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SEALING ARSENIC TRIOXIDE IN DRUMS
AT THE 1,500-FOOT WEST LEVEL OF THE O'BRIEN MINE -
SULPETRO MINERALS LTD., CADILLAC, QUEBEC

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|  Government of Canada / Gouvernement du Canada | | ACTION REQUEST | | FICHE DE SERVICE | |
| To - A | | Date <i>Sept 28 1985</i> | | | |
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| From - De | | <i>M. O'Brien for Neill</i> | | | |
| Language spoken - Langue utilisée | | Telephone No. - N° de téléphone | | Extension Poste | |
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GC 218 (89/08) 7540-21-907-5351

J.D. Charlton
Mine Geologist
March 11, 1985

A) Introduction

A total of 1,253 short tons of arsenic trioxide are stored in two galleries at the 1,500-foot west level of the O'Brien Mine. A by-product of the roasting process, they were placed there by the previous operator, the M.J. O'Brien Mining Co. Ltd., between 1940 and 1956, when the mine closed. The impermeable bulkhead constructed by the O'Brien Mine to contain the arsenic was demolished by Consolidated Goldfields in 1980.

Today, the O'Brien Mine is owned by Sulpetro Minerals Ltd. It is kept dry to below the 1,875-foot level, but is currently inactive.

The Quebec Department of the Environment must find and approve a permanent solution to the arsenic problem. The solution proposed in this report involves sealing the two galleries containing the drums of arsenic trioxide with thick concrete caps.

Two other solutions have been rejected. The first would have been to find a purchaser for the arsenic trioxide; but after an extensive search, we discovered that there is no market for this product. The second would have been to remove all the drums from the mine and transport them to Stablax Canada Inc., in Montreal. However, this approach would have been dangerous and very costly.

The solution presented here in detail was suggested by the Department of the Environment, and we (Sulpetro Minerals Ltd.) concur that it represents the most effective and safest approach. If it is approved, we can do the necessary work this summer (1985), under the supervision of a representative from the Department of the Environment.

B) Background

The O'Brien Mine was discovered in 1924 and began producing gold in 1927. Its own mill began operating in 1933. The mine was permanently closed in 1956 after having produced 1.3 million short tons of ore at an average grade of 0.467 ounces per ton. Recovery was high (an average of 96 percent) because three to four percent of the ore was arsenopyrite and, as a result, a roasting system had to be used. The matrix of the arsenopyrite crystals contained a variable percentage of ore, which was not recoverable in the roasting process. Arsenic trioxide was a by-product of roasting.

The M.J. O'Brien company sold a small percentage of the arsenic trioxide, but a market could not be found for the entire production. The surplus was put into 400-pound drums (empty cyanide drums) and eventually stored at the 1,500-foot level in a long abandoned drift west of No. 3 shaft. All the arsenic trioxide was stored there until the mine closed in 1956. Before allowing the mine to flood, O'Brien constructed an impermeable bulkhead across the entrance to the drifts.

The mine remained abandoned for several years. In 1972, Darius Gold Mines Inc. pumped it out to below the 1,500-foot level. For the next nine years, this company and the international mining company, Consolidated Goldfields, carried out exploration and development work, putting the mine into production from 1978 to 1981. In 1980, Goldfields thought that it had found a buyer for the arsenic and demolished the impermeable bulkhead. When the potential buyer decided not to purchase the arsenic, Goldfields looked all over the world but was unable to find another buyer.

In November 1981, Sulpetro Minerals Ltd. bought the O'Brien Mine. We (Sulpetro Minerals) also made several unsuccessful attempts to find a buyer for the arsenic trioxide. Stablax Canada Inc. also studied the problem, but their preliminary cost estimates for removing all the drums, transporting them to Montreal and making an insoluble cement were prohibitive.

We designed another impermeable reinforced concrete bulkhead which would have been installed in the same place as the O'Brien bulkhead, but which would have been thicker and stronger. The Department of the Environment rejected this design and recommended the two thick concrete caps which are proposed here. The drawings for the caps and a description of the rock works required are attached to this report. If it is approved, the project can be completed this summer (1985).

