DEPARTMENT OF INDIAN AFFAIRS AND NORTHERN DEVELOPMENT

GIANT MINE ARSENIC TRIOXIDE TECHNICAL WORKSHOP

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Evaluation of Two Pyrometallurgical/Selective Sublimation Technologies for Processing Crude Baghouse Dust at Giant to Recover Gold Values and Produce a Marketable Arsenic Trioxide Product:

- **WAROX Process**
- **El Indio Process**

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Table of Contents

i. Executive summary

Two pyrometallurgical, selective sublimation technologies have been subjected to a conceptual level evaluation as optional methods of treating crude baghouse dust produced and stored at the Giant Mine, namely:

- ✓ ***WAROX Process*; and**
- ✓ **Process developed and implemented at El Indio, hereafter referred to as the *El Indio Process.***

Both processes have been developed for the purpose of recovering contained metal values and producing a marketable arsenic trioxide product from baghouse dust. The El Indio Process has the advantage of full-scale operating experience while the WAROX Process has been tested only under pilot plant conditions. The applicability of the El Indio Process has not been tested on Giant's baghouse dust while the WAROX Process was developed on the basis of Giant's material. The fundamental difference in the flow sheets for the two processes is the manner in which fine dust in the fume reactor off-gas train is captured. The WAROX Process employs novel hot metal filtration technology and the El Indio Process employs a hot electrostatic precipitator (ESP) for equivalent purposes. The characteristics of the crude baghouse dust at Giant, expected to be significantly different in composition and more importantly in particle size distribution than the product generated at El Indio, could favour one dust collection technology over another.

The relative efficiencies of a metal filter baghouse versus an ESP in capturing the very fine non-volatile (under fume reactor conditions) component of Giant's baghouse dust determine the quality of the final arsenic product. Any portion that is not captured reports to the cold baghouse and becomes incorporated as impurities in the final arsenic trioxide product. Meeting antimony targets in the final product is expected to present technical challenges to any processing technology, given that antimony oxides are associated with the very fine fractions of Giant's crude baghouse dust. Based on pilot plant data, the hot metal filter technology employed by the WAROX Process achieved the processing target (0.2%) set for antimony during pilot plant trials. Equivalent information is not available for ESPs although the existing Cottrells at Giant, which represent out-dated ESP technology, do not consistently achieve this target under current roaster operations.

To compare the performance of the two technologies in processing Giant's baghouse dust and achieving desired objectives, much more information is required. To complete the conceptual evaluation of the two technologies, the following information is necessary:

- **Preliminary assessment by ESP suppliers, based on particle size distribution data for Giant's dust, as to the efficiencies of a hot ESP in capturing the non-volatile fine particulates present in the off-gas train of a fume reactor treating Giant's crude baghouse dust. TEMAC, the supplier of the ESP at El Indio, has conducted such an assessment and on this basis projects a 99% collection efficiency, similar to the metal filter baghouse.**
- **Resistivity tests and trials conducted by ESP suppliers, based on samples of Giant's dust, to refine the preliminary assessment (above).**
- **Comparative material balances based on information provided by El Indio and ESP suppliers (assessments described above) with respect to the El Indio Process and on information generated by pilot plant trials in case of the WAROX Process.**
- **Comparative evaluations/projections of arsenic trioxide quality based on these material balances (above).**

Executive summary ....

The processing technologies under evaluation provide a means for reducing environmental liabilities associated with arsenic-rich dust inventories at Giant and recovering the costs of implementation through recuperation of gold values and sale of refined arsenic trioxide. However, both processing options would produce solid and aqueous waste streams requiring treatment prior to storage or discharge and both would generate fugitive (in-plant) and stack (atmospheric) emissions. Stack losses for a processing plant employing the WAROX or El Indio Process is estimated to be 0.002% of throughput. Arsenic emission levels from a 10 short tons/hour dust processing plant employing the WAROX Process are expected to be in the order of 0.097 mg As/m^3 (B. Cross, 1999). Current emission levels at Giant, based on 1998 stack test results, are about 3.0 mg As/m^3, without a wet scrubber (K. Morton, 1999). Assuming a 98% capture efficiency for a wet scrubber, Giant's stack emissions would be expected to decline to about 0.06 mg As/m^3 through the addition a wet scrubber. The estimated arsenic emission level for a plant designed to treat Giant's baghouse dust (0.097 mg As/m^3) is lower than existing Arsenic Release Standards in BC (Canada), USA and France, which range from 0.1 mg/m^3 to 11.6 mg/m^3 (Environment Canada *et al,* 1997). There are no federal standards in Canada for atmospheric arsenic releases.

Should this type of waste management option be favoured over others under consideration by DIAND for management of baghouse dust stored and produced at Giant, more detailed investigations would be required as follow-up to this study. These future investigations would determine the economic and technical feasibility of reclaiming and processing current and future baghouse production at Giant through the WAROX or El Indio processes (or combination of the two). Decisions to reclaim and process Giant's baghouse dust would obviously be determined by many factors aside from technical and economic feasibility, including regulatory, socio-economic and political factors and cost-benefits of this option relative to others under consideration.

The results of the current study, while conceptual in nature, suggest that both processing technologies are technically feasible and applicable to Giant.

ii. Introduction

The Giant Yellowknife Mine, "Giant", a gold mine located near Yellowknife, Northwest Territories, Canada, has been in operation since 1947. Due to the refractory nature of the gold-bearing arsenical ores at Giant, concentrates from the milling process are pre-treated pyrometallurgically to achieve economic gold recovery through conventional cyanidation circuits. This pre-treatment involves a high temperature roasting operation, volatilizing, condensing and capturing arsenic and other minor constituents of roaster off-gas trains in baghouses as a fine dust. This arsenic-rich "baghouse dust" is conveyed to specially prepared underground chambers, or modified stopes, for storage. During the period 1981 to 1986, 6,700 tons of baghouse dust produced by Giant was sold, shipped in bulk by truck. The composition of baghouse dust stored in the underground mine at Giant differs from one storage chamber to another due to variations in ore and operating practices and efficiencies of the roaster and gas-cleaning operation over the operating life of the mine.

The volume of baghouse dust currently stored at Giant is about 265,000 short tons with an average As_2O_3 grade of 79%. Aside from arsenic, other components of the dust include iron oxides, silicates, antimony oxides and gold. Average gold content of the dust is estimated to be in the order of 0.5 oz/ton (K. Morton, 1999).

The most recent owner of Giant, Royal Oak Mines (ROM), is under receivership. The Department of Indian Affairs and Northern Development (DIAND) is interested in developing an action plan for the closure of the site in accordance with Canadian regulatory criteria and standards. In the context of this interest, DIAND is soliciting the assistance of consultants and practitioners in the evaluation of different clean-up and waste management options applicable to Giant. One option being considered in relation to baghouse dust stored underground at Giant involves the recuperation of this stored material, upgrading of its arsenic trioxide content through reprocessing and selling of the purified product to wood preservative manufacturers. In addition to the sale of refined arsenic trioxide, this type of option permits recovery of gold from the dust, estimated to be in the order of 138,000 ounces in total. Revenues from gold and arsenic trioxide sales could be applied towards the capital and operating costs of the clean-up operation.

This report has been prepared in accordance with the objectives of DIAND in evaluating the option of recovering arsenic-rich baghouse dust from storage stopes at Giant for the purpose of recuperating gold values and selling refined arsenic trioxide product through the reprocessing of this material. Two pyrometallurgical processing technologies are considered under this option:

- ✓ **WAROX Process; and**
- ✓ **Process developed and implemented at El Indio (El Indio Process).**

Due to the proprietary nature and status of applications for patents, this evaluation has been limited to the degree of information made available to DIAND. Given these limitations, the comparative assessment of the two processes had been confined to a conceptual level. The results of this preliminary study provide a framework upon which to evaluate the technical feasibility of this form of waste management strategy in relation to others under consideration by DIAND.

iii. Background conditions at Giant

Giant is located just north of Yellowknife, Northwest Territories, Canada. Giant Yellowknife Mine was incorporated in 1937. The mine was developed between 1945 and 1947 with the first gold brick poured in 1948. Ownership of Giant has changed hands several times over the last fifty years of operation. The most recent owner, Royal Oak Mines (ROM), is under receivership.

The ore at Giant is refractory with a significant portion of the gold locked up in arsenical minerals and not amenable to conventional cyanide leaching. To liberate gold and remove arsenic, roasting was introduced at Giant in 1949, originally employing an Edwards-type hearth roaster, replaced in 1952 by a two-stage slurry roaster and in 1958 by a larger two-stage fluidized bed slurry roaster.

A cold electrostatic precipitator (Cottrell) was installed in 1951 to capture a portion of the arsenic released to the atmosphere from roaster operations. In 1955, a hot Cottrell ESP was installed in parallel to the cold ESP, reducing arsenic releases to an estimated 2,900 kg/day. A Dracco baghouse was introduced in 1958, further reducing arsenic losses to levels of about 100 to 900 kg/day. In 1962, the cold Cottrell was converted to a hot ESP. No further changes have been made to the gas cleaning train since 1962 other than improvements to operating practices. Current atmospheric arsenic emissions, based on stack tests conducted in 1998, are about 3.0 mg/m3 (K. Morton, 1999).

