

SUPPORTING DOCUMENT 13

**GIANT MINE
PRESSURE OXIDATION PROCESS**

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**GIANT MINE
ASSESSMENT OF PRESSURE OXIDATION PROCESS
FOR ARSENIC STABILIZATION AND GOLD RECOVERY**

Prepared for:

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SUPPORTING DOCUMENT 13

GIANT MINE ASSESSMENT OF PRESSURE OXIDATION PROCESS FOR ARSENIC STABILIZATION AND GOLD RECOVERY

1. INTRODUCTION

This document presents the assessment of a process to recover gold from the Giant Mine arsenic trioxide bearing dust, and to convert the arsenic into a stable chemical form. Only one type of process is considered capable of satisfying both of these objectives efficiently, while also being proven technically feasible on a large scale. This process involves the oxidation and combination of arsenic and iron, at high temperature and high pressure, in an autoclave.

The following sections of this document provide details on the selection of the high temperature process, the conceptual design of a plant to apply the process, and the estimation of capital and operating costs for such a plant. This assessment of the pressure oxidation process was a collaborative project involving Lakefield Research Limited, H.G. Engineering Limited and SRK Consulting Inc.

2. PROCESS SELECTION

The pressure oxidation process involves the chemical conversion of arsenic trioxide to crystalline iron arsenate compounds, predominantly of, or closely related to, the scorodite mineral form, and the recovery of gold by conventional cyanide leaching. Although this is now the dominant industrial method of oxidizing refractory arsenic bearing gold ores in preparation for gold extraction, it is not the only method of forming stable arsenic compounds.

Insoluble iron-arsenic compounds can be formed at ambient temperatures, resulting in high removals of arsenic from solution, provided that the molar ratio of available iron to arsenic is greater than three, the iron is in the trivalent (ferric) state, and the arsenic is oxidized from the trivalent state to the pentavalent state. The compounds formed under these conditions are poorly crystalline ferric oxyhydroxides (or ferrihydrite) containing adsorbed arsenate ions (Riveros, 2000). The products of low temperature

(ambient to 100⁰C) processes are typically voluminous precipitates that are generally considered stable, provided that the iron to arsenic ratio is high, slightly acidic storage conditions are maintained, and reducing conditions are avoided. This type of process is widely used in the mining industry for the removal of arsenic from mine waters and process effluents, and is currently used for the treatment of arsenic contaminated mine water at the Giant Mine.

At the high temperatures achieved in an autoclave operating under high pressure, scorodite ($\text{FeAsO}_4 \cdot 2\text{H}_2\text{O}$) and related ferric sulphate-arsenate compounds can be formed, which are crystalline and compact, and incorporate iron at slightly greater than a 1:1 molar ratio to arsenic. Scorodite is found extensively in nature as a result of the oxidation of arsenopyrite, suggesting that it is stable in the natural environment. There has been extensive investigation of the stability of scorodite, with some researchers suggesting good stability, provided that calcium is not incorporated into the crystal structure of the scorodite and that the waste is stored in slightly acidic environments, and others suggesting metastability (impermanent stability) in pH neutral or reducing conditions (Riveros, 2000).

The high temperature process is being successfully operated at two mines in Canada; the Con Mine in Yellowknife, and the Campbell Mine in Balmertown, Ontario. Both operations use autoclaves to oxidize gold bearing arsenopyrite in flotation concentrates, and produce wastes containing crystalline ferric arsenates, as well as gold which is amenable to recovery by cyanide leaching. At the Con Mine, the process also stabilizes arsenic trioxide waste from former roasting operations, which is very similar to the Giant Mine material. The waste is added to the normal iron-sulphide autoclave feed at low rates, along with supplemental iron-bearing calcines, and the contained arsenic is converted to stable compounds (McElroy, 1999).

The high temperature process has the following advantages over the low temperature process for the precipitation of iron-arsenic compounds:

- Much lower iron requirements (Fe:As molar ratio 1.1:1 to 1.2:1, versus greater than 3:1);
- Crystalline compounds are produced, with reasonably well known stability characteristics; crystalline products are easier to filter and form relatively dense waste deposits, resulting in more efficient disposal;

- Plant operating parameters are available from large scale applications, and for the particular application of converting arsenic trioxide to scorodite;
- Elimination of the need for large quantities of chemical oxidants, such as hydrogen peroxide, to oxidize arsenic from As(III) to As(V); and
- Higher gold recoveries (typically over 90%)

On the basis of these advantages, the high temperature and high pressure process, using an autoclave, was selected for further consideration.

3. PROCESS DESIGN

The following sections describe the selection of major variables for the design of a conceptual plant to apply the process.

3.1 Processing Rate

The optimum rate of material processing would probably be determined by a compromise between the economics of the whole project, including efficient depreciation of capital assets, and limits on the duration of the project based on public and corporate acceptance. For the purpose of this assessment, the duration of the dust extraction and re-processing phase of the project was assumed to be 15 years. A relatively long processing phase was chosen due to the anticipated high capital cost of the processing plant, and the need for appropriate depreciation of the capital assets.

The concentration of arsenic (and arsenic trioxide) varies in the inventory of dust stored at the mine (Royal Oak Mines, 1998). Due to significant modifications made to the roaster gas cleaning circuits over a period of several years, which were finally completed in 1963, the collected material can be classified into two distinct inventories. These are material produced before the modifications were completed, which has a lower arsenic content and higher gold content; and material produced after the modifications were completed, which has higher arsenic content and lower gold content. These two inventories consist of:

- Low grade material: 59,000 dry tonnes, average 47% As, 43 grams Au/tonne
- High grade material: 178,000 dry tonnes, average 65% As, 10 grams Au/tonne

The overall rate of reaction for the stabilization process, and therefore the size of autoclave vessel required, is primarily dependant on the amount of iron to be oxidized.

