15, 1978 (Appendix 3.1). These guidelines also incorporate some of the requirements of the Pollution Control Branch. These guidelines were prepared for existing coal and metal mines and were not intended to regulate the disposal of radioactive materials. Regulations govern structural safety of tailings impoundments (*Mines Regulation Act*). The discharge of effluent flowing into the tailings impoundment as well as any discharges from the impoundment are controlled by the Pollution Control Permit (*Pollution Control Act,* section 5) and the environmental impact and revegetation of the tailings by the *Mines Regulation Act* (section 11).

### 3.1 Safety of Tailings Impoundments

The requirements specified in the *Guidelines for the Design, Construction, Operation, and Abandonment of Tailings Impoundments* are issued under the authority of the *Mines Regulation Act* [section 6(2c)].

Under these guidelines, issued by the authority of the *Mines Regulation Act* [section 7(3)], the Chief Inspector of Mines may require an engineering report, signed by a professional engineer registered in the province of British Columbia specializing in geotechnical engineering. An example of an engineering report that was prepared for an open pit mine is presented in part in Appendix 3.1.1.

#### 3.1.1 Design

The engineering report must include detailed site investigations and must consider the following: topography, geology, construction materials, climate, hydrology, and seismicity. The design should include a stability analysis of the proposed structure.

When the engineering report is received by the Chief Inspector of Mines, he arranges an on-site meeting with the company, their consultants, the District Inspector of Mines, a Ministry of Energy, Mines and Petroleum Resources' Engineer from Victoria, and in certain cases, the Pollution Control Branch.

When the design is approved by the Chief Inspector of Mines, the approval with any terms and conditions is submitted to the company and a copy is forwarded to the Pollution Control Branch prior to the issuing of a Pollution Control Permit.

### 3.1.2 Construction

Control is maintained during the construction of a tailings impoundment structure. The design consultant is required to be on site during construction and is responsible for ensuring that the design requirements are followed by the contractor. A copy of any report submitted to the mining company from the design consultant must be forwarded to the District Mine Inspector.

If the mining company is continually raising the dam after the Starter Dam is completed, the company is normally required to submit monthly reports to the District Mine Inspector concerning the results of monitoring of seepage, phreatic line, and other requirements to meet the design parameters. The District Inspector of Mines may, however, require reports on a less frequent basis.

Because of the chance that snow and ice may be incorporated within the structure, construction during freezing weather is usually not permitted.

### 3.1.3 Operation

Control is maintained during the operation of the tailings impoundment. Monitoring of the tailings dam and an annual report on its stability is required. This report includes the following:

Review of the stability – including vertical and horizontal movements.

Seepage – including controlled and any other evident seepages which might indicate new leakage.

Summary of the analysis of the water seepage as required by the Pollution Control Permit.

Water balance is required for the year's operation.

Summary of the phreatic levels in the dam cross-section and downstream foundation.

Construction details including dam height and amount and type of material.

Measured freeboard and projected freeboard available during the year with reference to the 200-year flood.

### 3.1.4 Post Operation

Tailings structures must, after the cessation of mining operations, have a permanent spillway that will be able to withstand the 200-year flood and must be revegetated. A report outlining the proposed design must be submitted and approved.

### 3.2 Control of Effluent

A permit is required by the Pollution Control Branch [*Pollution Control Act,* section (5)] for the discharge of effluents into the tailings impoundment and any discharge of effluents from the impoundment. Other agencies which are normally consulted in assessment of a permit application are the Fish and Wildlife Branch, Ministry of Agriculture, Ministry of Health, Water Rights Branch, and Environment Canada.

### 3.3 Environmental Impact and Reclamation

A permit authorizing surface work is required (section 11, *Mines Regulation Act*) for all mining operations. This permit is designed to ensure that a program of environmental protection and reclamation is undertaken in order to leave the land and watercourses in a condition 'satisfactory to the Minister.' The application for a permit is reviewed by an advisory committee on reclamation made up of members from government agencies including: Ministry of Forests, Ministry of Agriculture, Ministry of Lands, Parks and Housing (Lands Branch), Ministry of Environment (Water Rights Branch), and Ministry of Environment (Fish and Wildlife Branch). Section 11 of the *Mines Regulation Act* will be reviewed in detail in Phase VI of the Ministry's submission.

### 3.4 Tailings Structures Presently in Use in British Columbia

Until 1960, tailings impoundments in British Columbia were relatively small as most mines were underground and tonnages mined were low, compared to the large open pits of today. The tailings impoundments at Cominco's Sullivan mine at Kimberley and Princeton Tailings Ponds were the only large-scale structures.

The tailings disposal systems presently used in British Columbia are:

(1) Board and batten system;
(2) Underwater disposal;
(3) Tailings dam construction;
(4) Underground disposal.

The board and batten system has been one of the most common methods of tailings structure used. Examples of this system are Princeton, Salmo, and Craigmont. The boards and battens are constructed along a dyke as a framework for the tailings as the tailings pond is raised.

The tailings are spiggoted around the perimeter of the pond with coarse material forming the dyke and the fines and water going to the centre of the pond. Past experience has shown that these ponds do not retain water and the tailings are 70 per cent to 80 per cent solids.

Another method of tailings disposal has been underwater, both fresh and salt water. This method has been used in the past and is currently being used at three mines in British Columbia. Disposal underwater has the advantage that no land surface is disturbed and oxidation of sulphides is practically eliminated. Mines which have used or are using underwater tailings disposal are:

| **Mine** | **Location** | **Status** |
|---|---|---|
| Britannia | Howe Sound | Closed 1972 |
| Texada | Texada Island | Closed 1977 |
| Western | Buttle Lake | Operating |
| Jordan River | Jordan River | Closed 1975 |
| Brynnor | Toquart Bay | Closed 1968 |
| Wesfrob | Queen Charlotte Islands | Operating |
| Coast Copper | Benson Lake | Closed 1972 |
| Island Copper | Holberg Inlet | Operating |
| Kitsault | Alice Arm | Was operating — closed down; now re-opening |
| Bluebell | Kootenay Lake | Closed 1972 |
| Yale Lead and Zinc | Kootenay Lake | Closed |

The discovery of large porphyry orebodies brought on the development of large open pit mines in British Columbia. The daily tonnage of open pit mines varies up to 50,000 tons which essentially means that up to 50,000 tons of tailings are produced. In relation to small underground mines, the 50,000 tons/day open pit mine might correspond to a yearly tonnage or even the life time tonnage of a small mine. The large daily tonnage necessitates the construction of tailings dams. These are desgned using four methods: upstream, centreline, downstream, and conventional dam construction. It should be pointed out that a majority of tailings ponds are closed circuit, which means that water in the tailings pond is reused. Seepage from a dam is contained and either pumped back to the pond or released. If released, the water must meet the requirements of the Pollution Control Permit. Monitoring of seepage water is required on a basis determined by the Pollution Control Branch.

Another method of tailings disposal is the underground disposal system which employs tailings for backfill for ground support in underground mining. The tailings are classified prior to placement underground. Classification is defined as a process of separating and removing fines (or slimes) from the coarser tailings fraction so that the tailings can be dewatered by percolation once they have been placed as backfill. This process is used so that ground support is provided by the tailings while recovering pillars of ore. This method has been used at the Bluebell, Bralorne, Northair, and Western mines. Slimes must still be disposed of in a satisfactory manner.

## 3.5 Tailings Failures

There have been several failures associated with tailings structures in British Columbia during the past decade. These failures are described below in chronological order:

**Phoenix Copper Limited, September 12, 1969**

The failure occurred at the Twin Creek Pond at Granby's Phoenix mine near Greenwood, British Columbia. The following excerpt taken from a report by Ripley, Klohn and Leonoff International Ltd. describes what happened.

> The dam performed satisfactorily for the first 2½ years. The rock-fill section of the embankments has been completed to its full height. The downstream slope of the embankment was end dumped and remains at the angle of repose of the material at a slope of approximately 1 to 1.4. This slope has shown no signs of instability.
>
> The foundation investigation for the dam revealed a layer of hard stiff clay below the recent alluvial deposits. However, on inspection the soils show no signs of heave or displacement. It is concluded that the foundation soils are adequate for the support of the dam.
>
> Operation of the dam consisted of placing the cycloned sand against the rockfill. A delta of slimes and whole tailings was maintained upstream of the sand to retain the reclaim pond water.
>
> During the spring runnoff in 1969, the reclaim pond rose to such an extent that it came in contact with the cycloned sand at one particular point. On September 12, 1969, a pipehole developed at this point and a quantity of reclaim water passed through the rockfill. A description of the failure follows. Early in the morning, about 3:00 a.m., on September 12, 1969, the dam watchman heard trickling water as he was standing on the crest of the rockfill. By 7:00 a.m., the main flow of water occurred. By 11:00 a.m., the flow was reduced to about 800 gallons per minute as a result of emergency corrective measures enacted by Phoenix Mines. It was later estimated from high water marks downstream that the maximum flow was about 48,000 gallons per minute. About 10 million gallons were lost from the tailings dam.

**Endako Mines Limited, April 8, 1971**

A piece of timber left in the South Dam of No. 2 Tailings Pond during fall construction caused a rupture of the dam. During a period of less than one hour, more than 100,000 gallons of tailings escaped but most of the spillage was caught by the safety dam.

**Pride of Emory Mine, Giant Mascot Mines Ltd., August 30, 1971**

An overlow water culvert separated and permitted an escape of tailings which washed out a road and ran down into a creek.