Ore is crushed underground at Giant and hoisted as well as truck-hauled to surface through several underground ramp systems. Ore is further crushed and screened through a three-stage crushing plant comprising two parallel primary grinding lines each consisting of ball mills and spiral classifiers. Water is added at the feed end of ball mills. Spiral classifiers are used to screen the ground ore into coarse and fine fractions, with coarse fractions being returned to the grinding circuit. The screened classifier overflow is subjected to a two-stage flotation circuit, comprising a rougher circuit and a scavenger circuit. Flotation of sulfide minerals is achieved through addition of copper sulfate to coat the minerals, a flotation collector agent (xanthate), air and a frothing agent (Dowfroth). The sulfide mineral-rich froth is skimmed from the surface of flotation cells into a concentrate launder. Flotation concentrates from the rougher and scavenger circuits are combined, thickened and sprayed into the first stage of the two-stage roaster. Roaster calcines are water quenched and submitted to a regrind circuit. The washed calcines are neutralized to a pH of 11, using lime, prior to being subjected to a two-stage cyanide leach circuit. Leached calcine residues are rejected to the tailings impoundment area. Pregnant solution from cyanide circuits is deoxygenated in a Merrill Crowe tower, prior to addition of zinc dust for precipitation of gold. Gold-bearing zinc dust is collected through a filter press with filtrate or barren solution being recycled through the circuit and the filtered dust melted to form a gold dore bullion.

Arsenopyrite, one of the principal gold-bearing sulfide minerals in Giant's ore, is decomposed at and arsenic is volatilized at roasting temperatures of about 500° C. Off-gas trains from the roasters are combined, passed through cyclones to recover coarse particulates and then passed to a hot ESP, operated at 315° C, to capture the fine dust fraction or non-volatile component of the roaster feed. This hot ESP is a Type K, rod curtain collector, or *Cottrell.* Dust collected by the ESP is conveyed to cyanidation circuits for gold recovery. Off-gas from the ESP is air quenched to a gas temperature of between 105° C and 110° C to obtain arsenic concentrations in the vapour phase between 10 mg/m^3 and 15 mg/m^3. Desublimed arsenic is collected in a Dracco acrylic filter baghouse as As_2O_3. Baghouse dust is conveyed to underground storage chambers or specially prepared stopes. The filtered gas is drawn through a variable speed fan and discharged to the atmosphere via a 2.7 m diameter by 45.7 m high acid brick stack (WR Hatch Engineering, 1996).

Background conditions at Giant...

There are fifteen underground storage chambers at Giant. As of the end of 1998, an estimated 258,286 tons of baghouse dust had been stored underground with 300 tons accumulating monthly since then (K. Morton, 1999). The characteristics and composition of this material varies from one chamber to another in relation to the operating practices and efficiencies at the time individual chambers were in operation. Further, some older storage stopes have been re-opened to receive product from more recent operations.

In general, the efficiencies of the roaster and off-gas cleaning system at Giant have improved over the life of the mine resulting in correspondingly higher arsenic trioxide content of baghouse dust over time. As a result, higher gold values and lower arsenic trioxide content are expected in chambers storing materials collected during early mine operations and less gold and higher arsenic content in more recently stored dusts.

The principal impurities in Giant's baghouse dust, comprising about 20% of overall composition, are iron oxides, silicates and antimony oxides as well as gold. The moisture content of stored material ranges from about 1% to 6%. The *in situ* density of the material varies between 650 kg/m^3 and 1750 kg/m^3 and the angle of repose from 46° to 55° (K. Morton, 1999). These variations in composition, characteristics and conditions of storage will govern the applicability and anticipated effectiveness of different reclaim and processing technologies currently under consideration by DIAND as part of potential clean-up and closure scenarios.

The gold content in one of the older storage chambers is reported to be over 2 oz/ton in comparison to recent production in which the gold content of baghouse dust is in the order of 0.16 oz/ton. The arsenic trioxide content of baghouse dust from this same stope is reported to be 48% while recent production reportedly achieved levels in the order of 88%. The average gold content of stored material is expected to be 0.5 oz/ton and the average arsenic trioxide content 79%.

While the underground chambers were designed to facilitate extraction of the stored material, if warranted by economic conditions, five of the fifteen were former production stopes and are very irregular in shape, presenting technical challenges to a reclaim operation. All other underground chambers were constructed specifically for storage of baghouse dust and are more regular in shape. Giant has grouped the storage chambers by location according to a logical reclaim sequence, Group 1 comprising 5 of the chambers with the highest gold concentrations in stored material.

The recovery of materials stored underground at Giant is expected to include vacuum extraction of relatively dry and mechanical removal of wetter materials. Recovered materials would be stored on surface in a storage bin, wet material being dried prior to being stored. Final cleanup of storage stopes would require an additional step, either to extract remaining product with water or to stabilize the residual material in situ. Storage and treatment of contaminated water from reclaim operations could impact the operation of both the tailings pond and effluent treatment plant at Giant. As a result, extraction methods using water should be limited to the greatest extent possible.

The necessity to dry the material from underground and the humidity level targeted in a drying step would be determined by the impact of moisture content on energy consumption during processing. Screening would probably be required for all material recovered from the underground mine, to remove debris and rock fragments entrained during the recovery process. Product handling methods would be refined in development of an appropriate extraction process.

As the reclaim operation would be a common element of any reprocessing technology, the current study will not include an evaluation of this element of the operation.

iv. Pyrometallurgical upgrading of As_2O_3: state-of the art

Pyrometallurgical methods for obtaining relatively pure arsenic and antimony oxide products from impure feed materials, such as baghouse dusts, have been known for many years although few are in current practice due to the substitution of roasters by pressure oxidation (autoclave) technology in the pre-treatment of arsenical ores. Methods for achieving high-grade arsenic trioxide from impure baghouse dusts involve either selective sublimation or selective condensation of arsenic trioxide. As the two technologies under consideration in this evaluation both use selective sublimation, selective condensation methods will not be discussed.

The selective sublimation of arsenic and antimony oxides from impure baghouse dusts based on fuming technology was first applied more than two decades ago. About 25 years ago, Consolidated Murchison separated arsenic and antimony trioxides through use of a mixed roaster-fume reactor and through selective sublimation of respective products and recovery via an electrostatic precipitator in the case of antimony trioxide and an electrostatic precipitator-baghouse combination for arsenic trioxide (Pers. commun., JWR Fox, 1999). In this plant, temperature control was achieved through air quenching after some initial heat recovery above the sublimation points of both arsenic and antimony. Under this type of system, temperature control was required to avoid dewpoint problems related to SO_2 (corrosiveness of condensate, H_2SO_4) as the feed consisted of baghouse dust as well as a mixed sulfide concentrate. While maintaining the temperature of baghouses above the dewpoint of SO_2 is important under conventional roasting, this is much less of a problem under fuming conditions due to the virtual absence of sulfides in the feed (baghouse dust). Through control of temperature and percent oxygen in the gas phase, arsenic is volatilized while the sublimation of less volatile components of the feed dust, commonly antimony and mixed antimony-arsenic oxides, is suppressed.

The vapour forms of antimony and arsenic oxides are Sb_4O_6 and As_4O_6, however mixed oxides such as As_3SbO_6, $As_2Sb_2O_6$ and $AsSb_3O_6$ can also exist in vapour phases (JH Norman and GH Staley, 1964). Under high temperature and oxidizing conditions, arsenious oxide, As_4O_6, forms in the vapour phase and can proceed to As_2O_5, under high oxygen potentials. The pentoxide arsenic form can react with hematite to form ferric arsenate, $FeAsO_4$ (GA Brooks *et al*, 1994). Under conventional roasting conditions, in which sulfide concentrates provide the charge, these iron products can coat the sulfide particles, reduce their porosity and depress the gold recovery efficiencies achieved on roaster calcines through cyanidation. Temperatures of over 900° C are required to decompose ferric arsenates but these high temperatures can result in sintering of low melting point iron compounds, further hindering gold recovery (HJ Wouterlood *et al*, 1979). Formation of iron arsenates is less of a threat under fuming conditions due to the much lower iron content of the feed (baghouse dust versus sulfide concentrates) and to the moderate temperature and oxygen potentials employed relative to conventional roasting.

The following is a brief discussion of the generic components of a fuming system used to recover gold values from and upgrade the arsenic trioxide of crude baghouse dust consistent with market criteria. The two processing options under consideration have incorporated these types of components into their respective flow sheets:

- ✓ **Fume Reactor Feed (crude baghouse dust);**
- ✓ **Fume Reactor (sublimation of As_2O_3);**
- ✓ **Hot Calcine Catch (coarse particulate fraction);**
- ✓ **Hot Particulate Catch (fine particulate fraction);**
- ✓ **Primary As_2O_3 Catch (cold baghouse); and**
- ✓ **Secondary As_2O_3 Catch (gas scrubber).**

Pyrometallurgical upgrading of As_2O_3: state-of the art...

iv.1 Fume reactor feed (crude baghouse dust)

Feed to the fume reactor is typically crude baghouse dust, varying in chemical and physical characteristics from one roaster operation to another. Based on the data available on baghouse dust produced and stored at Giant, arsenic trioxide content varies from about 50% to over 80%, with total antimony levels reaching 3%, total iron 5% and levels of *insolubles* (refractory materials) reach 10% of overall composition in some of the older storage chambers. Humidity levels range from 1% to 6% in materials stored at Giant and, therefore, wetter materials would have to be dried prior to being fed to the fume reactor to minimize energy consumption (energy consumed through the evaporation of contained water) during the fuming process. Particle size and heat transfer characteristics of the feed dust governs the volatilization kinetics, residence time and throughput rates for fuming.

iv.2 Fume reactor (sublimation of As_2O_3)

Fuming technology involves the treatment of oxide materials, such as baghouse dust, through a converted roaster or specially designed fluid bed reactor, in either case heated externally typically through fuel-fired burners. Fuming requires externally supplied heating in contrast to autogenous roasting which relies to a greater extent on exothermic reactions, specifically the oxidation of sulfur in sulfide concentrates, to fuel the reactor. Oxygen partial pressure conditions in the reactor, controlled by the amount of excess air introduced with combustion gases, influence the rates and conditions of volatilization. The vapour pressure–temperature relationship for As_4O_6 has been studied by others. For temperatures greater than 180° C, the following vapour pressure relationship is reported (Handbook of Chemistry and Physics, 50th Edition):

$$\text{Log P } As_4O_6 \text{ (atm)} = \frac{5815.8}{T(K)} + 12.127$$

Optimally, gas-to-solid ratios achieve saturation of As_4O_6 in the vapour phase. Arsenic present in baghouse dust is volatilized in the fume reactor under controlled oxygen potentials and temperature conditions (400° C to 500° C) while the sublimation of antimony is suppressed. The sublimation process is greatly accelerated when dust particles are *fluidized*. Partial fluidization can be achieved by injecting baghouse dusts in a well-dispersed manner above the location of burners such that the up-casting of combustion gases within the roaster fluidizes finer particulates. The performance of the fume reactor is further controlled by feed characteristics (such as % humidity, levels and nature of impurities and particle size and specific densities ranges), bed height, fluidizing airflow, bed diameter, freeboard diameter, overall height and by percent oxygen and temperature conditions. These conditions factor into throughput rates, sublimation rates and efficiencies and the partial pressure of arsenic vapour (As_4O_6) in the reactor off-gas train.