Since iron is added in direct proportion to the amount of arsenic, material that is lower in arsenic can be processed in the same autoclave at a higher rate than material that has a higher arsenic content.

For the purpose of selecting plant equipment sizes, it was assumed that the low grade material would be processed first, in order to maximize gold production early in the project, at a rate of 2.7 tonnes per hour. The higher grade material could be processed in the same autoclave at the lower rate of 1.9 tonnes per hour. Although the plant feed rates would vary, the rate of arsenic stabilization would be the same. Assuming a plant availability of 85% (310 operating days per year), at these processing rates, the entire dust inventory would be treated over the 15 year processing phase of the project. Of course, a fully blended feed, representing the average arsenic grade of the entire inventory, could also be processed. The feed rate for a fully blended feed would be 2.1 tonnes per hour (50.4 tonnes per day).

3.2 Sources of Iron

A major challenge for the application of this process would be locating suitable, economically efficient sources of chemically reactive iron. Several options are available for different types and locations of iron sources.

Pyrite (iron sulphide, FeS_2) is a realistic iron source, due to its abundant natural occurrence. Currently, there is no known commercial production of pyrite concentrates in Canada, or the USA. Three potential pyrite sources have been identified for the estimation of iron supply costs, including two potential sources in the Northwest Territories. These cost estimates are provided in Appendix B. Of the sources investigated, the mining operations at Flin Flon, Manitoba, appear to be the most likely reliable source.

A locally produced source of pyrite is possible. There are some pyrite-rich deposits known in the Yellowknife area, and the presence of normally sub-economic amounts of gold would enhance the attractiveness of exploiting such deposits for the purpose of providing an iron source. Other known ore deposits containing pyrite are located within trucking distance of the Giant Mine via winter ice-roads, but would probably need to be developed for other metal products, in addition to pyrite, in order to be competitive with an existing mine as a source.

A pyrrhotite (FeS) concentrate is another potential source of iron. The major advantage of pyrrhotite is that the iron to sulphur molar ratio is double that of pyrite. This would halve the sulphuric acid produced by oxidizing pyrite, eliminating the need to add neutralizing agents such as magnesium oxide directly into the autoclave, and reducing the total neutralization costs. Currently, the closest source of a pyrrhotite concentrate would be Sudbury, Ontario, and therefore, transportation costs would be high.

Other potential sources are iron oxide minerals, such as goethite and hematite, which, as sources supplementing iron sulphides, would have the advantage of helping to control acid production. Concentrates of both minerals are available. The major disadvantages of the iron oxides are their high cost, low reactivity, and unproven performance in stabilizing arsenic.

Steel mill scale is a potential source of iron that could be transported to Yellowknife. This source could be combined with locally available scrap, converted to ferrous sulphate by reacting with sulphuric acid, and subsequently converted to ferric iron in an autoclave. Conceptually, the use of iron scrap appears to have some merit, but again transportation costs would be high.

Ferric sulphate is a widely used chemical and could be used to stabilize the arsenic as scorodite. The high temperature process parameters are not well developed, but it is expected that autoclave conditions would be significantly less aggressive, with lower pressures, temperatures and oxygen demand. However, ferric sulphate costs appear to be prohibitively high.

The potential iron sources are summarized in Table 3.1. For the purpose of this assessment, it appears that pyrite concentrates from Manitoba currently provide the highest level of certainty, with regard to technical feasibility and cost. Other options would require detailed evaluation and pilot testing.

TABLE 3.1
Sources of Iron for Arsenic Stabilization

| Material | Availability | Advantages | Disadvantages |
|--|---|--|--|
| Pyrite (FeS ₂) | Good, but not currently produced. | High reactivity. Multi source potential. Relatively moderate cost. | Large amount of acid produced. Need to develop source. |
| Pyrrhotite (FeS) | Good (Sudbury, Ontario). Low grade - need to upgrade. | High reactivity. Lower acid production. | Heavy metal content solubilized. Transport hazards (oxidation). High transportation costs. |
| Goethite (FeO.OH) | Poor | No acid produced. | Lower reactivity. Low heat of reaction. High cost. |
| Locally produced FeS ₂ or FeS concentrate | Unknown | Lower cost. Possible synergy with new mining operation. | Other metals solubilized. Possible As content in iron concentrate. |
| Hematite (Fe ₂ O ₃) | Good | No acid produced. | Very low reactivity. |
| Steel mill scale, scrap | Good | Easy to transport. | Need to convert to ferric iron with acid and oxidant. High cost? |
| Ferric Sulphate Fe ₂ (SO ₄) ₃ .9H ₂ O | Good | Iron in ferric form. Lower autoclave costs. | High cost. Difficult handling. |

3.3 Feed Preparation

The handling of large quantities of arsenic trioxide dust, while maintaining a safe working environment, represents a major engineering challenge. Because the material is very fine grained and easily dispersed into the air when dry, extraordinary management and engineering measures would be required to control air quality in the plant within regulated limits.

A great advantage would be realised by handling the material wet, rather than dry, as much as possible. For this reason, it is assumed that the mining processes would either produce a slurry of the material in water directly from the extraction point underground, or that the mined material would be made into a slurry as close as possible to the extraction point. All arsenic trioxide material is therefore assumed to enter the process plant as dilute slurry pumped through a pipeline, and would be handled as a slurry throughout the plant.

| | |
|-----------------------------------|---------------|
| Neutralization agent in autoclave | MgO |
| Oxygen utilization | 80% |
| Autoclave volume utilization | 60% (40% gas) |
| Maximum % solids in feed | 20 |
| Maximum arsenic in solution | 27 g/L |

Based on the available data from pilot and full-scale operating plants, these conditions are expected to result in a residual arsenic concentration of up to 1 gram-per-litre in solution. This represents a 96% conversion of arsenic to insoluble iron arsenate. Magnesium oxide has been chosen for the neutralization of excess acidity in the autoclave, which would otherwise impede the conversion of arsenic to scorodite. Hydrated lime would be a cheaper option for neutralization, but would result in problematic gypsum scaling in the autoclave and the pressure let-down equipment.