**Lornex Mining Corporation Ltd., November 18, 1973**

A small spill of tailings occurred from an emergency spill pond. The spill was attributed to drainage seepage reopening an inadequately blocked culvert used during the construction of the impoundment.

**Consolidated Churchill Copper Corporation Ltd., June 28, 1975**

During flood conditions, a creek overflowed its banks and entered the No. 1 Tailings Impoundment Area located adjacent to the Racing River. The errant creek breached the rock-fill dyke in three places and entered the Racing River, taking with it undetermined quantities of tailings. Two or three days elapsed before the flood conditions subsided and a crew was able to return the creek to its original channel.

**Brenda Mines Ltd., April 19–20, 1976**

A small leakage of tailings water (3,000 gallons) occurred from the safety dam during spring runoff.

## IV. WASTE ROCK AND OVERBURDEN

The deposition of waste rock and overburden is largely under the jurisdiction of the Ministry of Energy, Mines and Petroleum Resources through the *Mines Regulation Act*. The Act is concerned with safety and approval of mining systems (section 10) which includes studies to determine if ore is to be covered and rendered unminable by the dumps, and through environmental protection and reclamation of the surface of the land (section 11). As with tailings structures, legislation which may also apply includes the *Pollution Control Act, Health Act, Forest Act, Land Act, Water Act, Atomic Energy Control Act,* and *Fisheries Act.*

### 4.1 Safety

Waste rock and overburden dumps are usually structurally stable in metal mines in British Columbia. However, the legislation is in place to control the design, construction, operation and abandonment of waste dumps in the same manner as tailings structures. In several instances engineering reports have been required under section 7(3) of the *Mines Regulation Act*, and stability monitoring during waste dumping has taken place.

### 4.2 Control of Effluent

Effluent control is the responsibility of the Pollution Control Branch. Most mines have installed perimeter drainage ditches to divert surface water from the mining area. Mine drainage is normally monitored by the company and/or the Pollution Control Branch. Remedial action has been required in several instances when levels exceeding the acceptable limits of certain elements were detected in drainage water.

To reduce the possiblity that drainage problems will arise, low grade or marginal ore (which is often milled during the final stage of a mine's operation) is stockpiled separately from the main waste dump areas so that drainage may be isolated or confined within a tailings catchment area. Also, during the initial application for mine development, the Ministry of Energy, Mines and Petroleum Resources requires that tests be done to evaluate the potential of ore and waste rock to generate acid mine drainage.

### 4.3 Environmental Impact and Reclamation

Design and construction of dumps to minimize the environmental impact and enhance the potential for reclamation is the responsibility of the Ministry of Energy, Mines and Petroleum Resources.

Waste dumps may be required to be designed to ensure that:

(1) Materials which are not amenable to plant growth will be buried.
(2) Materials supporting plant growth which result in accumulation of toxic substances in plant material are buried.
(3) The most favourable growth medium is saved to be placed on the surface. In metal mines this is often glacial till overburden.

Input of other agencies occurs through the advisory committee on reclamation. A detailed description of this process will be discussed in the Ministry's submission to Phase VI.

## V. WASTE DISPOSAL IN URANIUM MINING

There are no operating uranium mines in British Columbia; consequently, the Ministry of Energy, Mines and Petroleum Resources has never had to regulate disposal of radioactive wastes. Within the Ministry of Energy, Mines and Petroleum Resources control of uranium mine wastes would be treated in a fashion similar to that applied to metal mines, using the latest technology and regulations for so doing.

### Legislation Governing Uranium Waste Disposal

The *Mines Regulation Act* applies to uranium mining. The procedures previously outlined in this submission, that the Ministry of Energy, Mines and Petroleum Resources have used in controlling the disposal of tailings, waste rock, and overburden in metal mines would apply to wastes generated from uranium mining. Additional regulations will be required to protect the health and safety of the workers, the public, and the environment from the effects of radionuclides.

### Experience in Uranium Waste Disposal

Waste disposal systems will be required to meet provincial legislation and the requirements of the Atomic Energy Control Board on a site-specific basis. This treatment will require that expertise be available within the Inspection and Engineering Division to form an overall judgment on the safety of the system. Currently, there is no specialist in uranium waste disposal within the Ministry of Energy, Mines and Petroleum Resources but a specialist in geotechnical engineering is being sought. The Inspection and Engineering Division has, however, the power to require a consultant's report and has the ability to obtain professional advice from experts outside the Ministry.

Although there is no specialist, members of the Inspection and Engineering Division have gained some experience in methods of waste disposal through attending seminars and visiting several uranium mines as follows:

The Uranium Mill Tailings Management Symposium was attended by J. D. McDonald in Fort Collins, Colorado, on November 20 and 21, 1978. While in Colorado, Mr. McDonald also visited the Technical Support Center (MESA) in Denver and obtained from them information on methods of measurement of radon and radioactivity. Four members of the Inspection and Engineering Division attended the National Conference on Nuclear Issues in the Canadian Energy Context in Vancouver on March 7, 8, and 9, 1979.

The Seminar on Uranium Mining and the Environment was attended by four Inspectors in Vancouver on April 11, 1979. At this seminar, Mr. J. D. McDonald presented a paper on the Role of the Uranium Steering Committee (*see* commission document accession number 285A).

The Third Annual Uranium Seminar was attended in Casper, Wyoming, on September 9, 10, and 11, 1979, by Mr. David Smith. One of the subjects in this seminar pertained to *in situ* mining of uranium.

A visit was made to the Eldorado underground uranium mine, near Radium City, Saskatchewan, by Messrs. W. C. Robinson, J. D. McDonald, and S. Elias, on June 4 and 5, 1979. On June 6 and 7, 1979, a visit was made by the same group to the surface uranium mining operation of Gulf Minerals at Rabbit Lake, Saskatchewan. Both these visits were made in company with Dr. Gordon Atherley, Director of Occupational Health and Safety for Saskatchewan. A visit was made by Mr. Robinson to the Whiteshell Nuclear Research Establishment at Pinawa, Manitoba, on September 12, 1979. Talks during this visit included a discussion on disposal of nuclear waste. On September 17 and 18, 1979, a visit to two uranium mines in Washington State, the Sherwood and Midnite mines, was made by Messrs. Robinson, Richardson, McDonald, and Elias.

Staff, therefore, are aware of the potential problems and many of the current solutions employed in disposal of wastes from uranium mining.

# APPENDICES

## APPENDIX 3.1

**Province of British Columbia**
Ministry of Mines and Petroleum Resources

# GUIDELINES
# FOR THE DESIGN, CONSTRUCTION, OPERATION, AND ABANDONMENT OF TAILINGS IMPOUNDMENTS

Tailings impoundments involve two important aspects of public concern and the additional concern of the safety of the workers. Structural stability of dams and impoundments is essential because, if failure occurs, large volumes of water and/or semi-fluid tailings would be released causing a serious threat to life and property and accompanying pollution problem. The other aspect of concern is the possibility of pollution during the operational and post-operational periods due to controlled discharges (by overflowing or decanting) and seepage downstream of the tailings dam.

In the Province of British Columbia there are two Ministries whose approvals are required before proceeding with construction of any tailings dam or tailings impoundment.

## A. MINISTRY OF MINES AND PETROLEUM RESOURCES

Under the authority of section 7 (3) of the *Mines Regulation Act* or section 6 (3) of the *Coal Mines Regulation Act,* the Chief Inspector of Mines shall require an engineering report, signed by a professional engineer registered in the Province of British Columbia specializing in geotechnical engineering. The Chief Inspector of Mines may waive certain requirements for small mining operations.

## B. MINISTRY OF THE ENVIRONMENT – POLLUTION CONTROL BRANCH

A permit is required by the Pollution Control Branch for the discharge of effluents to the tailings impoundment and any discharge of effluents from the impoundment. Other agencies which are consulted in assessment of a permit application are Ministry of Recreation and Conservation, Ministry of Agriculture, Ministry of Health, Water Rights Branch, and Environment Canada.

## PROCEDURE

### 1 SITE INVESTIGATIONS

Preliminary investigations can be done by the company where in-house engineering is available.

1.1 Topography of area

1.2 Geological and subsurface covering

- (a) Superficial geology and subsoil investigations
- (b) General geology – rock types, fracturing, faulting, permeability
- (c) Evidence of previous mudslides, rockslides
- (d) Assessment of the downstream area which might be affected by any dam failure

1.3 Availability of materials for dam construction – soil – gravels – waste rock – cycloned tailings

1.4 Climate data

1.5 Hydrology – evaluation of catchment area, total precipitation, rate of runoff, stream flows, evaporation, evidence of springs and artesian conditions

1.6 Seismicity

### 2 DESIGN ANALYSIS

An analysis of the integrity of the proposed design. The information should include:

2.1 Results of geological studies and site investigations including logs of drill holes, field permeability tests, and groundwater levels

2.2 Results of soil tests on foundation and abutment materials including shear strength and consolidation test data

2.3 Description of the engineering properties of the materials to be used for the construction of the dams

2.4 Type of construction

Upstream Construction – using tailings

Centreline Construction – using tailings

Downstream Construction – using tailings or borrow material

Conventional Dam Consturction – using open-pit waste or borrow material

Tailings dams are usually constructed in two phases with Phase I being the Starter Dam which is normally carried out in the same manner as conventional dams and is usually done by a contractor. Phase II is the continual raising of the dam which is normally carried out by the mining operator. Design must take into account the proposed ultimate height of the dam.