The underflow of the fume reactor, or hot calcine bleed stream, is combined with calcines captured by cyclones (below) and returned to the fume reactor or subjected to cyanidation for gold recovery.

iv.3 Hot calcine catch (hot cyclones)

Coarse particulates, or hot fume reactor calcines, containing partially reacted or unaltered particles (as well as sand grains if sand is employed to control the fluidized bed), are normally captured from the fume reactor off-gas train through a series of cyclones. This combined stream is returned to the reactor or combined with the fuming reactor underflow and submitted to cyanidation for gold recovery.

Pyrometallurgical upgrading of baghouse dusts: state-of the art ....

iv.4 Hot particulate catch (ESP versus mechanical filtration)

The off-gas train from the fume reactor following the cyclones is passed to systems for capture of the non-volatile component or fine dust fraction of the off-gas train, typically employing hot electrostatic dust precipitators (ESPs) or potentially mechanical filtration systems (hot baghouses). These systems must operate:

1) Above the dewpoint of arsenic trioxide to avoid contamination of this fine particulate phase and diminished gold recovery through cyanidation; and
2) Within allowable temperature ranges and pressure differentials of the equipment employed.

Electrostatic Precipitator

The gases from the cyclones are combined and air quenched to achieve a gas temperature of about 350° C upon entry to the hot ESP. Newer models comprise of different numbers of compartments and are typically double-walled with electrically heated air circulated through the outer shell to maintain the wall temperature above the dewpoint of As_2O_3. The ESP used at El Indio has 3 compartments. Based on a preliminary assessment of data provided on the dust at Giant, TEMAC, the supplier of the ESP at El Indio, expects that a 4-chamber ESP would be required at Giant to achieve a 99% fine dust collection efficiency (TEMAC, 1999).

Arsenic present in ESP dust is normally in the form of As_2O_5 or iron arsenate with very little present as As_2O_3 (PM Ferreira *et al*, 1989). The ESPs currently used at Giant do not have many of the features described above, such as double walls with circulating heat to prevent condensation of As_2O_3. As a result, a relatively high proportion of soluble arsenic reports to the gold recovery circuits at Giant and dust which should be captured by the ESP is passed on to the cold baghouse, raising impurity levels in the As_2O_3 condensate and contributing to gold losses.

Hot Metal Filter Baghouse

Sintered metal filters can be operated at the same temperature as off-gases from the fume reactor, without the need for cooling. The booster fan operated at the outlet of the hot filter must be capable of operating at a draft of up to 60" wg (water gauge). The fan simultaneously draws gas through the filters and quench air from the outside. The gas and air are mixed ahead of the fan to achieve a gas temperature of between 105° C and 110° C to maximize desublimation of arsenic in the cold baghouse (K. Morton, 1999).

Gas flows to the hot ESP are higher than to the metal filter baghouse due to the necessity for air quenching. The differential pressure associated with ESPs is typically 1.5" to 3" wg across the outlet louvers and 2" wg across the plenum diffuser, or about 5" overall, compared to 15" to 60" wg for sintered metal filters (K. Morton, 1999). Differential pressures reach the higher end of this range for metal filters during the processing of feeds with high (3%) antimony levels. In their favour, metal filters do not require the same temperature controls as the hot ESP, can be operated at higher temperatures and without insulation systems to control temperature differentials. Due to the reduced airflow (less dilution due to cooling), a metal filter baghouse would occupy about 10% of the area of an ESP.

The composition of dusts captured by hot metal filters or a hot ESP is expected to be similar although the collection efficiencies for different particle size ranges may differ. Depending on design specifications, electrostatic dust precipitators can collect 700 kg/hour. Metal filters are custom-built for each application, adjusting the number of filters to meet collection rate requirements. A solids loading rate of 1.6 kg of solids per m^3 of gas is achievable according to the design specifications for metal filters, although these kind of rates would not be approached under proposed applications at Giant (K. Morton, 1999). Actual dust collection rates depend on reactor throughput, residence time and levels of impurities associated with the feed (baghouse dust).

Pyrometallurgical upgrading of baghouse dusts: state-of the art ....

Hot particulate catch – ESPs versus sintered metal filters .....

Through operation of the particulate capture systems above the dewpoint of As_2O_3, gold-containing dusts can be recovered without significant condensation or contamination of arsenic. The collection efficiency of a 4-chamber hot ESP, based on the characteristics of Giant's baghouse dust, is expected to be 99% (TEMAC, 1999). Results from pilot plant tests conducted on the WAROX Process also achieved a 99% collection efficiency using a sintered metal filter baghouse. Dusts collected by ESPs or metal filters would be conveyed to storage bins supplying feed to cyanidation circuits for gold recovery. The gold collection efficiencies for ESPs and metal filters should be in the same range and greater than 95%. While the best gold recovery rates for dusts collected by current ESPs (Cottrells) at Giant are only about 88%, rates of almost 95% were achieved by hot metal filters during pilot plant trials.

IV.5 Primary As_2O_3 catch (cold baghouse)

Off-gases from the hot ESP or sintered metal filter baghouse are cooled by air quenching to achieve gas temperatures of between 105° C and 110° C, permitting the condensation of arsenic in the cold baghouse. Airflow to the baghouse is 4 to 5 times greater than to the hot ESP, as a result of air quenching (Southern Research Institute, 1980). ESPs are not generally appropriate for collection of As_2O_3 due to high mass loading and very fine particulate size distribution, requiring high currents (ion densities) to achieve high particulate number density (Southern Research Institute, 1980).

The condensed As_2O_3 product is typically collected in a multi-chambered baghouse with several hundred bags per chamber. These bags are usually made of acrylic material, 5 to 10 feet in length, 4 to 6 inches in diameter and arranged in rows. Air-to-cloth ratios are typically in the range of 2 $ft^3/min/ft^2$. Baghouses used for these purposes are of a pulsing or shaking type, divided into modules with sequential filter-and-shake or pulse cycles to discharge filtered arsenic trioxide from the filter tubes into the screw feeders below (USA-EPA, 1979).

Collection efficiencies for As_2O_3 through a cloth filter baghouse are generally above 99%. The volatile arsenic component remaining in the vapour phase at the baghouse outlet is monitored through partial pressure measurements. The maintenance schedule for a cold baghouse is determined by the life of the cloth bags, which is about two years (K. Morton, 1999). Appropriate maintenance of filter bags is a critical to the performance of the baghouse and control of atmospheric arsenic emissions (stack losses).

IV.6 Secondary As_2O_3 Catch (gas scrubber)

A gas washing system is often required as a final gas cleaning step to meet air emission targets for arsenic. Current stack emissions at Giant, without a wet scrubber, are about 3.0 mg/m^3 (K. Morton, 1999). While there are no federal standards in Canada for atmospheric arsenic emissions, Arsenic Release Standards set in BC (Canada), USA and France range from 0.7 to 11.6 mg/m^3. Assuming a 98% capture efficiency for a wet scrubber, stack emissions at Giant would be expected to decline to about 0.06 mg As/m^3 through addition of a wet scrubber.

Wet scrubbers comprise a collection chamber with water introduced through high intensity sprays. Scrubbing cools the gas and allows arsenic to precipitate and collect on fine water droplets. Compressed air is used to achieve water atomization. The discharges from the scrubber are filtered or thickened to achieve solid-liquid separation. Solids are stabilized and stored on site. Liquid effluent is treated to precipitate arsenic as ferric arsenate. Water treatment sludge and treated solids are managed and disposed of in accordance with chemical stability characteristics, water licences and regulatory guidelines. Alternatively, effluent could be treated through a small condenser-crystallizer circuit to recover contained As_2O_3 values. Wet solids could potentially be dried and mixed with baghouse product or recycled back to the fume reactor.