3.5 Gold Recovery

Gold would be recovered from the autoclave residue by conventional methods, involving cyanide leaching, activated carbon adsorption, and electrowinning. High recoveries of gold from autoclave products have been well demonstrated. A gold recovery of 90% was assumed for the assessment of this process.

3.6 Water Treatment

Water in the gold leaching residue stream would require treatment to detoxify cyanide before discharge to the environment, or re-use in the mining or processing operations. This could be achieved by oxidation with hydrogen peroxide in the proposed mine water treatment plant, or with sulphur dioxide in a dedicated INCO SO₂/Air treatment plant. For the purpose of this assessment, some additional consumption of hydrogen peroxide for cyanide detoxification was assumed.

An expected excess of dissolved iron in the autoclave residue would precipitate the remaining dissolved arsenic from solution in the following neutralization stages. Therefore, further treatment of process waste water for the removal of arsenic was assumed not to be required.

3.7 Con Mine Autoclave

The Con Mine, located just 7 km from the Giant Mine, currently operates an autoclave to oxidize gold bearing flotation concentrate, containing arsenopyrite and pyrite, and

to stabilize arsenic as iron-arsenates. The volume of the vessel, which was commissioned in 1992, is approximately 50 cubic metres.

The potential application of the Con Mine autoclave to the task of stabilizing the Giant Mine arsenic trioxide dust has been analysed for this assessment. The vessel volume is 42% of the volume of a new 120 m³ autoclave, which has been selected to process the entire dust inventory in 15 years. Since the vessel volume and pulp residence time are directly proportional to the feed rate of the arsenic to be stabilized, the use of the Con autoclave alone would require 36 years to process the dust inventory (15 years x $1/0.42 = 35.7$ years).

Assuming that it would be available, it would almost certainly be more costly to use the Con Mine autoclave than to construct a new autoclave of an appropriate size. Further, it seems unlikely that an arsenic trioxide management project of such duration would meet with regulator, public or corporate approval.

It may be possible to use the Con Mine autoclave in addition to a new vessel, in an effort to reduce project capital costs. The new vessel volume would be about 70 cubic metres and, operating in parallel together, the two autoclaves would provide the required capacity to process the dust inventory in 15 years. The impact of this option on the project costs is described in Section 5.1.

4. PLANT DESCRIPTION

Based on the major process variables discussed above, a conceptual plant design has been prepared. A process flow diagram for the plant is shown in Figure 1, and the plant operation is described below.

The arsenic trioxide bearing material would be received at the processing plant as a dilute slurry. Two stages of screening would separate trash (metal, wood, plastic) and rock chips from the fine material. Steel trash would be recovered with a magnetic separator, and the rock chips would be ground in a ball mill and returned to the screening circuit.

The slurry would be thickened in a conventional thickener with the aid of a chemical flocculant. Clear overflow water from the thickener would be recycled back to the mining process. The underflow pulp from the thickener would be delivered to a series of agitated tanks, providing a storage capacity equivalent to 20 days of plant feed. The

feed preparation section of the plant would operate for 35% of total time, processing material at a higher rate than the following plant circuits. This would allow the mining operation greater flexibility with respect to production schedules.

The pressure oxidation circuit would be available to operate for 85% of total time. Feed for the circuit would be drawn from the storage tanks and mixed with pyrite concentrate slurry in a feed preparation tank. A high-pressure pump would inject the arsenic trioxide and pyrite mixture into a multi-compartment autoclave. Oxygen would be generated in an adjacent plant and fed to the autoclave compartments under pressure. Water would be added to the autoclave compartments to aid in temperature control. Magnesium oxide slurry would be added to the later autoclave compartments, to neutralize acid generated by the process and maintain acidity within efficient operating limits. The autoclave product would be released from the last autoclave compartment through a pressure let-down system into a flash cooling tank, operating at atmospheric pressure.

Steam released from the flash tank would be collected in a wet scrubber, to minimize the release of arsenic bearing water vapour to the atmosphere. Contaminated scrubber water would be returned to the process.

The cooled autoclave product slurry would be delivered to a series of three thickeners, operating in counter-current decantation (CCD) mode, in which the solids are separated from the liquor, and the solids are washed to minimize acid residue. The acid liquor would be neutralized with lime in an agitated tank to form gypsum. The gypsum would be recovered from the liquor by pressure filtration and the filter cake would be transported to an on-site stabilized waste disposal facility. The clear neutralized liquor would be returned to the process, or sent to water storage facilities and eventual discharge to the environment.

The solids from the CCD circuit would be neutralized with lime in an agitated tank. Additional lime would be added to make the pulp alkaline in preparation for cyanide leaching. The solids pulp would be mixed with cyanide solution in a conditioning tank, and then fed to a series of six carbon-in-leach (CIL) agitated tanks, containing coarse granular activated carbon. Compressed air would be bubbled into the tanks to dissolve oxygen in the pulp. Gold would be leached into solution from the autoclave residue and concentrated by adsorption on the surfaces of the carbon granules. The leach pulp would be allowed to flow freely through the CIL tanks, and on to a pressure

filtration circuit. The leached autoclave residue, containing arsenic in a stable chemical form, would be filtered from the pulp and transported to the on-site stabilized waste disposal facility. The filtrate would be sent to water treatment facilities for detoxification of the contained cyanide.