2.5 Hydrology – design must take into consideration the hydrology of foundation area and the upstream and downstream areas. This should include surface and subsurface water conditions, diversion of water courses, drainage and runoff from the upstream basin, erosion control. Design should allow for a maximum of a 200-year flood runoff from the upstream basin – water balance to include operational water, recycle water, runoff water, mine water (if applicable), evaporation, seepage, and water entrained in solids. Decant systems using decant towers and pipes through the dam should not be used in major structures.

2.6 Seismicity – design should take into account the seismic activity in the area and the safety factor should be indicated.

2.7 Drainage Features – the design must indicate adequate drainage features to control the location of the phreatic line within the structure and uplift pressures in the foundation soils downstream of the dam.

2.8 Instrumentation – sufficient instrumentation must be used to determine settlement, pore pressure, seepage, phreatic line. Downstream monitoring of surface and subsurface waters is required to determine changes from the base line data.

2.9 Seepage Control – The impoundment design should ensure that seepage through and under the dam is minimized to prevent receiving water contamination downstream, unless the impoundment is deliberately constructed as an infiltration basis (the Pollution Control Branch should be consulted in this case).

## 3 CONSTRUCTION CONTROL

3.1 Construction Specifications – rate of Construction-Scheduling is to be drawn up and copies issued to the Chief Inspector of Mines, and the District Inspector and Resident Engineer.

3.2 Design Control – the design consultant is required to be on site during construction and shall be responsible to ensure that the design requirements are followed by the contractor. Copy of reports submitted to the mining company shall be forwarded to the District Mine Inspector.

3.3 Construction Phase II – when the mining company is continually raising the dam after Phase I Starter Dam is completed, the company is required to submit monthly reports to the District Mine Inspector concerning the results of monitoring of seepage, phreatic line, and other requirements to meet the design parameters. The District Inspector of Mines may require reports on a less frequent basis.

3.4 Construction During Freeze-Up – construction during freeze-up and winter months is not permitted. This period may vary with location and type of winter.

## 4 OPERATING CONTROL

4.1 Instrumentation – the basic instrumentation required to maintain surveillance on the performance of the tailings dam should include: piezometers to measure water levels and outline the phreatic water line in the dam and its foundations; settlement and alignment gauges to measure vertical and horizontal movements; gauges to measure seepage flows through the dam; determination and monitoring of seepage flows to be made on a regular basis as required by the Pollution Control Permit.

4.2 Annual Report – an annual report on the stability of the tailings dams and related works will be required to be submitted to the Chief Inspector of Mines, the District Inspector, and the Pollution Control Branch. The Pollution Control Branch normally requires submission of annual reports on seepage control, water balance, and other aspects related to pollution control. To simplify reporting requirements, it is preferable to submit one report to both agencies, with the report incorporating both Mines and P.C.B. requirements. The report shall be submitted by a qualified geotechnical engineer and can be in-house engineering with the permission of the Chief Inspector of Mines. The report shall contain the following:

Review of the stability – including vertical and horizontal movements

Seepage – including controlled and any other evident seepages which might indicate new leakage

Summary of the analysis of the water seepage as required by the Pollution Control Permit

Water balance is required for the year's operation

Summary of the phreatic levels in the dam cross-section and downstream foundation

Construction details including dam height and amount and type of material

Measured freeboard and projected freeboard available during the year with reference to the 200-year flood

## 5 POST OPERATIONAL

5.1 A report shall be submitted to the Chief Inspector of Mines outlining the proposed post-operational state of the dam, related seepage control works, mine water deportment, and post-operational monitoring.

5.2 Spillway – a permanent spillway shall be designed and installed prior to final abandonment of the tailings dam. The design shall take into consideration the runoff in the catchment area for the 200-year flood. (The minimum amount of impoundment water shall be considered in the design.)

5.3 Reclamation – a report on the proposed total reclamation of the tailings area shall be submitted to the Chief Inspector of Mines pursuant to section 11 of the *Mines Regulation Act* and section 8 of the *Coal Mines Regulation Act.*

## 6 GENERAL

6.1 Ministry of Mines and Petroleum Resources and Ministry of the Environment (Pollution Control Branch)

The following reports shall be submitted to the Chief Inspector of Mines, the District Inspector of Mines, and the Pollution Control Branch.

- Initial report on proposed new impoundments and any additional lifts proposed by the company.
- Report of the design by consultants is required. When the report is received, the Chief Inspector of Mines shall arrange an on-site meeting with the company, their consultants, District Inspector, a Ministry of Mines' Engineer from Victoria, and in certain cases, the Pollution Control Branch.
- The design must be approved by the Chief Inspector of Mines. Approval with any terms and conditions will be submitted to the company and a copy will be forwarded to the Pollution Control Branch prior to the issuing of a Pollution Control Permit.

6.2 Pollution Control Branch

Copies of all reports submitted to the Chief Inspector of Mines shall be submitted to the Pollution Control Branch.

6.3 Seepages Other Than Controlled

Any seepages which are observed other than the controlled seepage shall be reported to the District Inspector of Mines and the Regional Manager of the Pollution Control Branch. Mines shall make recommendations and issue instructions as the seepage affects stability and the Pollution Control Branch shall do the same as seepage affects pollution. Any malfunction in the seepage return works shall be reported to the District Inspector of Mines and the Regional Manager of the Pollution Control Branch.

6.4 All reports submitted shall be signed by a professional engineeer registered in the Province of British Columbia.

**W. C. Robinson, P. Eng.,**
**Chief Inspector of Mines.**

**Inspection and Engineering Division**
**Victoria, B.C.**
**March 15, 1978.**

KPA

KER, PRIESTMAN & ASSOCIATES LTD.

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L. H. McGill M.A.Sc., P.Eng.



17th November 1975

Our File 836/102

Department of Mines,
Parliament Buildings,
Victoria, B.C.

Attention: Mr. J.W. Peck, P. Eng.
Chief Inspector

Dear Sirs:

P.C.B. Application dated September 15/75
Tailing Disposal

In connection with the above application, we are pleased to enclose for your perusal a copy of the geotechnical report by Klohn Leonoff Consultants Ltd. entitled Report on Tailings Dams and dated February 27, 1975.

A copy was supplied to the Pollution Control Branch a few days ago.

Yours very truly,

KER, PRIESTMAN & ASSOCIATES LTD.

D.J. Pennington, P.Eng.

DJP/ej
Encl.

c.c. Pollution Control Branch
Attn: R. Dreidger

Earle J. Klohn
Cyril E. Leonoff
Donald M. Davison
Mark T. Olsen
Earl W. Speer
K. Ian Morrison
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**Klohn Leonoff Consultants Ltd.**

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C.H. (Bob) Maartman
Robert P. Richards
Walter Shukin
Adrian Wightman

Our file: VA 1836 November 14, 1975

Vancouver, B.C.

Dear Sirs:

Please note that the drawing KPA 836-F-316 as originally bound in this report, has been replaced by Revision A. References to this drawing have not been amended.

Yours very truly,
KLOHN LEONOFF CONSULTANTS LTD.

MARK T. OLSEN, P. Eng.
Executive Engineer

MTO/11

RECEIVED
NOV 17 1975
KER, PRIESTMAN
& ASSOCIATES LTD.

REPORT ON TAILINGS DAMS

Project:

Location:

Client:

Vancouver, British Columbia

VA1836 February 27, 1975

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TAILINGS DAM SCHEDULING ................................ KLCL D-1836-8

TAILING IMPOUNDMENT FLOW AND CAPACITY DIAGRAMS ........ KPA 836-F-316

GENERAL PLAN - TAILING IMPOUNDMENT .................... KPA 836-G-315

Earle J. Klohn
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VA1836

February 27, 1975

# REPORT ON TAILINGS DAMS

Project: Mines Limited (NPL)

Location: B.C.

Client:
Vancouver, British Columbia

## 1. INTRODUCTION

This report presents a design for tailings dams for the Mines project near , B.C. The report will form part of a submission by Mines to the British Columbia Pollution Control Branch for a permit to impound mine tailings.

Klohn Leonoff Consultants Ltd. are responsible for the dam site investigations and the design of the tailings dams. Ker Priestman and Associates are responsible for matters related to tailings storage volume calculations, transportation of tailings, discharge of tailings to the tailings pond, reclamation of clarified water, recovery of seepage water from below the tailings dam, and general control of the water balance. KPA drawings 836-G-315 and 836-F-316 are appended to this report for reference re hydrology, seepage control and storage volume requirements.

Authorization for this report was given by Mr. of , by letter dated August 21, 1974.

A previous report, entitled "Preliminary Foundation Report", dated November 29, 1973, examined a tentative alignment of tailings dams involving an unusual outward curvature which required extensive special measures in dam construction. Subsequent to the time of the above report acquired additional lands which allowed improvement of the dam alignment. This report deals with design of the dams in the revised configuration.

This report will be supplemented by detailed construction drawings prior to beginning dam construction. A tailings dam operating manual will be developed as dam-building techniques are established during the early stages of construction. Periodic inspection visits by a qualified consulting engineer will be made during dam construction.