Pyrometallurgical upgrading of baghouse dusts: state-of the art ....

iv.7 Emissions and waste handling, health and safety considerations

IV.7.1 Uncaptured arsenic – stack emissions

The overall arsenic collection efficiency of off-gas cleaning systems, including the capture of the non-volatile dust fraction (metal filter baghouse or ESP), and the vapour phase (baghouse and scrubber), is typically over 98% and often as high as 99.9%. Final stack emissions reflect the combined collection efficiency of the gas cleaning system employed. Particulate fractions not captured by a hot ESP or metal filter baghouse (in either case, achieving 99% collection efficiency) are captured in the cold cloth filter baghouse (over 99% collection efficiency). The wet scrubber (98% collection efficiency) captures arsenic vapour remaining in the off-gas train from the cold baghouse. Arsenic released in stack emissions represents the fraction of arsenic vapour present in the cold baghouse off-gas train not collected by the wet scrubber.

iv.7.2 Uncaptured arsenic – in-plant fugitive gas emissions

Fugitive emissions are typically captured through in-plant ventilation systems and/or exhaust hoods over unit operations. In the case of Giant, an in-plant ventilation system would generate significant energy costs during winter operations due to the make-up heat requirements.

iv.7.3 Uncaptured arsenic – in-plant fugitive particulate emissions

Mobile truck-mounted and/or fixed in-plant vacuum recovery systems are often employed for cleaning up spills and for general housecleaning purposes. These kinds of systems are used to recover dust accumulating during maintenance operations or within packaging areas of the plant. El Indio uses a "Guzzler" vacuum truck to clean-up spills during transfer or packaging of product and a stationary in-plant vacuum system for general housecleaning. Giant employs an in-plant vacuum system ("Hy-Vac") and a mobile vacuum truck for equivalent purposes.

iv.7.4 Waste handling and treatment considerations

The principal waste handling and treatment requirements would be associated with the wet scrubber. Recovery methods employing water for recuperating materials from underground stopes should be minimized to limit water treatment requirements and the potential risk of exceeding the capacity of existing water treatment plant operations at Giant. Contaminated water from the wet scrubber operation would be treated through Giant´s water treatment plant and solids would be physically/chemically stabilized prior to storage or dried and mixed with cold baghouse product. Alternatively, As_2O_3 values could be recovered through a small condenser-crystallizer circuit.

iv.7.5 Health, safety and industrial hygiene considerations

Any processing facility that handles, treats or processes arsenical oxide wastes or discharges arsenical oxides in gaseous, particulate or aqueous waste streams creates potential environmental and human health risks. Exposure to gaseous emissions of arsenic presents the greatest health risks to workers due to the high (100%) bioavailability of arsenic in gaseous phases. Particulate emissions of arsenical oxides also present health risks to workers, albiet lower due to the generally lower bioavailability of particulate (typically in the range of 50% to 75%) relative to gas phases. Risks of exposure due to contact or ingestion of arsenic-contaminated solutions are significantly lower, controlled through education and training programs for workers, protective equipment and clothing, standardized operating practices and engineering controls. Control of exposure by inhalation requires a plant-specific industrial hygiene program, mandatory respiratory protection, first aid and trained medical staff on site with ongoing exposure monitoring programs and dedicated analytical facilities. The existing programs and facilities at Giant would be evaluated and adjusted, as required, to control and monitor potential risks.

v. Criteria for evaluating two technologies

The object of the assessment is to determine the overall applicability of the two technologies under consideration with respect to conditions prevailing at Giant for the purpose of producing a saleable arsenic trioxide product and recovering gold values from crude baghouse dust. Given the conceptual nature of the assessment, the criteria used for comparative assessment of the technologies must also be conceptual. The criteria developed for the assessment include:

1) *Extent to which technology has been tested and demonstrated;*
2) *Restrictive ranges on feed quality and characteristics;*
3) *Applicability/consistency of fume technology with feed characteristics expected at Giant;*
4) *Daily, monthly or annual throughput capacity based on a single fume reactor;*
5) *Maintenance requirements for fume reactor;*
6) *Consistency of fume reactor design with existing roasters at Giant (requirements for retrofitting versus replacement);*
7) *Applicability of off-gas dust collection systems with existing equipment at Giant (Cottrells);*
8) *Dust collection efficiencies (sintered metal filters versus ESP);*
9) *Dust collection capacities for sintered metal filters versus ESP;*
10) *Maintenance requirements for dust collection systems (metal filters versus ESP);*
11) *Gold recovery efficiencies for dust captured by metal filters or by ESP;*
12) *Gold recovery efficiencies for calcines;*
13) *Efficiency of cold baghouse;*
14) *Applicability of arsenic dust collection system with existing equipment at Giant;*
15) *Maintenance requirements for cloth filter baghouse;*
16) *Efficiency of wet scrubber systems;*
17) *Consistency of wet scrubber design with existing equipment at Giant;*
18) *Maintenance requirements for a wet scrubber system;*
19) *Collection capacity of wet scrubber;*
20) *Waste handling and treatment requirements associated with the wet scrubber;*
21) *Post-scrubber arsenic emissions (kg/m^3);*
22) *Arsenic trioxide dust collection and packaging requirements;*
23) *Consistency with dust collection and packaging systems existing at Giant;*
24) *Arsenic trioxide and impurity levels in cold baghouse product;*
25) *Consistency of arsenic trioxide quality with market criteria;*
26) *In-plant ventilation requirements;*
27) *Applicability of in-plant ventilation systems with systems existing at Giant;*
28) *Safety equipment and hazard control systems;*
29) *Industrial hygiene equipment and controls;*
30) *Housecleaning equipment and consistency with equipment existing at Giant;*
31) *Solid waste handling and management systems;*
32) *Solid waste management/treatment requirements:*
    - *Cyanide tails;*
    - *Scrubber sludge; and*
    - *Housecleaning dust.*
33) *Consistency of waste management systems/requirements with systems at Giant;*
34) *Effluent treatment requirements;*
35) *Consistency of effluent treatment requirements with capabilities existing at Giant;*
36) *Energy requirements; and*
37) *Technical risks, research requirements and processing limitations relative to Giant.*

vi. Two processing alternatives: WAROX vs. El Indio

vi.1 WAROX Process

One of the novel features of the WAROX process is the use of high-temperature gas filtration technology to remove impurities from arsenic fume. The concept was first tested in the Falconbridge Metallurgical Lab in the late 1970s at the time Giant was beginning to sell crude baghouse dust. The first test involved a 1" fluidized bed reactor with a sand bed and nitrogen as the carrying gas. Crude arsenic dust was introduced into the heated reactor and the resulting fume/particulate off-gas train was passed through a fibrefrax filter to collect the non-volatile particulate fraction and then cooled to condense As_2O_3 from the vapour phase. A 99.7% pure As_2O_3 product was generated. While ceramic filters showed promise, large pressure differentials created by high antimony levels in feed materials limited their operating life.

The Research Productivity Council (RPC) tested the performance of sintered metal filters in their pilot roasting plant in New Brunswick as a replacement for the ceramic filter (RPC Phase I and II Reports). The arsenic trioxide product generated under pilot plant conditions, using baghouse dust produced at Giant as the feed, achieved market specifications, even with 2% to 3% antimony and 3% to 5% iron levels in the feed. A pilot test was conducted at Giant to evaluate the performance of these filters under actual roasting conditions. Five sets of filters from three different manufacturers were tested. On the strength of the results, a full-scale plant incorporating the hot metal technology, or *WAROX Process*, was designed (K. Morton, 1999). Further development was halted in 1990 when Royal Oak Mines acquired ownership of Giant.

Some of key findings from pilot plant studies on the WAROX Process are:

- ✓ Porous metal filter media, supplied by Mott Metallurgical Corporation, Farmington, Conneticut, USA, were employed in pilot trials conducted by RPC in November 1988. These filters are available down to 0.5 microns with finer filtration grades available on special order. The test work by RPC used 0.5-micron filter elements supplied by Mott.
- ✓ Pressure drops across the metal filters were in the range of 10 to 12" wg initially but increased to 40" wg at which time blow back was introduced for the first time.
- ✓ Iron levels were compliant with the desired market criterion. The deportment of antimony was about 30:70 between the hot metal filter baghouse and the cold cloth baghouse at low pressure drop ranges.
- ✓ The 0.5-micron filter failed to filter out the sub-micron antimony particulate fraction without the build-up of a thick filter residue characterised by higher pressure drops. *Note: These high pressure differentials would only be necessary when processing the very crude (high antimony containing) baghouse product and not on the majority of material.*
- ✓ There appeared to be a relationship between pressure drop across the filters and the deportment of antimony. As pressure drops increased, the antimony levels reporting to cold baghouse condensate decreased. After each blowback, antimony levels in condensate increased. At full-scale, several vessels would be employed, the one on stand-by sequence would be isolated to minimise changes in deportment of antimony following blowback.
- ✓ The antimony criterion of 0.2% in final As_2O_3 product was achieved when pressure differentials exceeded 58" wg and lower levels (<0.05%) with higher pressure differentials (70" to 80" wg).
- ✓ Arsenic levels in the hot filter residue were unacceptably high due to insufficient temperature control during the run. The condensation of arsenic on the filters was due to damaged heating coils and possibly due to an influx of outside air as a result of very high pressure drops. This problem associated with arsenic contamination reflects the limitation of the pilot plant rather than a problem that would persist under full-scale operations.

Two processing alternatives: WAROX vs. El Indio

WAROX Process.......