Carbon would be retained in the CIL tanks by inter-tank screens. Carbon loaded with gold would be removed from the CIL circuit in batches, and gold would be stripped from the carbon in a small pressure vessel, producing a concentrated gold cyanide solution. Gold would be recovered from the stripping liquor in an electrowinning circuit. Gold deposits would be washed from the electrowinning cathodes in batches, filtered, dried, and then smelted in a refining furnace. The plant would produce gold bullion for sale.

5. ESTIMATION OF COSTS & REVENUES

5.1 Capital Costs

The capital costs for the installation of the processing plant described above, in Yellowknife, have been estimated by H.G. Engineering Limited and are presented in detail in HGE 2001. Two major variants of the plant have been assessed, including the use of a purpose-built 120 cubic metre autoclave, and the use of a new 70 cubic metre vessel in addition to the Con Mine 50 cubic metre autoclave. These capital cost estimates are considered accurate within the range of plus or minus 25%. The costs include engineering, construction management, commissioning and transportation, as well as standard contingencies.

The total capital cost of an entirely new pressure oxidation plant incorporating a 120 m³ autoclave is estimated to be \$98,467,000. These costs are summarized in Appendix A. The estimated capital cost of a plant incorporating a new 70 m³ autoclave, to be operated in parallel with the Con autoclave, and all of the ancillary equipment to operate both autoclaves, is \$83,265,000.

The capital cost estimate for the Con autoclave option applies no costs to the purchase and relocation of the autoclave. Furthermore, the complexity of operating two autoclaves of different sizes in parallel would increase annual operating costs. Therefore, the use of the Con autoclave may not result in significant economic benefits, and the construction of a single new autoclave may be preferable. This has been assumed for further assessment.

5.2 Operating Costs

The annual operating costs for this processing plant, including labour, spare parts, supplies, energy and reagents, have been estimated, amounting to a total of \$18,713,000 per year. A table summarizing annual operating costs is provided in Appendix A.

5.3 Revenues

Revenues originate from the sale of gold bullion. For the purpose of this assessment, it has been assumed that 90% of the gold contained in the plant feed would be recovered to saleable bullion. This represents some 122,500 troy ounces. At an

assumed average realized price of \$470 per ounce (about US\$300), the sale of gold would generate an estimated \$3,840,000 per year.

5.4 Cost and Revenue Summary

Estimated capital and operating costs, and estimated revenue, are summarized in Table 5.1. It is important to note that these are the costs of just one component of a complete arsenic trioxide management alternative. The costs of dust extraction, water treatment, and waste disposal, for example, are not included here. The estimated revenue must be applied against total project costs, in order to calculate net project costs.

TABLE 5.1
Cost and Revenue Summary

| | |
|---------------------------|--------------|
| Capital Cost | \$98,467,000 |
| Operating Cost (per year) | \$18,713,000 |
| Revenue (per year) | \$3,840,000 |
| Plant Operating Phase | 15 years |

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Checked by: DBM

6. ACKNOWLEDGEMENTS AND AUTHOR

The process selection and conceptual plant design presented in this report was developed by Grant Feasby, P.Eng., and Dr. Cesar (Jo) Ferron of Lakefield Research Inc., working in collaboration with SRK Consulting. Capital costs and rates of energy consumption for the conceptual plant design were estimated by Ernie Burga, P.Eng., and Daryl Purdie, P.Eng., of H.G. Engineering Limited (HGE). Operating costs were estimated by HGE and SRK.

This report, **Giant Mine – Assessment of Pressure Oxidation Process for Arsenic Stabilization and Gold Recovery**, has been prepared by:

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Stephen Schultz
Project Engineer

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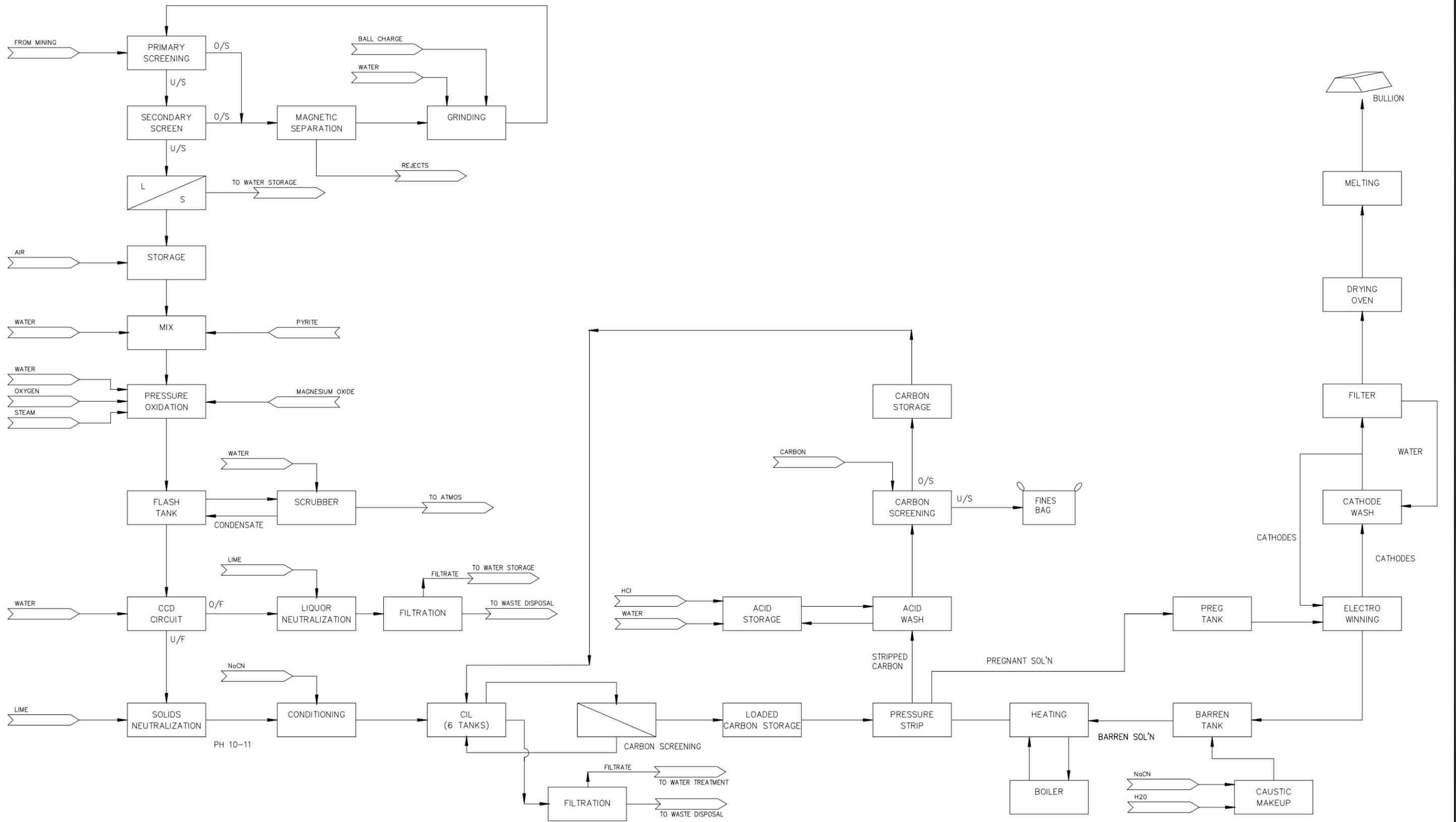
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FIGURES