C) Description of the arsenic trioxide storage site

1) General: A total of 1,253 short tons of arsenic trioxide are stored in 8,928 drums (400 pounds each) at the 1,500-foot level to the west of No. 3 shaft at the O'Brien Mine. The drums are located in two drifts (15-G-West and 15-F-West) west of 15-01 XC North (see plan). The 15-G-West drift is 200 feet long, and storage drums occupy 140 feet of this length. The 15-F-West drift is 1,740 feet long, with drums along most of its length. After 29 years under water, a large percentage of the drums are rotten.

At the present time, almost no water is escaping from the galleries. In other words, the galleries do not intersect any underground water channels. No opening, other than borehole 229, intersects the galleries. As shown on the plan, this is a horizontal hole which starts at the station beside the shaft. It will be plugged with an expanding cap and concrete.

2) Geology: To date, all ore-bearing veins are hosted by the Piché Group.

The Piché Group is a sedimentary-volcanic sequence, deposited above the Pontiac Group which lies to the south of the Piché. The Piché is bounded on the north by the schists of the Cadillac Break. The Piché Group strikes east-west and dips from 80 to 90 degrees south. In the western part of the O'Brien property, the sequence has a north-south thickness of 350-400 feet. From south to northeast, the sequence consists of mafic volcanic rocks (basalts), a tuffaceous quartz-feldspar porphyry, a conglomerate, another tuffaceous quartz-feldspar porphyry (richer in quartz), and finally a member which is a mixture of greywacke, tuff and graphitic argillite in contact with the Cadillac Break. The Piché Group has been subjected to a high degree of north-south compression.

The two drifts of interest here are located in the two northernmost members of the Piché Group. The 15-G-West drift is in the graphitic argillites and the graphitic schists of the mixed member. The talc and chlorite schists of the Cadillac Break are approximately twenty feet north of 15-G-West. The 15-F-West drift is a very long exploration drift, part of which is located in the quartz-feldspar porphyry (north) and part of which follows the north contact (with the mixed member). Both drifts follow the structure, which is basically parallel to the schistosity of the rock. The porphyry is very competent and hard.

There are very few inclined faults or joints in the two drifts and, along the faults which do exist, there has only been a few inches of displacement. Fracture planes are closed. In short, the rocks around both drifts are hard and competent and were not disturbed by mining operations. It is very difficult to imagine how a solution could travel very far in undisturbed structural conditions such as those which exist at the 1,500-foot west level.

D) The concrete caps (see plan)

Two concrete caps are proposed: one for the 15-G-West drift, and one for the 15-F-West drift. Both caps are in narrow sections and are 16.5 feet west of 15-01 XC North (the crosscut). The first arsenic drums are about forty feet to the west.

As stated earlier, some rock work will be required at each location before the concrete can be poured. This will consist first of cleaning both locations—particularly the floors—and then making two-foot-deep slashes in the walls, roofs and floors. Concrete cap 1 will not require a slash on the south wall because there is already one there. It is the shape of the cap that is most important to its strength.

The two caps will be seven to eight feet thick. Their maximum width and height will be the same as those of the drifts, plus two feet on each side, as shown. Their minimum dimensions will be the same as their respective drifts. Plywood forms supported by roundwood will be constructed to contain the concrete. The concrete will be poured through pipes from No. 3 shaft station to the wood forms, and the forms will be filled with concrete up to the top of the roof. In this way, no water will escape through the caps. The strength of the concrete to be used will be 3,000 pounds per square inch (the water pressure at the 1,500-foot level will only be 750 pounds per square inch), and it will be mixed with 3/4-inch aggregate.

A corrosion-resistant metal plate to be placed on each cap will bear an engraved warning stating the nature of the hazard and the date of construction of both concrete caps.

As mentioned earlier, where borehole 229 leaves the 15-F-West station and enters the drift, it will be plugged with an expanding cap and concrete. It will also be plugged with concrete in the 15-14 drift (see plan). This is the only borehole that intersects the arsenic trioxide storage drifts.

E) Conclusions

The proposal to construct two concrete caps to seal the arsenic trioxide at the 1,500-foot west level of the O'Brien Mine does not represent a perfect solution to the problem. But the two drifts in question are dry, solid, competent and isolated. Strong, impermeable caps will be constructed to eliminate the possibility of water leakage.