## 2. CONCLUSIONS AND RECOMMENDATIONS

### 2.1 The Site

The site of the Mines tailings pond is in the valley containing Lake, approximately 3 miles south of Lake and 9 miles west of on Highway . The tailings pond will be about 1 mile west of the proposed millsite and ½ mile west of the open pit. A key plan and general location plan are shown on KPA Drawing 836-F-316. The tailings pond will initially be enclosed by two large dams, one at each end of Lake, joining the high ridge on the north with the rising ground to the south. Two smaller dams will be built in stream channels to the south in later years. The dams will be built to an ultimate crest elevation of 2400 feet, roughly 285 feet above the present level of Lake. The dam, as shown on KLCL Drawing D-1836-6, will provide storage for approximately 95 million cubic yards. That volume represents roughly 27 million tons of tailings storage and 70 million tons of water, sufficient for 11 years production at a rate of 7200 tons of tailings solid per day.

## 2.2 The Dams

The tailings dams are designed with a triangular section of waste rock sealed by an impervious upstream membrane of compacted glacial till. Two filter zones of carefully selected granular materials will separate the impervious membrane and rockfill and provide protection against piping and cracking. The filter zones will extend beneath the rockfill zone to provide protection against upward piping of foundation soils. Typical dam sections are shown on KLCL Drawing D-1836-7.

## 2.3 Foundations

The dam foundations are mainly composed of a dense, well-graded silt-sand-gravel mixture (glacial till) of varying depth lying directly on bedrock. Bedrock is at or near ground surface at higher elevations. The glacial till and bedrock will provide excellent foundation support. The weathered upper surface of the bedrock must be reviewed for possible seepage problems during initial stripping operations at each damsite. Blanketting of the rock will be applied as necessary. Some pervious gravel or talus deposits on the abutments of the East Dam may also require special treatment for seepage control. At both the east and west ends of Lake, soft silt deposits of up to 10 feet depth will be removed from the damsites.

Geological work by Mines has indicated major fault systems are present at depth in the tailings pond area. Ground surface inspection and studies of air photographs indicate no fault movements in recent geologic times.

Appendix B contains a detailed resume of the damsite investigations with detailed drill hole and test pit logs, including test pit data from the preliminary site investigations. Drawing D-1836-5 shows the location of drill holes and test pits used for the
34 investigations and profiles of the general subsoil conditions along the dam axis.

## 2.4 Characteristics of the Tailings Material

The tailings material is expected to be a very fine slurry with a high slimes content. The very fine fraction is similar to Bentonite clay. The fine fraction of the tailings solids is not expected to settle rapidly enough to clarify the water sufficiently to allow reclaim of process water. Hence a larger storage volume will be required to impound process water along with the tailings solids. The dams will not be typical tailings dams in that a high head of dirty water will be in contact with the dam faces. In this regard the dams are similar to water dams and are designed as such.

## 2.5 Construction Materials

### 2.5.1 Glacial Till

Impervious material for the initial stages of construction is expected to come from the open pit overburden stripping. Glacial till may also be borrowed from sources within the reservoir area as required. The natural water content of the till is probably slightly above optimum for compaction but if placed during the summer months the hot dry climate should provide adequate drying.

### 2.5.2 Filters

Two grades of filter material are specified for the dams. At this time it is expected that the fine filter will be manufactured from waste or specially quarried rock. Some natural deposits of pit-run sand and gravel may be available for fine filter construction. The coarse filter may be visually selected from open pit waste.

### 2.5.3 Rockfill

Rockfill will be selected from open pit waste and should consist of hard, durable fragments with a minimum percentage of fines. Waste rock quality is expected to be variable but it should be possible to select the best material for dam building and spoil the weaker rock on the waste dump.

Placing and gradation recommendations for rockfill, fine and coarse filter materials, and glacial till are contained in Appendix C.

2.6 Slope Stability

The stability of a slope in homogeneous material is a direct function of the effective shear resistance of the material and the dimensions of the slope. The shear resistance is in turn governed by the angle of internal friction and the pore water pressure within the materials. In free draining rockfill material where no pore pressures develop the shear resistance is governed only by the angle of internal friction.

The anticipated angle of internal friction for the rockfill in the dams should be between 37 and 40 degrees. Under normal static conditions the steepest stable slope for a perfectly dry embankment in rockfill with a friction angle of 37 degrees will be approximately 1.3 horizontal to 1.0 vertical.

The Mines site is in seismic zone 3, which is a relatively active earthquake area. The letter and attached data in Appendix A from Mr. G. A. McMechan of the Division of Seismology, Victoria Geophysical Observatory, dated November 12, 1974 indicates that an earthquake having a return period of 100 years would have an acceleration approximately equal to 11 percent of gravity.

Dynamic loading such as produced by an earthquake will not affect the overall stability of the tailings dams but may result in some ravelling or surface sliding of the downstream slope. To provide additional safety during possible seismic tremors the final slope on the downstream side of the dam has been set at 1.5 horizontal to 1.0 vertical. This flattening of the slope from the natural angle of repose will be accomplished by stepping back individual lifts to leave 20-foot wide berms at 100 foot vertical intervals to provide the specified average slope.

## 2.7 Construction Details

### 2.7.1 Control of Settlement

The major design consideration for the dams is control of embankment settlements. Settlements could lead to cracking of the impervious membrane. Special rockfill placement procedures are specified to minimize settlement. In the typical dam section the rockfill is to be placed in two zones. Rock in the upstream zone is to be placed in lifts of 5 feet maximum depth and compacted with truck and bulldozer traffic and heavy vibratory rollers. In the downstream zone the rock may be end-dumped in lifts up to 100 feet. The compacted upstream zone will act as a semi-rigid zone which would settle more or less evenly and with a minimum of differential settlements. End-dumped rock is to be watered during placing in the ratio of at least one volume of water to one volume of rock.

### 2.7.2 Special Provisions for Areas of Outward Curvature

The area of outward curvature of the main dam will be subject to tensile stresses and perhaps some cracking as the tailings pond is slowly filled. The following special provisions are recommended in the outward curved area to minimize settlement and facilitate self-healing of cracks:

(a) The downstream slope will be flattened to an average slope of 2 horizontal to 1 vertical to provide extra buttressing against lateral downstream movement.

(b) The entire rockfill section will be placed in thin lifts and heavily compacted.

(c) The fine filter and coarse filter zones will be thickened from horizontal widths of 12 feet to 25 feet. The fine filter will be exceptionally high quality, preferably pit-run sand and gravel rather than processed waste.

The lateral extent of the area requiring the special provisions has been shown on a detail on Dwg. D-1836-6.

2.7.3 Initial Construction

Construction of the initial stage of the dams prior to start-up of the concentrator is planned to elevation 2204 to provide storage for the first year's tailings production. The starter dams will be the first stage of the Main and East dams.

The starter dams may be built in either one of two ways. The dams may be constructed as typical dam sections as shown on Section A-A, Dwg. D-1836-7, or may be constructed as homogeneous glacial till dams as shown on the alternate section on Dwg. D-1836-7. At this time it is expected that the starter dams will be of homogeneous glacial till construction. The typical dam section involves placement of the rockfill zone prior to placing the glacial till membrane against the rockfill. The development of the open pit will involve stripping a considerable volume of glacial till prior to the start of mining operations. It will likely be more economical to place the glacial till directly on the starter dams rather than stockpiling the till until after waste rock sources are developed.

For comparison purposes the material volumes for the alternate starter dam designs are summarized below:

| | Glacial Till Construction | Rockfill Construction |
|---|---|---|
| Glacial Till | 2,234,000 cu yd | 1,340,000 cu yd |
| Fine Filter | 71,000 cu yd | 277,000 cu yd |
| Coarse Filter | - | 260,000 cu yd |
| Compacted Rockfill | - | 965,000 cu yd |
| Total Volume | 2,305,000 cu yd | 2,842,000 cu yd |

Initial construction will also include stripping the starter dam bases, establishing borrow areas and construction of runoff diversion facilities and the seepage recovery dam.

We recommend that initial construction be carried out under the supervision of a qualified soils engineer. In addition to providing inspection of stripping operations, borrow areas and fill placement, the engineer would train personnel in dam-building procedures.

2.7.4 Scheduling

The crest of the dams will normally be at a considerably higher elevation than the tailings pond, however construction will be scheduled to ensure that the dam freeboard at any time will be not less than 5 feet. Freeboard for storage of spring runoff will be in addition to the minimim 5 feet specified.

Drawing D-1836-8 shows the anticipated rate of construction and sequence of placement of materials for the dams. The schedule is based on Ker Priestman and Associates Drawing 836-G-316 volume vs elevation curve. The schedule may be adjusted if annual volume requirements change.

The typical construction sequence for each lift will be outlined below. Detailed placing recommendations are given in Appendix C.

(a) The base for fine filter will be prepared by clearing and grubbing trees and roots, stripping organic material, and cleaning out any swampy areas or unstable soils. The glacial till base will be scarified, watered if necessary and compacted and fine filter placed where specified in drawings. A layer of compacted fine rock will be placed beneath dumped rockfill on areas of dam base not requiring fine filter.

(b) End-dumped rockfill, (zone a), will be placed in maximum 100-foot lifts up to the elevation of the top of the previous lift of compacted rock.

(c) The abutments will be stripped and compacted in preparation for placing filters beneath compacted rockfill. The fine filter (zone d) then coarse filter (zone c) will be placed in thin lifts of 12 to 18 inches up to the specified thickness of 5 feet.

(d) The compacted rockfill section (zone b) will be placed in lifts of maximum 5-foot thickness up to the required elevation. The compacted rockfill sections will have crest widths of 100 feet.