Source: Arsenic Trioxide Treatment – Capital Cost Estimates,
H.G. Engineering Ltd, Revision 2, April 2001



Giant Mine – Pressure Oxidation Process

PROCESS FLOW DIAGRAM
Pressure Oxidation Process

| | | | |
|--------------------------|-------------------|----------|-------------|
| PROJECT NO. 1C1001.07 | DATE Dec. 2002 | APPROVED | FIGURE 1 |
|--------------------------|-------------------|----------|-------------|

APPENDIX A
Capital and Operating Cost Summaries

Cost Estimate Summary sorted by account code

Date 17-Apr-01
Estimate no 55901-Case 2:GOLD RE
Plant
Building

55901
Giant Mine Arsenic Trioxide Dust Management
SRK Consultants

| <u>Account Code</u> | <u>Name</u> | <u>Total price Supply</u> | <u>Total price Install</u> | <u>Total cost</u> |
|---------------------------------|-------------------------------|---------------------------|----------------------------|---------------------|
| 000 | To be assigned | \$216,600 | \$93,900 | \$310,500 |
| 100 | Concrete | \$1,279,600 | \$853,100 | \$2,132,700 |
| 300 | Process equipment | \$31,672,300 | \$4,251,100 | \$35,923,400 |
| 320 | Auxiliary equipment | \$9,727,600 | \$1,952,960 | \$11,680,560 |
| 350 | Process piping | \$2,975,577 | \$1,380,900 | \$4,356,477 |
| 400 | Steel | \$3,025,900 | \$1,433,000 | \$4,458,900 |
| 420 | Steel secondary | \$150,000 | \$100,000 | \$250,000 |
| 500 | Instrumentation | \$2,621,777 | \$1,216,000 | \$3,837,777 |
| 600 | Electrical | \$2,804,100 | \$1,201,600 | \$4,005,700 |
| 620 | Electrical power distribution | \$500,000 | \$100,000 | \$600,000 |
| 80 | Site drainage | \$60,000 | \$40,000 | \$100,000 |
| 900 | Building | \$1,952,280 | \$1,119,710 | \$3,071,990 |
| Sub - total direct costs | | \$56,985,734 | \$13,742,270 | \$70,728,004 |

Indirect Costs

| | | |
|---------------------------------------|----------------------------|---------------------|
| | Owner's costs | \$2,500,000 |
| | Consultant services | \$10,609,000 |
| | Commissioning | \$707,000 |
| | Escalation | \$3,536,400 |
| | Capital Spares | \$2,849,000 |
| | Transportation | \$2,849,000 |
| Total indirect cost | | \$23,050,400 |
| Total direct and indirect cost | | \$93,778,404 |
| Project contingencies | | \$4,688,596 |
| Total project costs | | \$98,467,000 |