The alternative—taking out the 8,928 rotten drums and transporting them to Stablex—would be too dangerous and too expensive. Under these circumstances, the most effective and safest solution is to seal the arsenic trioxide and isolate it from the outside environment. The proposal described here would permanently eliminate the problem.

Signed this March 13, 1985

[original signed by]
Jack Charlton,
Mine Geologist

[original signed by]
E.S. Short,
Mining engineering consultant

at Cadillac, Quebec.

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[Page 7: Key to numbered translations]

- 1) western extension of the 15-F-West Drift
- 2) *EXTENSION OF THE As_2O_3 STORAGE DRIFT*
- 3) continued above
- 4) *ARSENIC TRIOXIDE STORAGE DRIFT*
- 5) *CONCRETE CAP 1*
- 6) 15-G-West Drift
- 7) 15-F-West Drift
- 8) *CONCRETE CAP 2*
- 9) 15-14 Drift
- 10) No. 3 SHAFT
- 11) To No. 2 Shaft
- 12)

| | | |
|--|---------------------------------|--|
| <i>SULPETRO MINERALS LIMITED</i> | | |
| <i>March 7, 1985</i> | | |
| Location of proposed concrete caps and As_2O_3 storage drums at the 1,500-foot level of the O'Brien Mine | | |
| Scale: 1"= 100' | Cadillac Township NTS 32/D/1 | Drawing: J.D. Charlton Approved: E.S. Short |

**CHARACTERIZATION AND MONITORING GROUP FOR
HAZARDOUS WASTE DISPOSAL AND STORAGE SITES**

BY: ANDRE PAQUET, ENGINEER, M.Sc.

**QUEBEC DEPARTMENT OF THE ENVIRONMENT
HAZARDOUS SUBSTANCES DIRECTORATE**

**CHARACTERIZATION REPORT
SITE 08-28B
"O'BRIEN-DARIUS ARSENIC TRIOXIDE REPOSITORY"**

OCTOBER 1989

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FOREWORD

The rapid development of industry and technology has resulted in the production, during recent years, of a growing number of hazardous and toxic chemical waste products. Inadequate scientific knowledge combined with society's lack of concern for protecting the environment have led many of the producers of this type of waste to dispose of it in a careless manner, often in inappropriate sites.

This situation is just as common in Canada as it is in other industrialized countries. It is therefore not surprising that we are now discovering repositories in Quebec containing waste that is potentially hazardous to the health of the population and the environment.

On October 28, 1983, the Quebec Department of the Environment announced the formation of the Group for the Study and Rehabilitation of Hazardous Waste Disposal Sites (GERLED), which has a mandate to produce an inventory of every site in Quebec where hazardous waste may be stored.

Each site in the inventory was evaluated according to the level of risk posed to public health and environmental quality. This evaluation was based on the following factors: the nature and quantity of waste, the containment capacity of the ground, the location of drinking water intakes, the risk to the population of direct contamination by odour and dust from the waste, and the risk of contamination of the food chain, ecosystems and sensitive natural environments.

Based on an analysis of these various factors, each inventoried site was classified in one of the following three categories:

- Category I: sites which currently pose a potential risk to public health and/or a serious potential risk to the environment,
- Category II sites which currently pose a moderate potential risk to the environment and/or a low potential risk to public health, and
- Category III sites which currently pose a low potential risk to the environment and no risk to public health.

This initial phase of work led to the publication, in December 1984, of an inventory of 317 hazardous waste disposal sites, 63 of which were Category I sites. The inventory is updated periodically and, on April 1, 1989, it contained 333 sites, including 66 in Category I.

These Category I sites are now the primary concern of the Department of the Environment's Hazardous Waste Directorate.

A five-stage action plan for the characterization and rehabilitation of these sites has been

developed.

Stage one involves characterizing the sites with a view to obtaining as precise an account as possible of every aspect of the contamination and defining the health risks to the public and the environment in each case. Waste products and contaminants are identified and their impact on the environment and the population is assessed with a view to making a reliable diagnosis of the level of contamination and setting environmental objectives. Hydrogeological and ecotoxicological studies may be necessary.

The second stage involves formulating and selecting remedial measures. The purpose of this stage is to find ways to eliminate or reduce the real and anticipated impact at each hazardous waste storage site with a view to developing a specific rehabilitation program. The remedial measures selected will generally involve eliminating or confining the source of pollutants in order to stop or reduce their release into the environment.