(e) The coarse filter (zone c), fine filter (zone d) and impervious membrane (zone e) will be placed on the upstream side of the compacted rockfill zone. Placement of the filters and impervious zone will proceed more or less simultaneously so there will be no more than 5 feet difference in elevation between zones during construction. The seepage cutoff trench will be excavated and backfilled simultaneously with the placing of the impervious membrane as the top surface of the fill is raised up the abutments.

Where bedrock is exposed or near surface at the base of the impervious membrane, the seepage cutoff trench will be eliminated and replaced with an upstream blanket of compacted glacial till to lengthen the seepage path, and reduce the amount of seepage.

2.7.5 Waste Rock Dump

Waste fill will be placed to the northeast of the East Dam and will be continuous with the East Dam. Fill within the East Dam will be placed as described in the report and drawings prior to dumping any waste material against the downstream slope of the dam. Waste rock outside the dam outline may be randomly selected and placed.

The topography beneath the waste dump forms a depression in which seepage and runoff water could accumulate against the downstream side of the impervious membrane. The water level in the waste dump must be kept below the tailings pond level to prevent displacing the impervious membrane into the reservoir. Ker Priestman and Associates have proposed a pump to be buried beneath the waste dump. Care must be taken to ensure the pump remains operational.

2.7.6 Spigotting

Bedrock outcrops in various areas within the reservoir and between the dam structures. We recommend that tailings be spigotted over these areas to permit the fine sand to seal any fractured rock which may allow seepage to discharge into the local groundwater system. The critical bedrock areas will be reviewed as construction of the starter dams proceeds. As an alternative to spigotting, a layer of compacted glacial till could be placed over critical bedrock areas.

### 2.7.7 Testing and Instrumentation

Research should be continued on methods of settling the bentonite fraction of the tailings. Clarification of the process water would allow water reclaim and would greatly decrease the tailings storage volume requirements. The dam design can be adjusted to provide smaller storage if water reclaim is put into effect.

Continuous records should be kept of the pond water levels and of the tailings levels. Observations should be made of seepage patterns and regular records should be kept of quantities of flow in all seepage collection ditches.

### 2.7.8 Provision for Shutdown

Provisions will be made to ensure there is no danger of overtopping of the tailings dams by runoff water in the event of any prolonged shutdown or permanent closure of mining operations. Ker Priestman and Associates hydrologic data on the enclosed KPA Drawing 836-F-316 indicates that under average climatic conditions, evaporation losses will slightly exceed the total inflow from runoff and direct precipitation. Adequate freeboard will be provided for normal runoff storage. Provision will be made however, for extreme flood years. An emergency spillway will be constructed at the north abutment of the East Dam in the event of any shutdown. The spillway will have its discharge into the open pit to prevent any contaminated water from entering the local runoff system.

## 3. DISCUSSION

### 3.1 General

The Mines tailings dams will have more of the nature of conventional water storage dams than tailings dams. The usual mine tailings material allows clarification and reclaim of the process water. The use of reclaimed process water minimizes the volume of fresh makeup water and the small water surface in the tailings pond can usually be separated from the dams by a long spigotted beach. The dams, however, will have a high head of dirty water directly in contact with the dam faces. As a result the dams must be designed and constructed to provide a water-tight containment.

3.2 Prevention of Piping

Embankment settlements must be carefully controlled to prevent cracking which could lead to high seepage losses. The relatively long construction period of the dams will aid in reducing post-construction settlements. Much of the settlement of each lift of waste rock will occur prior to placement of the next lift. Sluicing rock during dumping and dumping in relatively high lifts are the main accepted methods of reducing post-construction settlements in end-dumped rockfills. The zone of compacted rockfill will act as a semi-rigid member which will minimize differential settlement under the applied reservoir load.

Filter zones are the principal line of defense against piping should cracking occur, either through differential settlements or the unlikely event of any foundation adjustment. Production and placement of filter material will be carefully controlled to ensure high quality filter zones.

3.3 Compaction of Rockfill

The upstream rockfill zone will be compacted with heavy vibratory rollers and by truck and bulldozer traffic. We have not specified water to aid compaction at this time. Watering may be specified at a later date if satisfactory compaction is not being achieved.

3.4 Area of Outward Curvature

The area of outward curvature on the Main Dam has been conservatively designed by conventional standards. This is necessary because any settlements in this area will lead to cracking of the impervious membrane. The flatter downstream slope and fully-compacted dam section are specified to limit embankment movement. The extra wide filter zones will prevent erosion and facilitate healing if any cracking does occur.

3.5 Camber

It is usual practice to design dams with a camber, or extra crest height, to accommodate settlements. No camber has been provided for the dams for the following reasons:

(a) The long construction period will allow most settlements to occur before completion of the ultimate facility.

(b) Adequate freeboard has been provided.

(c) The wide dam crests would allow addition of extra height if necessary.

3.6 Seepage

Seepage beneath the dams will be limited by the seepage cutoff trench beneath the impervious membrane. Seepage through the dams will be intercepted by ditches at the dam toes and diverted to the seepage recovery dam. We have also considered the possibility of seepage through non-dam portions of the reservoir. The weathered upper surface of the bedrock exposed at higher elevations may require blanketting to minimize seepage losses through the bedrock. We recommend that tailings lines be extended to allow spigotting tailings on the bedrock surface. The most critical bedrock areas are on the high ridge to the north between the Main and East Dams and to the south between the East and Southeast dams. The alternative to blanketting with tailings would be the placing of a layer of compacted glacial till over bedrock surfaces.

## 3.7 Stability

Free-draining rockfill material will normally provide adequate slope stability at its natural angle of repose of approximately 1.3:1. For additional stability during possible earthquake tremors, the downstream dam slopes will be flattened by the addition of berms to an average slope of 1.5:1.

Property restrictions have dictated an area of outward curvature on the Main Dam. To provide additional slope stability and provide buttressing against lateral movement, the average downstream slope will be flattened to 2:1 in the outward curved area.

Respectfully submitted,
KLOHN LEONOFF CONSULTANTS LTD.

PETER C. LIGHTHALL, P.Eng.

Mark Olsen

MARK T. OLSEN, P. Eng.
Executive Engineer

PCL/MTO/mc

cc: (6 copies)

# APPENDIX A

SEISMIC RISK ANALYSIS

Department of Energy, Mines and Resources
Ministère de l'Énergie, des Mines et des Ressources
CANADA

Victoria Geophysical Observatory
5071 West Saanich Road, R.R. 7
Victoria, B.C.

File Number
Nº à rappeler

November 12, 1974.

Mr. P. Lighthall,
Klohn and Leonoff Consultants Ltd.,
Suite 204,
1847 W Broadway,
Vancouver, B.C.

Dear Mr. Lighthall,

Please find enclosed a seismic risk analysis for a site near at coordinates

N
W

as you requested on the phone.

Sincerely,

George

G.A. McMechan,
Division of Seismology.

GAM:dc

THIS IS AN ESTIMATE OF THE EARTHQUAKE PROBABILITY OF A SITE NEAR

THE GEOGRAPHICAL CO-ORDINATES OF THE SITE ARE
50 DEGREES 39 MIN NORTH LATITUDE
128 DEGREES 28 MIN WEST LONGITUDE

EARTHQUAKES BETWEEN 1899 AND 1970 INCLUSIVE ARE INCLUDED IN THE ANALYSIS.

DURING THIS PERIOD THERE ARE 2300 EARTHQUAKES IN THE EARTHQUAKE CATALOGUE FOR THIS REGION. THERE WERE 108 EARTHQUAKES WHICH COULD HAVE BEEN FELT AT THIS LOCATION DURING THIS 72 YEAR PERIOD.

THIS SITE HAS EXPERIENCED A MAXIMUM ACCELERATION OF 4. PERCENT GRAVITY OR A MAXIMUM INTENSITY OF VI

TABLE 1 IS A LIST OF THE EARTHQUAKES WHICH REACHED AN INTENSITY OF II OR GREATER AT THIS SITE. ALL OF THE EVENTS IN THIS LIST MAY HAVE BEEN FELT.

TABLE 2 IS A LIST OF THE PREDICTIONS FOR THIS SITE. PLEASE READ THE FOLLOWING REMARKS BEFORE USING THE DATA.

THE VALUES FOUND IN TABLE 2 ARE BASED UPON A STATISTICAL ANALYSIS OF THE EARTHQUAKES WHICH HAVE OCCURRED OVER THE ABOVE INTERVAL OF TIME. THIS IS TOO SHORT A PERIOD OF OBSERVATION FOR ACCURATE PREDICTIONS ABOUT TECTONIC ACTIVITY. HOWEVER, THE DATA HAVE BEEN PROCESSED TO PROVIDE AN ESTIMATE OF THE POSSIBLE LEVEL OF EARTHQUAKE ACTIVITY IN THE NEAR FUTURE ASSUMING A CONTINUATION OF THE STATISTICAL PATTERN OF THE PAST YEARS. ALTHOUGH PREDICTIONS CAN BE MADE FOR MANY RETURN PERIODS. THE NUMBERS GIVEN FOR RETURN PERIODS GREATER THAN 100 YEARS ARE MORE LIKELY TO BE ALTERED BY CHANGING PATTERNS OF EARTHQUAKE ACTIVITY.