| Arsenic Trioxide Dust Treatment | | | | |
|---|------------------------------------|--------------------|-------------------------------------|--------------------|
| Arsenic Stabilization & Gold Recovery by Pressure Oxidation (Blended Dust Feed, 15 Year Processing Phase) | | | By: D. Purdie (HGE) 17-Apr-01 | |
| | | | Revised: S. Schultz (SRK) 31-May-01 | |
| | | | Revised: S. Schultz (SRK) 12-Aug-02 | |
| | | | Revised: S. Schultz (SRK) 6-Dec-02 | |
| Plant Operating Cost Summary | | | | |
| Plant capacity | 50.40 dry tonnes per operating day | | | |
| Operating time | 310 days per year | | | |
| Plant Through-put | 15,624 tonnes per year of raw dust | | | |
| Gold Production | 8,170 troy ounces per year | | | |
| Revenue - Gold Sales | 470 Cdn\$/ounce | \$3,839,900 | Cdn\$/year | |
| PLANT OPERATING COST | | | Annual Cost | Cost/tonne |
| 1 OPERATING LABOUR | Number | Labour Cost | | |
| Operators (12 hr shifts) | 20 | \$85,000 | \$ 1,700,000 | \$ 108.81 |
| Supervisors | 6 | \$110,000 | \$ 660,000 | \$ 42.24 |
| Maintenance | 8 | \$105,000 | \$ 840,000 | \$ 53.76 |
| Staff (management, technical, admin) | 3 | \$110,000 | \$ 330,000 | \$ 21.12 |
| Sub-total Cost | | | Cdn \$ 3,530,000 | \$ 225.93 |
| 2 OPERATING SUPPLIES & SPARES | | | | |
| Spare parts | | | | |
| Operating supplies | | | | |
| Sub-total Cost (1% of capital cost per year) | | | Cdn \$ 985,000 | \$ 63.04 |
| 3 UTILITIES | | | | |
| Electric Power | \$ 0.120 per kWh | 20,187,659 kWh/yr | \$ 2,422,519 | \$ 155.05 |
| Sub-total Cost | | | Cdn \$ 2,422,519 | \$ 155.05 |
| 4 REAGENTS | Cost per unit | | | |
| 4.1 Grinding Balls | 1 \$/kg | 2 kg/d | \$ 625 | \$ 0.04 |
| 4.2 Quick Lime | 250 \$/tonne | 35.3 mtpd | \$ 2,736,153 | \$ 175.13 |
| 4.3 Magensium Oxide | 600 \$/tonne | 14.4 mtpd | \$ 2,671,704 | \$ 171.00 |
| 4.4 Pyrite Concentrate | 176 \$/tonne | 67.1 mtpd | \$ 3,660,016 | \$ 234.26 |
| 4.5 Oxygen (Purchased Plant) | 100 \$/tonne | 77.1 mtpd | \$ 2,390,472 | \$ 153.00 |
| 4.6 Flocculant | 2.5 \$/kg | 25 kg/d | \$ 19,651 | \$ 1.26 |
| 4.7 Sodium Cyanide | 3 \$/kg | 218 kg/d | \$ 202,482 | \$ 12.96 |
| 4.8 Activated Carbon | 1000 \$/tonne | 0.22 mtpd | \$ 67,183 | \$ 4.30 |
| 4.9 Hydrogen Peroxide (50%) | 0.9 \$/kg | 97 kg/d | \$ 27,063 | \$ 1.73 |
| Sub-total Cost | | | Cdn \$ 11,775,349 | \$ 753.67 |
| TOTAL ANNUAL OPERATING COST | | | Cdn \$ 18,712,868 | \$ 1,197.70 |

APPENDIX B
Pyrite Supply for Autoclaving Arsenic Trioxide Dust
(SRK, May 2002)

**PYRITE SUPPLY FOR AUTOCLAVING
ARSENIC TRIOXIDE DUST
GIANT MINE, NWT**

Prepared for:

DEPARTMENT OF INDIAN AFFAIRS AND NORTHERN DEVELOPMENT

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**PYRITE SUPPLY FOR AUTOCLAVING
ARSENIC TRIOXIDE DUST
GIANT MINE, NWT**

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**PYRITE SUPPLY FOR AUTOCLAVING
ARSENIC TRIOXIDE DUST
GIANT MINE, NWT**

1. BACKGROUND

The Department of Indian Affairs and Northern Development (DIAND) has commissioned a number of studies regarding remediation options for the arsenic trioxide dust stored in underground chambers at the Giant Mine in Yellowknife, NWT.

Cost estimates to a varying degree of accuracy have been carried out for the various remediation options and their individual components. DIAND is in the process of having the cost estimates for some of the options and components thereof refined in order to increase the confidence in the input to the process of finding decisions based on a number of parameters. Costs are one of the influential parameters in the decision finding process.

One of the remediation options under consideration is the extraction of the arsenic trioxide dust and the treatment thereof in an autoclave to convert the arsenic trioxide into scorodite ($\text{FeAsO}_4 \cdot 2\text{H}_2\text{O}$) and to extract gold from the residue by subsequent cyanidation.

In a study carried out by Lakefield Research in Ontario (Lakefield) pyrite has been identified as the optimum source of iron as well as of the energy (by the exothermal process of pyrite oxidation) to bring the autoclave temperature to the required process temperature of 210°C.

Lakefield also identified the Operations of Hudson Bay Mining and Smelting at Flin Flon, Manitoba, and the Nico Project of Fortune Minerals Ltd., in NWT as potential sources and provided preliminary respective cost estimates of \$ 200.00 and \$ 100.00 per tonne of pyrite concentrate f.o.b. Yellowknife .

The objective of this study is to identify additional potential and practical sources of pyrite and to provide more detailed estimates of the cost of this reagent f.o.b. Yellowknife.

2. ARSENIC STABILIZATION AND GOLD RECOVERY BY AUTOCLAVING

The process of autoclaving arsenical and refractory sulphide ores of gold is standard practice in the industry and currently applied in Canada at Miramar's Con Mine at Yellowknife, NWT, and at Placer Dome's Campbell Mine at Balmerton, Ontario. The process and its parameters are described in Supporting Document B6 of the Study of Management Alternatives Giant Mine Arsenic Trioxide Dust by SRK Consulting in co-operation with Senes Consultants Limited, HGE and Lakefield Research, dated May 2001.