The next stage involves implementation of the remedial measures.

The fourth stage consists in monitoring and evaluating the remedial measures. Its purpose is to ensure the physical integrity of these measures over time, providing for corrective action where necessary.

Finally, stage five involves establishing a surveillance program at the sites being studied. An environmental follow-up is necessary in three types of situations: firstly, in the context of the GERLED drinking water program, in order to verify the quality of water intakes located close to hazardous waste disposal sites; secondly, following a characterization study which concludes that while the risks currently associated with the presence of hazardous waste do not justify immediate remedial action, it is reasonable to assume that a longer-term hazard remains; and finally, following implementation of remedial measures, in order to verify the effectiveness of such measures in the case of rehabilitated sites and assess long-term residual effects.

Characterization of disposal sites for potentially hazardous waste is supervised by the Department, under the responsibility of the owner of the site. The Department participates in the study by providing a multidisciplinary team to supervise the progress and implementation of the characterization study and prepare the Department's position concerning the environmental objectives to be achieved.

This report represents the completion of the first stage of the action plan. It combines the information needed to determine rehabilitation needs and prepare an environmental follow-up.

INTRODUCTION

The arsenic trioxide repository at the O'Brien-Darius mine has been classified as a Category I site under the GERLED (Group for the Study and Rehabilitation of Hazardous Waste Disposal Sites) inventory process. This site poses a potential threat to public health and the receiving waters.

Some 8,938 drums of arsenic trioxide (approximately 1,150 metric tonnes) were stored in two abandoned drifts, which were then sealed before the mine was finally flooded in 1985.

This report deals with the problems of deep underground disposal of this toxic waste and describes the physico-chemical properties of receiving the waters and the contaminants in question. The potential impact of the presence of this repository of toxic waste is assessed. Finally, an environmental follow-up is proposed with a view to monitoring the fate of these contaminants in the environment.

I. DESCRIPTION OF THE MINE SITE

1.1 Introduction and location

The O'Brien-Darius mine site is located in the Abitibi-Témiscamingue administrative region (region 08), about 1.5 km northwest of the municipality of Cadillac (Figure 1). The site can be located on topographic sheet NTS 32D/01.

The site is currently owned by Sulpetro Minerals Ltd. (O'Brien division), which purchased it in 1981.

1.2 History of operations

The O'Brien-Darius Mine was discovered in 1924 and was in production from 1927 until 1956. During this period, the deposit produced approximately 1,150,000 metric tonnes of ore assayed at an average of 16.0 grams Au/tonne with a recovery of 96 percent.⁷ Data collected show a total production of 18,566 kg of gold and 1,625 kg of silver.

Tailings from the O'Brien-Darius Mine were kept in two containment areas of 3 and 7 hectares, respectively. However, these tailings do not seem to have been the source of any particular problems. A healthy plant cover has grown up naturally in an area of approximately 2 hectares. The chemistry of these tailings is given in Table 1.

[Page 20: Key to numbered translations]

1) To Rouyn-Noranda

2) To Val-d'Or

Figure 1

LOCATION OF THE O'BRIEN-DARIUS MINE SITE (08-28)

Source: Department of Energy, Mines
and Resources, Canada
Topographic map 32D

SCALE 1:250,000

Table 1: Chemistry of the O'Brien-Darius mine tailings

| <u>Parameter</u> | <u>Average</u> | <u>Range</u> |
|----------------------|----------------|--------------|
| Ag (g/t) | 0.9 | 0.1 - 3.4 |
| Al (%) | 6.56 | 6.13 - 7.50 |
| As (%) | 0.098 | 0.040 - 0.26 |
| Au (g/t) | 0.1 | |
| Ca (%) | 3.96 | 3.02 - 4.77 |
| Cd (ppm) | <0.2 | <0.2 |
| Co (ppm) | 31.5 | 22 - 66 |
| Cu (ppm) | 76 | 54 - 123 |
| Fe (%) | 6.19 | 5.45 - 7.36 |
| Hg (ppb) | 23 | 10 - 50 |
| Mn (ppm) | 990 | 835 - 1,105 |
| Ni (ppm) | 53 | 41 - 75 |
| Pb (ppm) | 14 | 4 - 42 |
| pH | 7.6 | 6.6 - 8.4 |
| S (%) | 0.09 | 0.04 - 0.14 |
| SiO ₂ (%) | 56.9 | 50.8 - 61.3 |
| Zn (ppm) | 122 | 80 - 195 |

1.3 ORE PROCESSING

Primary crushing of the ore took place in the mine. The ore was then shipped to the surface for processing, which involved crushing, grinding, and gravimetric separation of native gold. The fine gold was then recovered by flotation, grinding and cyanidation followed by absorption of the gold in solution onto carbon.