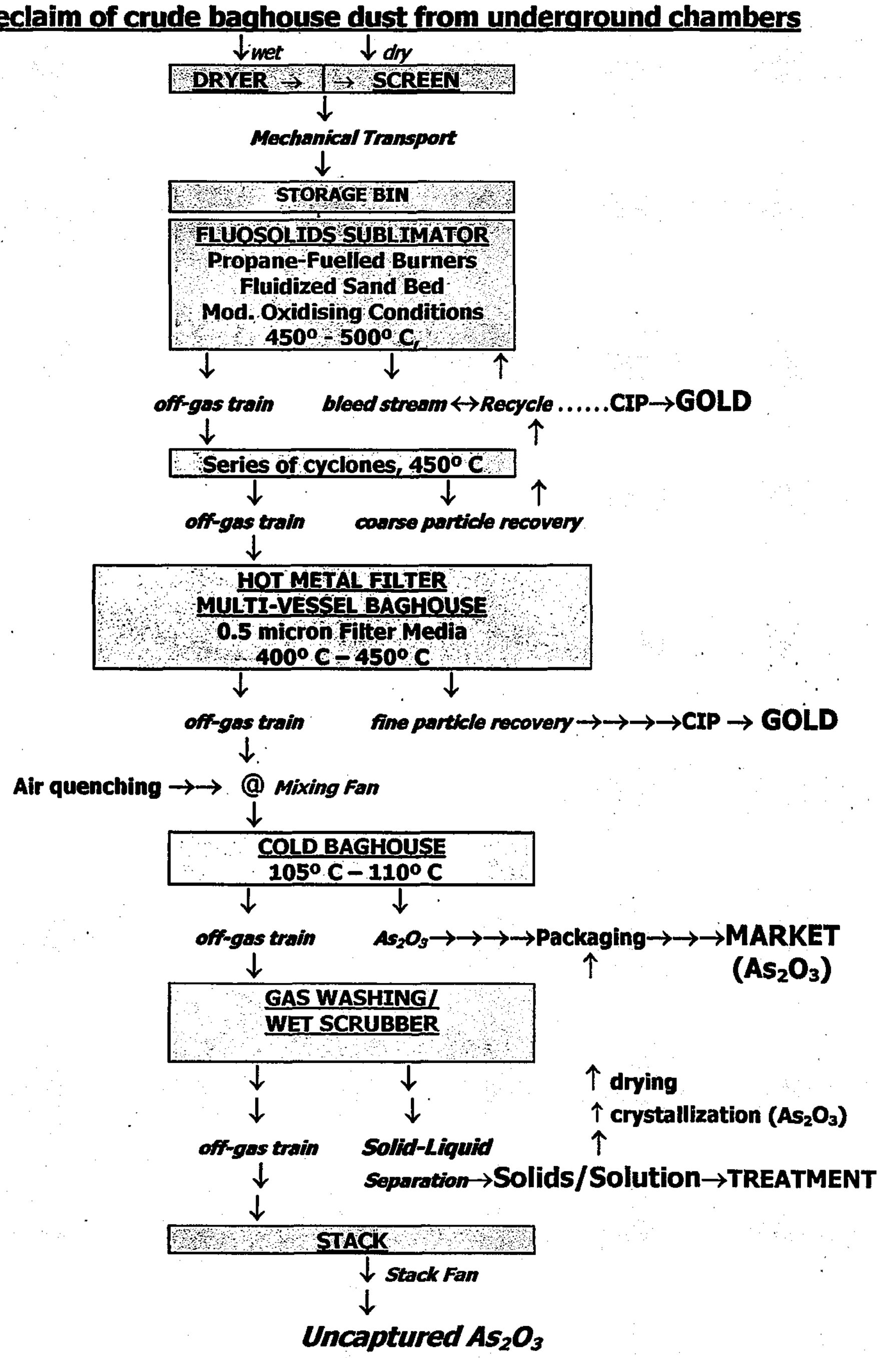
vi.1.1 Conceptual process flow sheet (WAROX Process)

A conceptual flow sheet has been developed and is displayed in Figure 1.

- Under this scheme, material recovered from the underground mine would be dried, if necessary, screened and transferred to a main storage bin on surface.
- Arsenic dust would be mechanically conveyed to a specially designed fluidized sand bed fume reactor equipped with external propane-fuelled burners and fitted with a refractory-lined windbox and refractory arch. This reactor would be operated between 450° C and 500° C under controlled oxygen partial pressure conditions (percent excess air).
- Coarse particulates (combination of sand used to control the fluidized bed and the non-volatile hot calcine fraction) would be captured by a series of cyclones. This coarse fraction would probably be returned to the reactor but could be combined with the reactor bleed stream and fed to a dedicated Carbon-in–Pulp (CIP) plant for gold recovery.
- The fine particulate fraction of the off-gas train from the fume reactor, after the cyclones, would be collected by a multi-vessel hot metal filter baghouse employing 0.5-micron filter media. One of the vessels would be isolated in blowback mode to avoid changes in antimony deportment following blowback. Recovered dust would be fed to the CIP plant for gold recovery.
- The off-gas train from the filters would be air quenched through a mixing chamber to achieve a gas temperature of between 105° C and 110° C, facilitating condensation of arsenic fume in the cold cloth filter baghouse. The dust from the cold baghouse would be packaged for market in 30 USG drums, 1 tonne bags or in bulk.
- Arsenic fume remaining in the cold baghouse off-gas train would be captured through a wet scrubber. The effluent from the scrubber could be filtered or thickened.
- Solids from the wet scrubber would be chemically stabilized and stored either on surface or underground or, alternatively, dried and combined and sold with refined baghouse product.
- Solutions from the wet scrubber would be treated through the existing treatment plant at Giant or, alternatively, treated through a small condenser-crystallizer operation for recovery of As_2O_3 values.
- Tailings from the CIP plant will be discharged to the tailings pond.

Two processing alternatives: WAROX vs. El Indio....

Figure 1. Conceptual Flow Sheet for WAROX Process



Waste products and emissions
Marketable products

Two processing alternatives: WAROX vs. El Indio....

VI.2 El Indio Process

El Indio, operated by Compañía Minera El Indio and owned by Barrick Gold Corporation (Barrick), is located 180 km northeast of La Serena, Chile at an altitude of 3850 meters. Gold-copper ore enters a flotation circuit and flotation concentrates are treated through a conventional roasting operation to remove arsenic (EH Smith, 1986). Arsenic volatilized through roasting is captured by a teflon filter baghouse as arsenic trioxide, As_2O_3. This arsenic product is sold to wood preservative manufactures if market criteria are met (Grades A, B or C). Product that does not meet market specifications, or off-specification (off-spec) material (Grade F), is stockpiled in 1 tonne bags or 30 US gallon drums (L. Buckingham and L. Wilson, 1998).

Grade A product must meet or exceed 95% purity as As_2O_3 and contain less than 0.3% iron and 350 parts per million (ppm) mercury. Grade B product must contain less than 1% iron. A Grade C specification, generated to meet an alternate market specification, requires that the product meets or exceeds an 88% purity target for As_2O_3 and contain less than 2% iron and less than 500 ppm mercury. Grade B product can be blended with material that exceeds Grade A specifications to obtain an overall Grade A product. Grade C product was sold in the past for the cost of shipping.

The stockpile of off-spec arsenic trioxide grew from the commencement of operations in 1981 until 1996, reaching a peak of 12,500 tonnes. Some reduction in the stockpile was achieved through the introduction of small volumes (less than 1% of roaster feed) of this material into the conventional roasting circuit (L. Buckingham and L. Wilson, 1998).

As part of the "Arsenic Stockpile Reduction" program implemented at El Indio, research and development was conducted on methods for re-processing the off-spec material through pyrometallurgical means and for achieving product specifications consistent with market criteria. This program, introduced in 1996, resulted in the development of a process that reportedly achieves these objectives. As the process developed at El Indio is currently being patented, only conceptual information was provided by Barrick for the purpose of this study.

Some of the steps and measures taken by El Indio in achieving their objectives in elimination the arsenic trioxide stockpile on site include (L. Buckingham and L. Wilson, 1998):

✓ System for mechanically transporting ESP dust without human contact.
✓ Overhaul of existing baghouses to improve capture of arsenic trioxide fume.
✓ Purchase of a high performance vacuum truck (Guzzler) to remove accumulations of dust from the operating plant.
✓ Increased instrumentation and control of roaster operations.
✓ Installation of a central vacuum system to improve housecleaning capabilities.
✓ Implementation of an arsenic monitoring and exposure reduction program and installation of an industrial hygiene laboratory facility.
✓ Design, construction and commissioning of an off-gas washing system (wet scrubber). Solids recovered from the wet scrubber are stabilized and disposed of in the tailings basin.
✓ Stripping of existing electrostatic precipitators and installation and retrofitting of new state-of-the-art components. *

* TEMAC, the supplier of the ESP at El Indio, conducted a preliminary assessment on the applicability of a hot ESP in the treatment of Giant's feed dust based on compositional and particle size distribution data. This supplier suggests that a 4-chamber ESP (versus a 3-chamber ESP at El Indio) would achieve 99% collection efficiency if applied to Giant´s dust. (TEMAC, 1999).

Two processing alternatives: WAROX vs. El Indio....

El Indio Process......

vi.2.2 Conceptual flow sheet (El Indio Process)

As the process technology employed at El Indio is considered proprietary and is currently being patented, no information was released by Barrick to DIAND for the purposes of the current study. Any information provided in this report is based on a document summarizing the processes under development for upgrading the off-spec baghouse dust to achieve a marketable arsenic trioxide product (L. Buckingham and L. Wilson, 1998).

A conceptual flow sheet has been developed and is displayed in Figure 2.