Lakefield Research has provided the following selected design criteria for the process:

| | |
|--|--------------------------|
| Operating Temperature | 210 ^o C |
| Operating Pressure (gauge) | 2600 kPa |
| Mean Retention Time | 90 minutes |
| Iron Source | pyrite (80% concentrate) |
| Fe/As molar ratio | 1.1/1 |
| Maximum H ₂ SO ₄ | 50g/L |
| Neutralization agent in autoclave | MgO |
| Oxygen Utilization | 80% |
| Autoclave volume utilization | 60% (40% gas) |
| Maximum % solids in feed | 20 |
| Maximum arsenic in solution | 27g/L |

3. QUANTITIES OF PYRITE

Lakefield Research selected a 120m³ autoclave for its base case. This size of autoclave would accommodate a feed rate of 51.4 tonnes/day of blended arsenic trioxide dust (there are two distinct inventories of 59,400Tonnes @ 61.4% As₂O₃ and 179,600 tonnes @ 85.5% As₂O₃) and, operating 310 days per year, process 239,000 tonnes of blended dust over a time period of 15 years.

The resulting pyrite requirement is 68 tonnes/day of a pyrite concentrate containing 80% pyrite. This translates into an annual requirement of 24,752 or approximately 25,000 tonnes of pyrite concentrate.

4. POTENTIAL SOURCES OF PYRITE

There is only a limited number of potential sources for pyrite concentrates. A pyrite concentrate is not a normal product of a mining/milling operation and would have to be produced especially for this purpose at all sites. The following potential sources have been considered and are briefly discussed as follows:

- Flin Flon, Manitoba,
- The Nico Project of Fortune Minerals in NWT,
- The Izok Lake Project of Inmet in NWT,
- The Nicolet Project at Crandon, Wisconsin, and
- The Sudbury District, Ontario

Flin Flon, Manitoba

The operations of Hudson Bay Mining and Smelting are the only currently active operation and therefore the most realistic source at this time. It is therefore the base case for the cost estimates below.

The Nico Project of Fortune Minerals, NWT

The Nico project is an advanced exploration project 160km northwest of Yellowknife. Lakefield Research, which has done metallurgical test work on the project, names it as one of the potential sources. Fortune Minerals states that 34km of new all weather road would connect it to the former all weather road from the head of Marian Lake to the former Rayrock Mine. In this study it is considered a hypothetical source and the estimates are based on a factored cost of the pyrite concentrate f.o.b. the mine site plus

winter road trucking costs per tonne/km, comparable to those to and from the Lupin mine.

The Izok Lake Project of INMET, NWT

This project has a defined mineral inventory and has seen several feasibility studies in the past. While the project is far more advanced than the Nico project, the reality of it becoming a source of pyrite will depend on future metal prices and the outcome of a future feasibility study. Assuming the same factored costs for the pyrite concentrate f.o.b. mine site, the cost of freight at the rate of the Lupin Mine winter road rate has been added to arrive at a cost f.o.b. Yellowknife.

The Nicolet Project at Crandon, Wisconsin

While this project could well be a source of pyrite it has reached a second eight-year period of environmental permitting and is an unlikely source for the foreseeable future. It is located in the USA and, apart from the much greater distance from Yellowknife, compared to Flin Flon, it would involve the use of more than one railroad company, disproportionately escalating the cost of transport. It is not considered a realistic option.

The Sudbury District, Ontario

While pyrite and/or pyrrhotite concentrates could probably be obtained from this mining district, its distance from Yellowknife is approximately twice the distance from Flin Flon, with commensurably higher freight costs. It is not considered a viable source in this study.

5. COST ESTIMATES

5.1 Distances

The following are the distances and modes of transportation involved in the possibly viable options for sources of pyrite concentrates transported in “super bags”.

Rail:

| | |
|------------------------|----------|
| Flin Flon to Hay River | 2,480 km |
|------------------------|----------|

All Weather Highways/Roads:

| | |
|----------------------------|--------|
| Hay River to Yellowknife | 480 km |
| Enterprise to Yellowknife | 445 km |
| Yellowknife to Tibbet Lake | 70 km |
| Rae to Yellowknife | 108 km |

Winter Roads:

| | |
|--------------------------|--------|
| Nico to Rae | 96 km |
| Izok Lake to Lupin | 80 km |
| Lupin to Tibbet Lake | 567 km |
| Izok Lake to Yellowknife | 711 km |

5.2 Freight Rates and Freight Costs

Cost estimates, i.e. pro forma quotes have been received from Northwest Transport Ltd. via Nuna Logistics for a winter haul from Izok Lake to Yellowknife, including loading and unloading of “Super Bags” of 160.00 \$/tonne over the total distance of 711 km.

This translates into a rate of 0.225 \$/tonne-km for winter hauls.

A pro forma quote from the same source gave a rate of 49.00 \$/tonne including loading and unloading of “Super Bags” from Hay River to Yellowknife, or

0.102 \$/tonne-km for all-weather road hauls. This rate is in keeping with earlier estimates carried out by the author, using quotes from a different carrier but also for northern routes.

CN Rail has provided a pro forma quote of 68.45 \$/tonne for rail transport from Flin Flon, Manitoba to Hay River, NWT.

| <u>Flin Flon to Yellowknife</u> | <u>\$/tonne of py.conc.</u> |
|--------------------------------------|-----------------------------|
| Rail to Hay River | 68.45 |
| Truck to Yellowknife | 39.00 |
| <u>Super bag handling, Hay River</u> | <u>10.00</u> |
| <u>Total</u> | <u>117.45</u> |

| <u>Nico to Yellowknife (incl. loading & unloading)</u> | |
|--|-------|
| 204 km @ winter rate \$ 0.23/tkm | 46.92 |
| 204 km @ all weather \$ 0.12/tkm | 24.48 |
| 96km winter, 108km all weather | 33.10 |

| <u>Izok Lake to Yellowknife</u> | |
|---------------------------------|---------------|
| 711 km winter rate | 150.00 |
| <u>Loading and unloading</u> | <u>10.00</u> |
| <u>Total</u> | <u>160.00</u> |

5.3 Cost of Pyrite Concentrate

Hudson Bay Mining and Smelting has provided estimated capital and operating costs for producing a 80% pyrite concentrate delivered in Super Bags f.o.b. CN Rail siding in Flin Flon, Manitoba.