Most of the gold in the O'Brien-Darius deposit was found in the gangue (50-55%); the remainder was either native gold in veins (25%) or in the crystal lattice of arsenopyrite (25%).¹⁴ The latter accounted for 3 to 4 percent of the ore processed.⁷

In the roasting process, sulfides are heated in air inside a closed reaction chamber. In this way, much of the sulphur, arsenic and antimony are converted to gaseous oxides, producing a porous, permeable residue. This residue then undergoes a cyanide leach in a series of aeration tanks to dissolve the gold. Lime is then added to precipitate the other dissolved metals, and the solution is filtered. The addition of zinc causes the precipitation of a gold-zinc slurry, which is then sent to the smelter, where gold and a base-metal slag are produced.

The gases produced by the ore-roasting process contain calcination residues, sulphur dioxide (H_2S)* and gaseous arsenic trioxide (AsH_2)** at a temperature of approximately 425°C . Dust is removed from these gases in cyclone collectors; they are then cooled before being passed through electronic precipitators, where the remainder of suspended particles are collected. The dust collected in this way will be processed later on with cyanide to recover any gold it may contain.

When the gas produced is cooled to 108°C , the arsenic trioxide is condensed and collected in filter chambers. Once the gas has been "cleaned" in this way, it is discharged through the stacks. The arsenic trioxide dust collected is then placed in water-tight drums for storage on the surface or in underground storage drifts, or sold to potential buyers.²⁰

* The formula for sulphur dioxide is SO_2 ; H_2S is the formula for hydrogen sulphide. [TR]

**The formula for arsenic trioxide is As_2O_3 ; AsH_2 would be an unstable compound. [TR]

II. TAILINGS SITE

2.1 INTRODUCTION AND LOCATION

The 8,938 drums of arsenic trioxide (approximately 1,150 metric tonnes) produced at the O'Brien-Darius deposit were stored in two abandoned drifts. These drifts are approximately 2 metres in width and 2 metres in height and are located at the 450-metre level, to the west of the No. 3 shaft.

The 15-G-West drift is 61 metres in length, and drums are stored along 43 metres of this length. The 15-F-West drift is much longer (almost 530 metres) and there are drums stored along almost its entire length (Figure 2).

2.2 BACKGROUND

- 1956 The drums were stored inside two abandoned drifts. The entrance to each drift was first sealed with a 1.2-metre-thick impermeable concrete cap, and the mine was allowed to flood.
- 1972 Darius Gold Mines pumped out the mine down to below the 460-metre level. Consolidated Goldfields merged with Darius Gold Mines to develop and explore the deposit.
- 1978 The deposit was mined until 1981.
- 1980 Consolidated Goldfields believed it had found a buyer for the arsenic trioxide residue and demolished the concrete bulkhead. A short time later, the buyer withdrew.
- 1981 Sulpetro Minerals Ltd. purchased the O'Brien Mine and tried unsuccessfully to find buyers for the arsenic trioxide residue. The cost of bringing the arsenic trioxide back up to the surface was estimated at \$0.73 per kilogram, while the price offered on the market was barely \$0.37 per kilogram.
- 1985 Second attempt to find a buyer for the arsenic trioxide residue. The cost of having it disposed of by the Stalex process was considered prohibitive.
- April 1985 The Quebec Department of the Environment authorized the installation of a new impermeable, reinforced concrete cap (about 2.3 metres thick) at the entrance to each drift.
- August 1985 The final flooding of the mine was authorized by the Quebec Department of the Environment.