THE EXTREME VALUE METHODS OF STATISTICS ARE USED FOR THESE CALCULATIONS. THE SLOPE OF THE CURVE IS FOUND BY A LEAST SQUARES SOLUTION OF THE DATA FOR THE YEARS WHEN THERE WAS ACTIVITY ABOVE A FIXED THRESHOLD LEVEL. THE CURVE IS REPRESENTED BY THE EQUATION

LOG(ACC) = MODE + K(-LOG(-LOG(P)))

WHERE NATURAL LOGARITHMS ARE USED. P IS THE PROBABILITY THAT ACC WILL BE EXCEEDED IN 1 YEAR. R IS THE RETURN PERIOD ( IN YEARS) OF ACCELERATION AMPLITUDE LOG(ACC) AND EQUALS 1/1-P .

FROM THIS THE ACCELERATION AMPLITUDE IS

ACC = EXP(LOG(ACC))

AND THE INTENSITY

I = 3*LOG10(ACC) + 4.5

I IS THE INTENSITY BY THE MODIFIED MERCALLI INTENSITY SCALE OF 1931. IN THE TABLES THE VALUE IS ROUNDED TO THE NEAREST INTEGER AND PRINTED IN ROMAN NUMERALS. ACC IS THE ACCELERATION AS A PERCENTAGE OF GRAVITY.

THE VALUES OF ACCELERATION LISTED IN TABLE 2 ARE FOR FIRM SOIL. OTHER TYPES OF FOUNDATION MATERIAL MAY ALTER THE VALUES BY AT LEAST ONE UNIT OF I.

THE SEISMIC ZONING MAP IN THE NATIONAL BUILDING CODE OF CANADA (1970)
USES THE ACCELERATION AMPLITUDES WITH RETURN PERIODS OF 100 YEARS AS THE
CRITERIA FOR ZONE BOUNDARIES. THIS IS CALLED ACC100. THE FOLLOWING ARE
THE ZONE BOUNDARIES IN THE 1970 CODE.

```
ZONE 0                ACC100 < 1.    R = 0
ZONE 1    1. <=       ACC100 < 3.    R = 1
ZONE 2    3. <=       ACC100 < 6.    R = 2
ZONE 3    6. <=       ACC100 <       R = 4
```

50 39 128 28

TABLE 1 DATA

| DAY | MONTH | YEAR | MAG | LAT | LONG | DISTANCE MILES | KMS | ACCELERATION PERCENT G | INTENSITY |
|---|---|---|---|---|---|---|---|---|---|
| 4 | 9 | 1899 | 8.20 | 60.00 | -142.00 | 833 | 1341 | 0 | III |
| 10 | 9 | 1899 | 8.60 | 60.00 | -140.00 | 786 | 1265 | 1 | IV |
| 10 | 9 | 1899 | 7.80 | 60.00 | -140.00 | 786 | 1265 | 0 | II |
| 9 | 10 | 1900 | 8.20 | 60.00 | -142.00 | 833 | 1341 | 0 | III |
| 11 | 3 | 1912 | 6.50 | 51.00 | -131.00 | 113 | 182 | 1 | IV |
| 21 | 7 | 1914 | 6.50 | 49.00 | -130.00 | 132 | 213 | 1 | IV |
| 1 | 7 | 1917 | 6.40 | 50.00 | -128.00 | 49 | 79 | 3 | VI |
| 23 | 12 | 1917 | 6.50 | 50.00 | -128.00 | 49 | 79 | 4 | VI |
| 6 | 12 | 1918 | 7.00 | 49.75 | -126.50 | 106 | 172 | 2 | V |
| 1 | 7 | 1919 | 5.50 | 50.00 | -128.00 | 49 | 79 | 1 | IV |
| 10 | 7 | 1919 | 5.00 | 50.00 | -128.00 | 49 | 79 | 0 | III |
| 29 | 3 | 1920 | 6.40 | 50.50 | -129.50 | 46 | 74 | 4 | VI |
| 28 | 5 | 1921 | 5.50 | 49.20 | -129.20 | 105 | 169 | 0 | II |
| 2 | 5 | 1923 | 5.00 | 50.00 | -128.00 | 49 | 79 | 0 | III |
| 13 | 10 | 1923 | 5.00 | 50.50 | -129.50 | 46 | 74 | 0 | III |
| 30 | 3 | 1924 | 6.00 | 50.50 | -129.50 | 46 | 74 | 2 | V |
| 30 | 10 | 1926 | 6.10 | 48.50 | -129.00 | 150 | 242 | 0 | III |
| 31 | 10 | 1926 | 6.60 | 48.75 | -128.50 | 131 | 211 | 1 | IV |
| 1 | 3 | 1929 | 6.10 | 51.50 | -130.75 | 115 | 185 | 0 | III |
| 16 | 4 | 1929 | 5.50 | 49.50 | -130.00 | 104 | 168 | 0 | II |
| 26 | 5 | 1929 | 7.00 | 52.80 | -129.50 | 154 | 249 | 1 | V |
| 17 | 9 | 1929 | 6.30 | 49.70 | -132.00 | 169 | 272 | 0 | III |
| 16 | 4 | 1930 | 5.50 | 49.50 | -130.00 | 104 | 168 | 0 | II |
| 18 | 8 | 1932 | 5.50 | 49.00 | -129.00 | 116 | 187 | 0 | II |
| 5 | 5 | 1933 | 5.50 | 49.30 | -129.20 | 98 | 158 | 0 | III |
| 24 | 9 | 1935 | 6.20 | 49.30 | -129.20 | 98 | 158 | 1 | IV |
| 29 | 9 | 1937 | 5.50 | 49.20 | -129.90 | 118 | 191 | 0 | II |
| 22 | 3 | 1938 | 6.30 | 52.60 | -132.10 | 205 | 331 | 0 | II |
| 22 | 4 | 1938 | 5.50 | 49.20 | -129.90 | 118 | 191 | 0 | II |
| 18 | 7 | 1939 | 6.50 | 49.20 | -129.90 | 118 | 191 | 1 | IV |
| 3 | 7 | 1939 | 6.50 | 48.50 | -130.00 | 163 | 263 | 0 | III |
| 1 | 10 | 1941 | 6.00 | 49.50 | -130.00 | 104 | 168 | 0 | III |
| 6 | 11 | 1941 | 6.00 | 49.00 | -130.00 | 132 | 213 | 0 | III |
| 19 | 7 | 1942 | 6.00 | 51.20 | -130.00 | 76 | 123 | 1 | IV |
| 9 | 5 | 1942 | 5.75 | 49.20 | -129.90 | 118 | 191 | 0 | III |
| 10 | 3 | 1944 | 6.25 | 50.90 | -130.70 | 99 | 159 | 1 | IV |
| 13 | 8 | 1944 | 5.80 | 50.50 | -132.00 | 155 | 249 | 0 | II |
| 23 | 6 | 1946 | 7.30 | 49.90 | -124.90 | 165 | 266 | 1 | V |
| 28 | 2 | 1948 | 6.50 | 53.90 | -132.10 | 271 | 437 | 0 | II |
| 22 | 7 | 1948 | 5.50 | 50.30 | -130.70 | 101 | 162 | 0 | II |
| 22 | 7 | 1948 | 5.50 | 50.30 | -130.70 | 101 | 162 | 0 | II |
| 30 | 12 | 1948 | 6.00 | 50.90 | -130.70 | 99 | 159 | 0 | IV |
| 13 | 4 | 1949 | 7.00 | 47.20 | -122.60 | 357 | 574 | 0 | II |
| 21 | 8 | 1949 | 8.00 | 53.75 | -133.25 | 294 | 474 | 1 | V |
| 23 | 8 | 1949 | 6.40 | 52.60 | -132.10 | 205 | 331 | 0 | III |
| 29 | 7 | 1949 | 4.60 | 50.00 | -129.00 | 50 | 81 | 0 | II |
| 7 | 8 | 1949 | 4.80 | 50.50 | -130.00 | 68 | 109 | 0 | II |
| 22 | 5 | 1950 | 5.70 | 51.50 | -130.50 | 105 | 170 | 0 | III |
| 27 | 9 | 1951 | 5.50 | 49.00 | -129.00 | 116 | 187 | 0 | II |
| 14 | 5 | 1953 | 5.00 | 50.00 | -129.70 | 70 | 113 | 0 | II |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 20 | 5 | 1953 | 5.50 | 50.00 | -129.70 | 70 | 113 | 0 | III |
| 4 | 12 | 1953 | 6.00 | 49.50 | -129.10 | 84 | 135 | 1 | IV |
| 10 | 3 | 1954 | 4.50 | 51.00 | -128.00 | 31 | 50 | 0 | III |
| 19 | 2 | 1956 | 6.80 | 51.70 | -131.40 | 146 | 235 | 1 | IV |
| 28 | 6 | 1956 | 6.30 | 48.80 | -129.30 | 133 | 214 | 0 | III |
| 30 | 11 | 1956 | 5.00 | 49.70 | -129.40 | 77 | 124 | 0 | II |
| 21 | 12 | 1956 | 6.75 | 51.80 | -129.20 | 85 | 137 | 2 | V |
| 24 | 3 | 1957 | 6.80 | 50.00 | -129.70 | 70 | 113 | 3 | VI |
| 16 | 12 | 1957 | 6.00 | 50.00 | -127.00 | 78 | 126 | 1 | IV |
| 10 | 7 | 1958 | 7.90 | 58.60 | -137.10 | 647 | 1042 | 0 | III |
| 15 | 1 | 1959 | 4.20 | 50.50 | -128.90 | 21 | 34 | 1 | IV |
| 26 | 8 | 1959 | 5.70 | 52.20 | -129.90 | 123 | 198 | 0 | II |
| 4 | 7 | 1960 | 6.00 | 52.00 | -131.00 | 143 | 231 | 0 | III |
| 4 | 7 | 1960 | 6.62 | 52.00 | -131.50 | 160 | 258 | 1 | IV |
| 12 | 8 | 1960 | 4.90 | 50.60 | -129.60 | 49 | 80 | 0 | III |
| 1 | 12 | 1960 | 6.00 | 48.50 | -129.10 | 151 | 243 | 0 | III |
| 2 | 6 | 1962 | 5.75 | 49.90 | -129.80 | 78 | 126 | 1 | IV |
| 12 | 7 | 1963 | 4.80 | 50.30 | -129.60 | 55 | 89 | 0 | III |
| 2 | 9 | 1963 | 4.60 | 50.30 | -129.20 | 40 | 64 | 0 | III |
| 2 | 9 | 1963 | 4.40 | 50.40 | -129.10 | 32 | 52 | 0 | III |
| 5 | 9 | 1963 | 4.20 | 50.30 | -129.10 | 36 | 59 | 0 | II |
| 31 | 3 | 1964 | 5.70 | 50.78 | -130.12 | 72 | 117 | 1 | IV |
| 21 | 2 | 1965 | 3.10 | 50.50 | -128.50 | 10 | 16 | 0 | III |
| 31 | 8 | 1965 | 3.80 | 50.50 | -129.00 | 25 | 41 | 0 | II |
| 11 | 9 | 1965 | 4.70 | 50.30 | -129.50 | 51 | 82 | 0 | III |
| 30 | 3 | 1966 | 5.10 | 49.80 | -129.90 | 86 | 138 | 0 | II |
| 26 | 10 | 1966 | 4.30 | 50.40 | -129.30 | 40 | 65 | 0 | II |
| 29 | 4 | 1967 | 5.30 | 51.10 | -130.10 | 77 | 125 | 0 | III |
| 16 | 6 | 1963 | 5.10 | 50.80 | -129.50 | 46 | 74 | 1 | IV |
| 12 | 7 | 1963 | 4.00 | 50.40 | -129.00 | 29 | 46 | 0 | II |
| 12 | 7 | 1963 | 4.80 | 50.30 | -129.60 | 55 | 89 | 0 | III |
| 2 | 9 | 1963 | 4.60 | 50.50 | -129.40 | 42 | 68 | 0 | III |
| 2 | 9 | 1963 | 4.40 | 50.40 | -129.10 | 32 | 52 | 0 | III |
| 5 | 9 | 1963 | 4.20 | 50.30 | -129.10 | 36 | 59 | 0 | II |
| 15 | 12 | 1963 | 4.00 | 51.00 | -128.80 | 28 | 45 | 0 | III |
| 31 | 3 | 1964 | 5.60 | 50.80 | -130.20 | 76 | 123 | 0 | III |
| 3 | 9 | 1964 | 5.00 | 50.50 | -129.50 | 46 | 74 | 0 | III |
| 1 | 10 | 1964 | 5.30 | 49.30 | -128.80 | 94 | 151 | 0 | II |
| 12 | 8 | 1965 | 4.90 | 50.20 | -129.70 | 62 | 100 | 0 | II |
| 31 | 8 | 1965 | 3.90 | 51.00 | -128.60 | 24 | 39 | 0 | III |
| 11 | 9 | 1965 | 4.90 | 50.00 | -129.50 | 63 | 102 | 0 | II |
| 11 | 10 | 1965 | 4.80 | 50.50 | -129.50 | 46 | 74 | 0 | III |
| 11 | 10 | 1965 | 4.20 | 50.80 | -129.30 | 37 | 60 | 0 | II |
| 8 | 2 | 1966 | 4.90 | 51.20 | -129.20 | 49 | 79 | 0 | III |
| 30 | 3 | 1966 | 5.30 | 49.80 | -129.70 | 80 | 128 | 0 | III |
| 20 | 5 | 1966 | 5.00 | 50.20 | -129.70 | 62 | 100 | 0 | III |
| 1 | 9 | 1966 | 4.40 | 50.60 | -129.40 | 41 | 66 | 0 | II |
| 26 | 10 | 1966 | 4.30 | 50.40 | -129.30 | 40 | 65 | 0 | II |
| 29 | 4 | 1967 | 5.30 | 51.13 | -130.41 | 91 | 146 | 0 | II |
| 27 | 8 | 1967 | 5.10 | 50.20 | -130.00 | 74 | 119 | 0 | II |
| 28 | 8 | 1967 | 4.00 | 50.40 | -129.10 | 32 | 52 | 0 | II |
| 28 | 8 | 1967 | 4.50 | 50.40 | -129.60 | 52 | 84 | 0 | II |
| 28 | 8 | 1967 | 5.20 | 50.40 | -129.90 | 65 | 105 | 0 | III |
| 28 | 8 | 1967 | 5.10 | 50.40 | -129.80 | 61 | 98 | 0 | III |
| 1 | 2 | 1968 | 5.40 | 50.00 | -129.80 | 74 | 119 | 0 | III |
| 18 | 3 | 1969 | 5.00 | 50.14 | -129.96 | 74 | 120 | 0 | II |
| 3 | 11 | 1969 | 4.50 | 50.74 | -129.54 | 47 | 76 | 0 | II |
| 24 | 6 | 1970 | 6.50 | 51.75 | -131.02 | 134 | 216 | 1 | IV |