In the cost estimate provided by Hudson Bay Mining and Smelting, the company had to consider installing a dedicated flotation circuit with attendant thickeners, concentrate dewatering, bagging, storage and loading facility. Similar installations would have to be added to the concentrating facilities at Izok Lake and Nico, where such an operation would be associated with significantly higher capital and operating costs because of their remote northern location. While the size of the pyrite circuit would be the same at all installations, the capital and operating costs would differ, depending on the capacity of the general concentrating facility at each site, factors that are largely unknown at this time. The costs of power and labour must be expected to be higher at Izok Lake than at Nico, both of which would be higher than at Flin Flon. In the absence of a feasibility study for either Izok Lake or Nico their respective

estimated costs for pyrite concentrate has been factored from the base case provided by Hudson Bay Mining for Flin Flon.

5.3.1 Base Case, Flin Flon

Given the required parameters of 25,000 tonnes per year of an 80% pyrite concentrate, Hudson Bay Mining and Smelting has provided SRK Consulting with order of magnitude estimates of capital and operating costs for a dedicated pyrite circuit added to the existing mill at Flin Flon:

| | |
|-----------------|---|
| Capital Costs | \$ 500,000 to \$ 1,000.000 |
| Operating Costs | \$ 20 – 30 per tonne of pyrite concentrate in Super Bags f.o.b. Flin Flon |

Using the mid-range of these estimates (capital costs of \$ 750,000 and operating costs of \$ 25 per tonne of concentrate) this would translate into the following **total costs per tonne of pyrite concentrate:**

| | |
|--|---------------------------------|
| Operating costs | \$ 25.00 |
| Capital cost recovery | |
| \$ 0.75 M @ 10% over 15 years | \$ 3.94 (750,000*0.13147/25000) |
| handling, storage and loading on rail | \$ 10.00 |
| Profit 50% | \$ 19.47 |
| Total per tonne f.o.b Flin Flon | \$ 58.41 |

5.3.2 Nico and Izok Lake

Given that the two projects are not yet in operation, the costs estimates for pyrite concentrate f.o.b. these two sites must be considered to be somewhat speculative.

Capital costs for the additional circuits at these two sites will definitely be higher than in Flin Flon, but will also depend on the respective capacities of the contemplated mills. For the purpose of this study a capital cost of \$ 1,000.000 has been assumed for these two sites.

The operating costs will be higher due to the higher costs of, predominantly, power, consumables, reagents and - due to automation to a lesser degree - labour. For the dedicated circuit, there may be no benefit of scale from the larger capacity of one or

the other facility. Power costs are also more specific to the tonne of product than the daily capacity. Typically they constitute 28% of total processing costs at operations like Polaris and Nanisivik, versus 12% at Ruttan (north of Flin Flon).

The labour components vary from 13.8% at Polaris (modern mill?) to 20.7% at Nanisivik and 23% at Ruttan, in spite of the much higher daily capacity at Ruttan (5800tpd versus 2850tpd and 2150tpd respectively for Polaris and Nanisivik).

Given that new mills in the north will be highly automated, the difference in operating costs will therefore largely be a function of the higher costs of power, consumables and reagents. On site Diesel generated power at Nico and Izok Lake will be 2.5 to 3 times as costly as power taken from a provincial grid. Therefore, if approximately 12% of the costs at Flin Flon ($25 \times 0.12 = 3.00$ \$/tonne of pyrite concentrate) are power costs, approximately 8-10 \$/tonne of pyrite concentrate should be added to the base costs of \$ 25.00/ tonne at Flin Flon, to account for the higher costs of power, consumables and reagents at Nico and Izok Lake.

The costs per tonne of pyrite concentrate f.o.b Nico and Izok Lake are therefore estimated to be:

| | |
|------------------------------|-----------------------------------|
| Operating costs | \$ 35.00 |
| Capital cost recovery | |
| \$ 1.0 M @ 10% over 15 years | \$ 5.26 (1,000.000*0.13147/25000) |
| handling, storage | \$ 10.00 |
| <u>Profit 50%</u> | <u>\$ 25.13</u> |

Total per tonne f.o.b Nico & Izok L. \$ 75.39

5.4 Total Costs of Pyrite Concentrate f.o.b. Yellowknife

| Ex Flin Flon | \$/tonne of py. conc. |
|---|------------------------------|
| Pyrite Concentrate | 58.41 |
| Freight, rail | 68.45 |
| <u>Freight, truck, handling Hay River</u> | <u>49.00</u> |
| Total ex Flin Flon, rounded | 176.00 |

| Ex Nico | \$/tonne of py. conc. |
|--|------------------------------|
| Pyrite Concentrate (incl.handling & storage) | 75.39 |
| <u>Freight (winter road haul)</u> | <u>44.96</u> |
| Total ex Nico rounded | 120.00 |

Ex Izok Lake \$/tonne of py. conc.

| | |
|---|---------------|
| Pyrite Concentrate (incl. handling & storage) | 75.39 |
| <u>Freight</u> | <u>160.00</u> |
| Total ex Izok Lake rounded | 235.00 |

The estimated costs per tonne of pyrite concentrate f.o.b. Yellowknife are 12% lower than the Lakefield estimate for Flin Flon (\$ 200.00) and 20% higher for Nico (\$110.00) as the sources.

This report, **1CI001.07.421 - Pyrite Supply for Autoclaving Arsenic Trioxide Dust** has been prepared by:

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