- Off-spec material is transported to a transfer box serviced by a monorail and electric winch. Material is discharged from barrels or bags from the monorail to the transfer box. Bags are lowered from the monorail onto a cutting knife which tears the bags and allows material to pass through a stainless steel screen to separate out lumps and debris. As material is discharged, it is mixed with hot air from ducting connected to the main shaft cooling air from one of conventional roasters. This hot air dries and improves the pneumatic transport of the material.
- The transfer box has a double bottom with side openings and is connected to a suction line. The dust is suctioned into the transfer box to the fuming reactor feed hopper fitted with a baghouse filter.
- Solids from the hopper pass through a rotary valve to control flow and then ~~to a feed gun. The~~ solids are dispersed with compressed air into the second of 14 hearths. The upper hearths of the fume reactor are maintained at temperatures between 425° C and 475° C (compared to conventional roasting of 500° C). Feed dust is injected with compressed air into the hot combustion gas stream to allow intimate solid-gas contact and accelerated sublimation. Burners located in the lower seven hearths of the reactor provide heat for the reactor. The resulting rising column of hot gases fluidises the dust particles. Up-casting gas velocity between the hearths suspends the finer particles (37 micron or 400 mesh).
- Coarser particles are collected by rotating rakes and dragged to drop holes where they are re-suspended in the up-cast gas or fall to the lower hearth where they are discharged with the underflow calcine charge from the reactor.
- Calcines from the underflow, containing gold, copper and iron oxides, antimonious oxides and vitreous As_2O_3, are recovered and currently shipped to a local smelter for gold recovery. If this process were introduced at Giant, this material would be fed to a CIP plant for gold recovery.
- Coarse particles in reactor off-gases are collected by a series of cyclones and returned to the reactor or combined with reactor underflow and treated for gold recovery.
- Hot combustion gases and arsenic vapour and entrained particulates comprise the off-gas train from the fume reactor following the cyclones. This gas train enters electrostatic precipitators where fine particles are captured. ESP dust is currently recovered and shipped to a local smelter for gold recovery. If applied at Giant, ESP dust would be fed to a dedicated CIP plant for gold recovery.
- Off-gas from the ESPs is air quenched to about 120° C prior to entering a cold filter baghouse for collection of condensed As_2O_3.
- Arsenic fume remaining in the off-gas train from the filter baghouse is captured through a gas washing system or wet scrubber. Effluent from the wet scrubber is stabilized and discharged to the tailings basin.
- Final emissions pass through a main stack.

Two processing alternatives: WAROX vs. El Indio....

Figure 2. Conceptual Flow Sheet for El Indio Process
(if applied at Giant)

Reclaim of crude baghouse dust from underground chambers

↓ *wet* ↓ *dry*

DRYER → | → SCREEN

↓

Pneumatic Transport

↓

HOPPER/FILTER BAGHOOUSE

FUME REACTOR
Fuel-Fired Burners
Partially Fluidized Bed
Mod. Oxidising Conditions
425° - 475° C,

↓ ↓

off-gas train ***reactor underflow*** ↔↔ ***Recycle*** →**CIP**→**GOLD**

↓ ↑

Series of cyclones, 450° C

↓ ↓ ↑

off-gas train ***coarse particle recovery*** →→ ⌋

Air quenching →→ @ ***Mixing Fan***

↓

HOT 3-COMPARTMENT ESP
350° C

↓ ↓

off-gas train ***fine particle recovery*** →→→→**CIP** → **GOLD**

↓

Air quenching →→ @ ***Mixing Fan***

↓

COLD BAGHOUSE
110° C – 120° C

↓ ↓

off-gas train As_2O_3→→→→**Packaging**→→→**MARKET** **(As_2O_3)**

↓ ↑

GAS WASHING/
WET SCRUBBER

↓ ↓ ↑ **drying**

↓ ↓ ↑ **crystallization (As_2O_3)**

off-gas train ***Solid-Liquid*** ↑

↓ ***Separation***→**Solids/Solution**→**TREATMENT**

↓

STACK

↓ ***Stack Fan***

↓

Uncaptured As_2O_3

Waste products and emissions
Marketable products

Two processing alternatives: WAROX vs. El Indio....

vi.3 Approximate arsenic balance (WAROX Process)

Below is a very approximate arsenic balance for a processing facility designed to treat the accumulated baghouse dust at Giant (assumed to be in order of 265,000 tons) within a 4.5-year period based on the WAROX Process and on the following assumptions:

I) Assuming upper range of Sb and Fe levels in Giant's feed (crude baghouse dust);
II) Assuming 10 tons of baghouse dust is processed per hour (60,000 tons per year);
III) Assuming a 99% collection efficiency for hot metal filter baghouse;
IV) Assuming a 99.9% collection efficiency for the cold baghouse;
V) Assuming a 98% collection efficiency for the wet scrubber; and
VI) Assuming an overall arsenic capture efficiency of over 99.9%.

Baghouse Dust (10 stph)
As_2O_3 = 80%
Fe (Fe_2O_3, $FeAsO_4$, Fe_2AsO_7) = 5%
Sb (Sb_2O_4, Sb_3O_4) = 3%
$SiO_2/Al_2O_3/CaO/MgO/Au$ = 11%
H_2O = 1%

Propane (17.5 L/min)
4,778.9 L/min (gas)

Air (10%)

↓ ↓ ↓

FLUOSOLIDS SUBLIMATOR
3.305 m diameter, fuming temperature: 410° c

↓

HOT METAL FILTER
MULTI-VESSEL BAGHOUSE

↓→→ $SiO_2/Al_2O_3/CaO/MgO/Au$
Sb (Sb_2O_4, Sb_3O_4)
Fe (Fe_2O_3, $FeAsO_4$, Fe_2AsO_7) **1.881 tons dust/hour**

COLD BAGHOUSE

↓→→→ **As_2O_3** **7.992 tons As_2O_3/hour**
$SiO_2/Al_2O_3/CaO/MgO/Au$ 0.011 tons/hour
Sb (Sb_2O_4, Sb_3O_4) 0.003 tons/hour Sb
Fe (Fe_2O_3, $FeAsO_4$, Fe_2AsO_7) 0.005 tons/hour Fe

PRODUCT: 0.04% Sb/0.06% Fe/99.8% As_2O_3

GAS WASHING/
WET SCRUBBER

↓→→→ **As_2O_3** **0.00784 tons As_2O_3/hour**

STACK

↓→→→ **As_2O_3** **0.00016 tons As_2O_3/hour***
stack loss **0.0965 mg As/m^3****

* The percentage of arsenic lost in stack emissions is expected to be about 0.002%. This translates to a daily stack loss of 3.5 kg As for a 24-hour operation, based on the foregoing assumptions and flow sheet.

**Based on "Summary of Operating Parameters for Fuming of Baghouse Dust", B.Cross, 1999. This projected arsenic emission level for the plant is lower than existing arsenic release standards in the USA, France and British Columbia, which range from 0.7 mg/m^3 to 11.6 mg/m^3, for different industrial sectors (Environment Canada *et al*, 1997). There are no federal standards in Canada for atmospheric arsenic releases.

vii. Existing facilities at Giant

Below is a list of materials and equipment existing at Giant, perhaps available and potentially applicable to either of the two technologies under consideration.

Item	Prevailing Conditions /Existing Equipment	Specifications	Throughput	Additional Treatment, Equipment or Retrofitting
Feed material	Assume 265,000 tons of material	Crude dust: 48 – 85% As_2O_3 Up to 3% Sb Up to 5% Fe 1% – 6% Humidity	Assuming an accumulated inventory of 265,000 tons: 10 tons/hour and 60,000 tons /year	**Reclaim equipment; Screening System; Thickeners/Industrial Filters;**
Dryer (feed)	None	Capacity to reduce moisture content to 1% in all feed dust.	Based on treatment schedule	**Dryer**
Roaster	Existing roasters are not available due their use in ongoing operations.	Retrofitting of existing roasters even if available for use in proposed application may not be feasible	Dependent on treatment schedule	**New Dorrico 2-stage fluosolid reactor** (WAROX) or **Fluidized bed fume reactor** (El Indio)
Fume Reactor Controls ❖ **Temperature** ❖ **Combustion air** ❖ **Feed rate** ❖ **Fluidizing airflow**	Existing roasters have limited temperature control, no controls on combustion air, feed rate and limited control on fluidizing airflow	Requirements would depend on processing option adopted		**New equipment would include these controls**
Exhaust ducting	Equipment exists	Retrofitting requirements would depend on processing option and ventilation systems adopted		Existing equipment may be adaptable
Screw conveyors	None	Specifications depend on process adopted		**Screw conveyors**
Cyclones	Existing	Requirements would depend on processing option adopted		Existing equipment may be sufficient
Hot dust collection	ESPs	Existing Cottrells have very limited controls compared to newer technology. Retrofitting is probably not feasible.		**ESP or hot metal filter baghouse**
Baghouse	Existing equipment	Existing equipment may be adaptable if available		**Cloth filter baghouse**
Scrubber	None	New equipment may be required to meet emission criteria under compressed processing schedule		**Wet scrubber** may be required
De-watering thickener	Equipment exists	Requirement for new equipment will depend on the condition and availability of existing equipment at Giant.		
Water treatment	Hydrogen peroxide/iron precipitation	Requirements for scale-up and/or retrofitting of existing equipment will depend on the reclaim methods used.		Existing plant should be capable of meeting effluent treatment requirements
Arsenic sludge treatment	None	The requirement to stabilized arsenical wastes from the wet scrubber will depend on final process design.		**Treatment facilities** may be required
CIP plant	Existing plant	Requirements for scale-up or modifications to existing facilities versus installation of a new plant depend on availability/capacity of existing CIP plant.		Dedicated **CIP plant**
CIP tailings storage	Existing tailings storage would be adequate.			(existing tailings pond)
In-plant ventilation	New plant facilities and building may be required to achieve objectives			**Air-to-air heat exchanger**
In-plant dust collection	Giant has an in-plant vacuum system (Hy-Vac)			No new equipment is required.
Blower/Rotary fans	Rotary fans	Requirements for new equipment depend on processing option adopted.		
Instrumentation	None	Processing facility would require extensive instrumentation to achieve objectives		

viii. Comparative evaluation of two technologies

The two technologies are compared below on the basis of their projected applicability to the conditions prevailing at Giant and respective capacities to achieve desired criteria and objectives: recovering gold values from crude dust and producing a marketable As_2O_3 product.