TABLE 2

50 39 128 28

MODE FOR THIS SITE = -1.77
K FOR THIS SITE = 0.91

ACC100 FOR THIS SITE = 11.4 PERCENT GRAVITY

| PROBABILITY OF ACC BEING EXCEEDED IN ONE YEAR. | ACC IN PERCENTAGE GRAVITY | INTENSITY (MODIFIED MERCALLI) | EQUIVALENT RETURN PERIOD |
|---|---|---|---|
| 0.333 | 0 | III | 3. |
| 0.100 | 1 | V | 10. |
| 0.033 | 4 | VI | 30. |
| 0.020 | 6 | VII | 50. |
| 0.010 | 11 | VIII | 100. |
| 0.005 | 22 | IX | 200. |
| 0.003 | 31 | IX | 300. |
| 0.001 | 94 | X | 1000. |

# A P P E N D I X   B

FIELD AND LABORATORY INVESTIGATIONS

SYMBOLS AND TERMS SHEET

TEST HOLE LOGS

# TAILING DAM

## FIELD AND LABORATORY INVESTIGATIONS

## 1. INTRODUCTION

This appendix describes the subsoil investigations performed in the Mines tailings dam area. Included are the investigations presented in our Preliminary Foundation Report of November 29, 1973. Drill hole and test pit locations and subsoil profiles are shown on Dwg. D-1836-5.

## 2. FIELD WORK

The field investigation at the site consisted of a total of six machine drill holes and 44 backhoe test pits, including the test pitting done for the preliminary report. The drill was a Longyear 38 diamond drill. Piston samples were attempted at 5 foot intervals in the upper 15 feet and at 10 foot intervals below 15 feet. Cores were obtained when the holes penetrated bedrock. The drill holes were grouted up after completion of drilling.

### (a) West Dam

Investigations on the west dam consisted of 5 test pits on or near the dam axis and four machine drill holes; three in the valley bottom at the west end of Lake and one in a low spot near some hayfields to the south.

The profile on dwg. D-1836-5 shows that the site is generally underlain by glacial till or bedrock with shallow deposits of compressible organic silts near surface in the valley to the west of Lake and in the hayfields near TH1004. The glacial till is generally dense to very dense and varies in depth from a few feet to over 200 feet in TH1001. The glacial till deposits are predominantly a silt with sand and gravel. Cobble and boulder sizes occur throughout the deposits. The upper 3 feet of the till is generally weathered and contains white alkali salts.

The bedrock outcrops are hard rock but often fractured at surface. Bedrock was encountered in TH1002 and TH1003.

(b) East Dam

Investigations on the east dam consisted of 2 drill holes in the valley bottom at the east end of Lake and 10 test pits scattered on or near the dam axis.

The east dam is also underlain by bedrock or glacial till on top of bedrock. TH1005 encountered a conglomerate bedrock at 105 ft which indicates that the till probably lies directly on the bedrock.

The composition of the glacial till is generally the same as the till under the west dam - predominantly silt with sand and gravel with some boulders and cobbles throughout.

The surface soils, however, are more complex under the east dam than the west. High on the left abutment hard bedrock is exposed, in some places quite fractured. On the gentler slopes below on the left abutment there is up to 10 feet of silty sand and gravel overlying glacial till. In the valley bottom shallow organic silts overlie the glacial till. On the right (south) abutment the bedrock is shallow or exposed and the upper 5 feet are highly fractured in places. Where not exposed, the bedrock is overlain by glacial till, sand and gravel, or talus deposits.

(c) <u>South East Dam</u>

The small south-east dam was investigated with two backhoe pits on the dam axis. In TP505 and TP506, fractured bedrock was encountered at 7 feet and 4 feet respectively. The bedrock is overlain by stiff silt at TP505 which is in the low part of a small stream channel and by weathered glacial till at TP506.

(d) <u>South Dam</u>

Four test pits were excavated to investigate the axis of the south dam. The relatively flat-sloping left (east) abutment of the dam is covered with clean sand and gravel to a depth of 3 feet where glacial till is encountered. The steep east slope of the main gully appears to be controlled by bedrock which outcrops at spots along this gully, TP507, in the main channel of Creek, showed a fairly narrow water-bearing sand and gravel deposit which appears to be lying on bouldery glacial till at 5 feet. The right or western slope of the dam axis is on dense glacial till.

(e) <u>Seepage Recovery Dam</u>

The seepage recovery dam, located roughly 1000 feet downstream of the ultimate toe of the west dam, was investigated with two test pits on the dam axis. TP501, on low flat ground beside the stream, showed soft silts and water bearing sand and gravel overlying medium dense glacial till at 6½ feet. The gently sloping dam abutments are on dense glacial till.

3. BORROW INVESTIGATIONS

A number of test pits were excavated throughout the area at locations which examination of aerial photographs indicated could be possible sources of filter material. Although some small granular deposits were found, there do not appear to be any sources large enough to supply filter material for dam construction.

Test pits 510 and 511, on two small esker-like ridges north of the Creek damsite, showed good clean sand and gravel but in small quantity. A rough estimate shows perhaps 5000 cubic yards in each of the two eskers.

Test pits 519, 520, 521 and 522, on small esker or outwash features at the foot of the slope south of Hughes Lake, and TP524, higher up the slope on the east dam centerline, showed reasonably clean sand and gravel throughout their depth. Each of these features on which the above pits are located is estimated to contain roughly 3000 cubic yards so the total deposit in this area may contain 15,000 cubic yards of filter gravel.

4. LABORATORY INVESTIGATIONS

The laboratory investigations consisted of visual examination and classification of samples and determination of their natural water contents. Detailed logs of the drill holes and test pits are attached. The average natural water content of the till is roughly 11%. From our experience this is slightly above the optimum moisture content for compaction.

Sieve and hydrometer analyses were performed on two samples of glacial till. The results of these analyses are shown on a grain size curve in Figure 1.

The high blow counts recorded in driving the piston sampler indicate that the till has high in-place densities resulting from heavy preconsolidation by ice loading during glaciation. As a result of the preconsolidation the tills will be a strong relatively unyielding foundation material.

# APPENDIX C

PLACING AND GRADATION RECOMMENDATIONS

## TAILINGS DAMS

## PLACING AND GRADATION RECOMMENDATIONS

1. COMPACTED TILL

Glacial till placed in the starter dams, impervious membrane and seepage cutoff dam will be compacted to a minimum density equal to 95% of the maximum dry density as determined by ASTM D-1557-70 (Modified Density Test). It is expected that this density will be achieved by placement in layers not greater than 9 inches before rolling and by 6 passes of a sheep's foot type roller of weight not less than 4000 pounds per foot length of drum. All boulders larger than 6 inches in diameter will be removed from the fill. The original ground surface will be stripped of all soft or organic soils prior to placing glacial till. The water content will be adjusted as required to achieve the specified density.

2. FINE FILTER

Fine filters in the dams shall consist of clean pit-run sand and gravel or crushed waste or quarried rock conforming to the gradation requirements shown on Figure 2. Prior to placing fine filters the base will be stripped of all soft or organic materials and well compacted. It may be necessary to scarify and water the base prior to compaction. Placement of fine filter material shall be in layers not greater than 12 inches without segregation of particle sizes. Compaction of this material should be equivalent to at least 2 passes of a heavy vibratory roller. During construction the top surface of the fine filter should be kept at a lower elevation than the top of the coarse filter to ensure definition of the two zones. Extra care will be taken in compacting the filters at contacts between zones.

3. COARSE FILTER

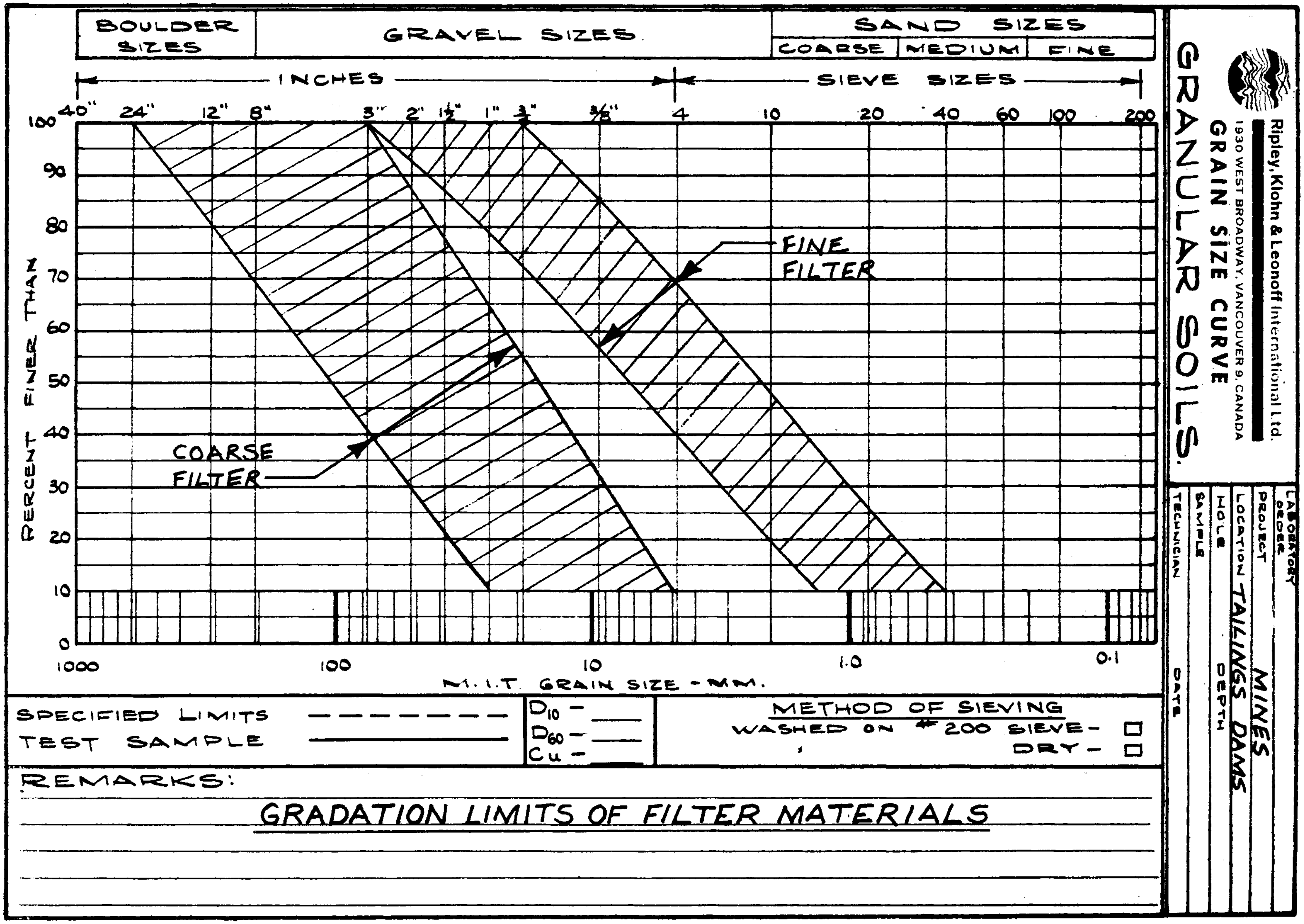
The coarse filter shall consist of specially selected or processed waste rock conforming to the gradation requirements in Figure 2. Placement of coarse filter shall be in layers not greater than 18 inches without segregation of particle sizes and compaction should be equivalent to at least 2 passes of a heavy vibratory roller.

4. COMPACTED ROCKFILL

Rockfill placed in compacted sections of the dams should consist of hard, durable rock with a maximum size of 24". Rock should be spread in maximum 5 foot layers and compacted with at least 6 passes of a heavy vibratory roller.

5. END-DUMPED ROCKFILL

End-dumped rockfill zones will consist of the most durable, coarsest waste rock available and shall be dumped in lift heights not exceeding 100 feet. The rockfill shall be sluiced during dumping with a minimum quantity of one volume of water for every one volume of rock. The top of each lift will be thoroughly scarified before placing the next lift to prevent formation of horizontal zones of low permeability.



BOULDER SIZES
GRAVEL SIZES
SAND SIZES
COARSE
MEDIUM
FINE
INCHES
SIEVE SIZES
40"
24"
12"
8"
3"
2"
1½"
1"
¾"
⅜"
4
10
20
40
60
100
200
PERCENT FINER THAN
100
90
80
70
60
50
40
30
20
10
0
1000
100
10
1.0
0.1
M.I.T. GRAIN SIZE - MM.
FINE FILTER
COARSE FILTER
GRANULAR SOILS.
Ripley, Klohn & Leonoff International Ltd.
1930 WEST BROADWAY, VANCOUVER 9, CANADA
GRAIN SIZE CURVE
LABORATORY ORDER
PROJECT MINES
LOCATION TAILINGS DAMS
HOLE
DEPTH
SAMPLE
TECHNICIAN
DATE
SPECIFIED LIMITS
TEST SAMPLE
D10 -
D60 -
Cu -
METHOD OF SIEVING
WASHED ON #200 SIEVE -
DRY -
REMARKS:
GRADATION LIMITS OF FILTER MATERIALS


FIG. 2


**Province of British Columbia**

Ministry of Energy, Mines and Petroleum Resources