BASIS OF COMPARISON	WAROX Process	El Indio Process	Comments	Favoured Process
Scale technology has been demonstrated	Pilot plants (RPC and Giant)	Full-scale operation	Hot metal filter technology has not been tested at full-scale but scale-up should not be complicated.	**El Indio Process**
Operating range of feed conditions/ characteristics	Antimony levels may be limiting	No reported limitations but the process has not been subjected to the range of feed conditions anticipated at Giant	High antimony levels will cause high differential pressures across hot metal filters in case of WAROX Process. El Indio process has not been tested with Giant's feed and applicability in unknown.	Difficult to assess
Applicability to Giant's feed material	All test work conducted on Giant feed	Applicability has not been tested	Same as above	**WAROX Process**
Fume reactor throughput capacity	Based on treatment schedule. Flexible	Based on treatment schedule. Flexible	Treatment capacity will depend on number of reactors employed	No difference
Maintenance of reactor	Typically very low	Typically very low	Fume reactors for two processes employ the same principles.	No difference
Compatibility of reactor design with Giant roaster	Depend on ultimate design criteria	Roasters at Giant may be adaptable if available	As current roasters are in use, new equipment is probably required.	No difference
Compatibility of hot dust collection with equipment at Giant	New equipment required	Existing ESP would have to be replaced	New equipment would be required under the two processing options.	No difference
Hot dust collection efficiency	Over 99% (pilot plant scale)	Over 95% (full-scale)	Do not have current data from El Indio	**WAROX Process**
Hot dust collection capacity	Higher than required at Giant	No information	No limitation	No difference
Maintenance of hot dust collection systems	Very low	Very low	Both systems require little maintenance	Similar
Gold recovery efficiencies for fine dust	Up to 90% (limited data)	Reportedly 95%	Dependent on porosity and soluble arsenic content	**El Indio Process**
Gold recovery efficiencies for calcines	Up to 90% (no data at full scale)	Reportedly 95% (full-scale)	Dependent on soluble arsenic levels	**El Indio Process**
Efficiency of baghouse collection systems	Over 99%	Over 99%	Same equipment	No difference
Applicability of existing baghouse at Giant	Depends on condition and availability of existing equipment		These components of the process are equivalent for WAROX or El Indio and therefore do not require separate discussion	No difference
Baghouse maintenance requirements	Replacement of bags every two years			
Efficiency of wet scrubber	Expect 98%			
Applicability of scrubber systems at Giant	No existing equipment exists at Giant.			
Maintenance required on scrubber system	Very low			
Collection capacity of wet scrubber (kg/hour)	Very flexible and dependent on treatment rate			
Waste handling/ treatment requirements for scrubber sludge and effluent	Waste handling requirements are the same for the two processes with the principal waste streams being CIP tails, scrubber solids and scrubber effluent. Wastes from reclaim operations present additional waste handling/treatment requirements.			No difference
Post-scrubber arsenic emissions (kg/m^3)	Should be the same for both processes and very low			No difference
Arsenic trioxide dust collection and packaging	Depending on whether material is shipped in bulk by truck or in drums/bags, the packaging plant requirements would be different. Giant shipped in bulk in the past when crude baghouse dust was marketed.			No difference
Consistency with dust collection and packaging systems existing at Giant	Giant shipped in bulk in the past when crude baghouse dust was marketed. Systems are available for conveying in bulk but not for packaging into drums/bags.			No difference
Refined arsenic trioxide quality/impurity levels	Product purity would have to be demonstrated at full-scale. Pilot plant trials obtained 99% purity.	Reported to be >95% As_2O_3 and consistent with market criteria	WAROX may achieve higher purity levels	**WAROX Process**
Consistency of As_2O_3 quality with market criteria			El Indio is meeting market criteria for As_2O_3 at full-scale.	**El Indio Process**
In-plant ventilation requirements	An in-plant ventilation system would require a new plant facility, as existing buildings are not in appropriate condition.			No difference

Comparative evaluation of technologies.....

BASIS OF COMPARISON	WAROX Process	El Indio Process	Comments	Favoured Process
Housecleaning equipment: consistency with equipment existing at Giant	In both operations, there are mobile and stationary vacuum systems.		Giant has similar equipment and capabilities as El Indio	No difference
Solid waste handling/management	In both operations, solid wastes are treated and/or stored in secure waste storage facilities.		The two processes generate the same type and volume of wastes.	No difference
Solid waste management/treatment requirements: ❖ **CIP tails** ❖ **Scrubber sludge** ❖ **Housecleaning dust**	Giant stores CIP tails in the existing tailing pond and waste dusts from the plant in a hazardous landfill.	El Indio does not have a cyanidation circuit so does not produce CIP tails. Solids from the wet scrubber are fixed chemically and stored in the tailings basin. Dusts from the plant are fed into the fume reactor.	The fume reactor would provide a means for treating dusts collected by vacuum systems and reduce the volumes of material requiring storage in landfills.	No difference
Consistency of waste management systems/requirements with systems at Giant	All wastes generated by WAROX could be handled in the same manner as those from the existing roasting operation.	The El Indio Process does not generate any wastes that would require different handling requirements.	Waste management practices would be similar to those existing at Giant.	No difference
Effluent treatment requirements	Waste handling and treatment requirements are same			No difference
Consistency of effluent treatment requirements with facilities at Giant	Excluding reclaim operation, existing plant should be able to meet water treatment requirements			No difference
Energy requirements	High energy requirements for booster fan associated with hot filter system	Energy requirements are expected to be lower	Difficult at this stage to predict the differences in energy consumption	**El Indio Process**
Consistency of energy requirements with systems available at Giant	WAROX is expected to have higher energy requirements than the El Indio Process	Similar to existing plant at Giant	Difficult at this stage to predict the differences in energy consumption	**El Indio Process**
Technical risks, research requirements/processing limitations relative to Giant	WAROX Process has been fully tested at the pilot plant scale and approval to proceed to full-scale was approved by Giant's management and Board of Directors prior to the halting of its advancement in 1990 when Royal Oak acquired ownership.	While El Indio's process has been implemented at full-scale, its applicability to the baghouse dust produced and stored at Giant is untested. Based on the assessment of one ESP supplier, a hot ESP would achieve 99% collection efficiency (similar to the hot metal baghouse) for the non-volatile fine dust component of Giant's baghouse dust.	The hot fine dust collection system is the single element of difference between the two processes. The efficiencies of an ESP versus a hot sintered metal filter baghouse would have to be compared when applied to Giant's dust, both from technical and economic feasibility perspectives.	**WAROX Process,** given that this process has been developed on the basis of Giant's baghouse dust. **El Indio Process,** given that ESP technology is widely used by the industry in similar applications.

ix. Conclusions

The two pyrometallurgical technologies under consideration for processing current and past baghouse production at Giant for the purpose of recovering gold values and producing a marketable arsenic trioxide product have been subjected to a conceptual level evaluation. The two technologies are very similar at the conceptual level, with the only significant difference being the manner in which the non-volatile fine dust fraction from the fume reactor is captured. In the WAROX Process, this fraction is captured through mechanical filtration using very fine metal filter media. The process developed and employed by El Indio collects this fraction with a hot ESP.

Giant's dust is expected to be significantly different in composition and particle size distribution from the material produced and processed by El Indio. These differences could result in one form of fine dust collection being favoured over another: mechanical filtration or ESP. As this is the element of principal difference between the two processes under consideration, differences in fine dust collection efficiencies achieved by metal filters (WAROX) versus an ESP (El Indio) when applied to feed materials from Giant becomes key to the overall assessment.

Hot Metal Filters (WAROX Process)

Under pilot plant conditions employing crude baghouse feed from Giant, 0.5-micron metal filter media achieved high collection efficiencies for the antimony-rich fine particulate fraction in the fume reactor off-gas train but only under very low blowback and high pressure drop conditions. Immediately following blowback, antimony levels in condensate collected in the cold baghouse increased. Under a full-scale operation, a multi-vessel hot metal filter baghouse would be employed with one vessel isolated in blowback mode. With this configuration, dust collection efficiencies are held relatively constant even following blowback. Sequential blowback in isolated sections of a multi-vessel filter is standard technology for this type of filter. The technology is based on simple principles of mechanical filtration and, therefore, scale-up from pilot scale to full industrial scale is expected to be straightforward. Energy requirements could be significantly higher for the hot filter baghouse than for an ESP due to much higher (10- to 20-fold higher) differential pressures. Metal filter baghouses are not used in the mining industry and, therefore, there are no similar applications upon which to compare the performance achieved in pilot plant trials.

ESP (El Indio Process)

While the hot ESP employed by El Indio reportedly achieves high collection efficiencies, the particle size distribution of baghouse dust produced by El Indio is expected to be significantly different to the size distribution of materials produced by Giant. Based on a preliminary assessment of data provided on Giant's baghouse dust, TEMAC (supplier of the ESP used at El Indio), projects a 99% collection efficiency for a hot four-chamber ESP (similar to the metal filter baghouse). Maintenance requirements are generally low for an ESP, although short-circuiting can be a problem. Energy requirements are expected to be significantly lower for an ESP relative to the hot filter baghouse (see comments above). ESPs are widely used in the mining industry in applications very similar to those being considered at Giant.

Both processing technologies demonstrate the commercial potential of pyrometallurgical-selective sublimation techniques to 1) upgrade the arsenic trioxide content of baghouse dusts produced from roasting operations to levels consistent with market specifications and 2) recover gold values contained in these dusts. The El Indio Process is operating at full-scale but its applicability to Giant's feed is untested. The WAROX Process has been tested with Giant's feed but only at the pilot plant scale. The extent to which the performance of the two processes can be directly compared has been severely limited by the information made available to the study. In the case of El Indio's Process, information could not be supplied due to the status of patent applications. In the case of the WAROX Process, information is limited to the pilot plant scale. Hot metal filter technology is not used in the mining industry.

Conclusions........

At a conceptual level of comparison, the following unknowns remain with respect to which of the two processes is the more technically sound, extensively tested, used or demonstrated, flexible to wide fluctuations in feed quality and characteristics and consistent with existing facilities at Giant:

✓ **Are there differences in operating conditions or design of the fume reactor employed by El Indio relative to the fluosolids sublimator proposed by WAROX that could influence the quality of arsenic trioxide produced and/or efficiencies of gold recovery?** *These issues can not be assessed on the basis of available information.*

✓ **Could an ESP, such as employed in the El Indio Process, effectively capture the non-volatile fine particulate fraction in the off-gas train generated from a fume reactor during the processing of Giant's baghouse dust?** *This is critical to the comparative evaluation of the two processing technologies. Based on a preliminary assessment by the same supplier of the ESP used at El Indio, a hot ESP would achieve a 99% collection efficiency for the fine dust fraction which is similar to the efficiencies reported by the hot metal filter technology of WAROX in pilot plant trials.*

✓ **How practical are very fine (0.5 micron) metal filter media under commercial application?** *The information on the WAROX Process identifies no operational limitations.*

✓ **What are the comparative gold recovery efficiencies for the non-volatile particulate fraction generated in the processing of baghouse dust from Giant when collected by 1) a hot metal filter baghouse in the WAROX Process and 2) an ESP in the case of the El Indio Process?** *Insufficient information is available for an assessment. Efficiencies are expected to be very similar.*

✓ **Can the El Indio's Process be adopted at Giant without significant test work or modification?** *The applicability of an ESP in place of the fine metal filter media employed by the WAROX Process would have to be assessed. A preliminary assessment by the supplier of the ESP at El Indio indicates that ESP technology is applicable to Giant's baghouse dust. Other elements of the El Indio Process are very similar to the WAROX Process and would not be expected to require significant test work or modification if applied to Giant.*

✓ **How much further testing is required on the WAROX Process to achieve final design specifications?** *As the metal filter technology is simple in principle, scale-up from the pilot plant to full scale should be relatively straightforward.*

✓ **Which processing technology carries more technical risk under application at Giant?** *The El Indio Process theoretically carries less risk due to its experience at full operating scale. This process has not, however, been tested with Giant's baghouse dust. The WAROX Process has been developed on the basis of Giant's baghouse dust but only to the pilot plant scale. According to one ESP supplier, TEMAC, a hot ESP would achieve the same fine dust collection efficiencies as the hot filter baghouse, based on an assessment of data provided on the baghouse dust produced at Giant. ESP technology carries less risk in general than hot metal filter technology due to its much wider use under very similar application.*

✓ **Which of the two processing technologies has been more extensively demonstrated?** *The El Indio Process has been tested at full operating scale and employs more conventional dust collection technology than the WAROX Process, tested only at the pilot plant scale.*

✓ **Can the process flow sheet at El Indio be adapted to incorporate the WAROX filter technology or the flow sheet for the WAROX Process modified to incorporate an ESP in place of a metal filter baghouse?** *Both alternatives might be worth considering if modifications to existing process flow sheets are warranted on the basis of comparative data.*

✓ **Could either of the two processing technologies be extended to produce a marketable antimony oxide product?** *This could be accomplished with the WAROX Process, using a 2-stage filtration step. This type of separation has been tested under pilot plant conditions. Potentially 4,000 tons of antimony oxide would be generated with a market value of about $1.50/lb.*

Conclusions........

- ✓ **Are there differences in the quality of arsenic trioxide produced by the WAROX Process and the El Indio Process and if so do these represent different market potential?** *The WAROX Process may produce a higher purity product than El Indio's process when applied to Giant's crude baghouse dust based on pilot plant data and current purity levels achieved at El Indio. However, the collection efficiencies projected for a metal filter baghouse versus those for a hot ESP are virtually identical and all other elements of the two processes are the same. If the two processes produce different quality products, there could be differences in the marketability of these products.*
- ✓ **Which of the two technologies requires more process control and equipment maintenance?** *The requirements should be very similar.*
- ✓ **What is the projected stack emission levels under the two processing scenarios?** *Based on information generated on the WAROX Process, an emission rate of 0.0965 mg As/m^3 is expected for a 10 ton/hour treatment facility (B. Cross, 1999). Similar results are expected for the El Indio Process.*
- ✓ **What are the comparative environmental and human health risks associated with the two processes?** *The processes present the same types and levels of risks. The controls required to control these risks would apply in either case.*

The fundamental question in the assessment of the two processes is the following:

Is the baghouse dust produced at Giant so fundamentally different from the material generated at El Indio that the novel hot metal filtration technology of the WAROX Process is favoured over the more conventional ESP technology used in the El Indio Process for capture of the refractory and gold-bearing particulate fraction of the fume reactor off-gas train?

If the answer to the question above is yes, then the WAROX Process would be favoured as the remaining aspects of the two processes are very similar. The collection efficiency of the equipment selected to capture the non-volatile fine particulate is a critical factor in any process adopted at Giant, both in minimizing impurities levels in the final arsenic trioxide product and in maximizing gold recovery from Giant's crude baghouse dust.

The processing technologies under evaluation provide a means for reducing environmental liabilities associated with arsenic-rich dust inventories at Giant and recovering the costs of implementation through recuperation of gold values and sale of refined arsenic trioxide. However, both processing options would produce solid and aqueous waste streams requiring treatment prior to storage or discharge and both would generate fugitive (within the plant) and stack (to the atmosphere) emissions potentially comprising both gaseous and particulate arsenic phases. Stack losses for a processing plant employing the WAROX or El Indio Process is estimated to be 0.002% of throughput. Arsenic emission levels from a 10 short tons/hour dust processing plant employing the WAROX Process are expected to be in the order of 0.097 mg As/m^3 (B. Cross, 1999). Current emission levels at Giant, based on 1998 stack test results, are about 3.0 mg As/m^3, without a wet scrubber (K. Morton, 1999). Assuming a 98% capture efficiency for a wet scrubber, Giant's stack emissions would be expected to decline to about 0.06 mg As/m^3 through the addition a wet scrubber. The estimated arsenic emission level for a plant designed to treat Giant's baghouse dust (0.097 mg As/m^3) is lower than existing Arsenic Release Standards in BC (Canada), USA and France, which range from 0.1 mg/m^3 to 11.6 mg/m^3 (Environment Canada *et al*, 1997). There are no federal standards in Canada for atmospheric arsenic releases.

The decision to reclaim and process Giant's baghouse dust would be influenced by many factors aside from technical and economic feasibility, including regulatory, socio-economic and political factors and the comparative cost-benefits derived from this option compared to others being considered.

The results of the current study, while very conceptual, suggest that both processing options are technically feasible and applicable to Giant.

x. Recommendations

The El Indio Process has the advantage of full-scale operating experience while the WAROX Process has been tested only under pilot plant conditions. The El Indio Process has not been tested on Giant's baghouse dust while the WAROX Process was developed on the basis of this material.

To assess the performance of the two processing technologies in achieving the desired objectives of recuperating gold values and generating a marketable arsenic product from Giant's crude baghouse dust, much more information is required. To complete the conceptual level evaluation, the following is required:

- **Preliminary assessment by ESP suppliers, based on size distribution data for Giant's dust, as to the collection efficiencies of an ESP for capturing the non-volatile particulate fraction of the off-gas train produced in the fuming of Giant's crude baghouse dust. TEMAC (supplier of ESPs installed at El Indio) has conducted this type of assessment on data provided on Giant's baghouse dust and predicts a collection efficiency of 99% or the same as the metal filter technology of WAROX (TEMAC, 1999).**
- **Resistivity tests by ESP suppliers, based on samples of Giant's dust, to refine the preliminary assessment (above).**
- **Comparative material balances for two process options with an ESP in place of a metal filter baghouse based on information provided by ESP suppliers (above) for El Indio Process and pilot plant data for WAROX Process.**
- **Comparative projections of As_2O_3 quality based on material balances (above).**

With this additional data, the projected performance the two processes in treating dust from Giant can be more directly compared, assuming that all elements of the two processes other than fine dust collection are equivalent.

Should this type of waste management option be favoured over others under consideration by DIAND for management of baghouse dust stored and produced at Giant, more detailed investigations would be required as follow-up to this study. These future investigations would determine the economic and technical feasibility of reclaiming and processing current and future baghouse production at Giant through the WAROX or El Indio processes (or combination the two).

In conjunction with the foregoing, parallel investigations should be initiated on potential reclaim operations:

- **Vacuum extraction techniques and associated equipment requirements;**
- **Mechanical extraction techniques and associated equipment requirements;**
- **Strategies, techniques and equipment requirements for final clean up and closure of the 15 underground storage chambers at Giant;**
- **Methods and associated equipment required for drying dust;**
- **Methods and associated equipment required to screen crude dust recovered from underground to remove debris and entrained rock fragments;**
- **Methods and associated equipment required for conveyance of dust from consecutive stages of the reclaim and preparatory process to the fume reactor;**
- **Standard operating practices and health and safety equipment and protocols for workers involved in the reclaim operation; and**
- **Industrial hygiene and exposure monitoring programs for workers involved in the reclaim operation.**

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