- 1) *ARSENIC TRIOXIDE STORAGE DRIFT*
- 2) CONCRETE CAP 1
- 3) 15-G-West Drift
- 4) 15-F-West Drift
- 5) CONCRETE CAP 2
- 6) 15-14 Drift
- 7) No. 3 SHAFT
- 8) To No. 2 shaft
- 9) Figure 2

PLAN VIEW OF THE ARSENIC TRIOXIDE

the Cadillac Break. The Piché Group is approximately 120 metres thick in the western part of the O'Brien property. This sequence strikes east-west and dips from 80 to 90 degrees south (Figure 3).

From south to north, the sequence consists of basalts, a tuffaceous quartz-feldspar porphyry, a conglomerate, a second tuffaceous quartz-feldspar porphyry (richer in quartz), and finally a member which is a mixture of greywacke, tuff and graphitic argillite in contact with the Cadillac Break.

The 15-F-West and 15-G-West drifts were driven into the two upper members of the Piché Group. The smaller drift (15-G-West) is located in the graphitic argillites and graphitic schists. The talc and chlorite schists of the Cadillac Break are 6 metres north of the 15-G-West drift. The 15-F-West drift, which is further south, is the longer of the two drifts and is located in the quartz-feldspar porphyry in contact with the mixed member.

These two drifts follow the local geologic structures, which basically parallel the schistosity of the rock. There are almost no inclined faults (displacements are minimal) or joints,

and fracture planes are closed. Charlton (1985) states that the rocks around both drifts are hard, competent and do not appear to have been disturbed by the mining of the deposit.

[Page 27: Key to numbered translations]

- 1) **Figure 3**
GEOLOGY OF THE O'BRIEN-DARIUS MINE
- 2) **Source:** **Quebec Department of Natural Resources**
DP-367
- 3) **SCALE**

2.4 ENVIRONMENTAL REMEDIATION

Drums of arsenic trioxide were stored in two underground drifts at the 450-metre level until mining operations ceased in 1956. Water was constantly pumped out to provide uninterrupted access to these drifts and to keep the drums dry. Before allowing the mine to flood, the entrance to each drift was blocked by a 1.2-metre thick concrete wall.

In view of the deterioration of the drums and the various failed attempts to sell the arsenic trioxide, the best option was to contain the drums inside the underground drifts and seal each entrance with a 2.3-metre-thick concrete cap which extended 60 cm beyond the perimeter of the drift opening (figures 4a and 4b). These caps, constructed with 2-cm aggregate, were designed to withstand pressures of the order of 210 kg/cm^2 .

[Page 29: Key to numbered translations]

- 1) Borehole No. 229
- 2) CONCRETE CAP 1
- 3) End of 15-G-West drift at 710 W (90' from this point)
- 4) Drums of arsenic trioxide
- 5) CONCRETE CAP 2
- 6) End of 15-F-West drift at 2240 W (1620' from this point)
- 7) Expanding concrete plug
- 8) Old stope
- 9) Scale: 1"=20'
- 10) Borehole No. 229
- 11) concrete plug in this borehole
- 12) No. 3 SHAFT, 1,500 level
- 13) Figure 4a
LOCATION OF THE CONCRETE CAPS SEALING THE DRIFT ENTRANCES
- 14) Source: J.D. Charlton, Consulting engineer, Ref. 7

[Page 30: Key to numbered translations]

- 1) CONCRETE CAP 1
- 2) CONCRETE CAP 2
- 3) PLAN VIEW
Scale: 1"=10'
- 4) PLAN VIEW
Scale: 1"=10'
- 5) LONGITUDINAL CROSS-SECTION A-A'
- 6) Roof
- 7) Floor
- 8) LONGITUDINAL CROSS-SECTION A-A'
- 9) Roof
- 10) Floor
- 11) Figure 4b
SKETCH OF THE CONCRETE CAPS SEALING THE DRIFT ENTRANCES
Source: J.D. Charlton, Consulting engineer, Ref. 7

2.5 CONDITIONS AT THE STORAGE SITE

During a visit in October 1981, shortly after the bulkheads were demolished, members of the Department of the Environment found that the drums were rusty and in very poor condition. The walls of the drums were considered to be so fragile that it was concluded, at the time, that the bottoms of the drums would probably not support the weight of their contents. At another location further on it was decided that it would be difficult to transport all the drums. A build-up of arsenic trioxide was also noted throughout the storage drifts.¹⁰

These conditions imply that water was able to infiltrate the drifts during the time preceding demolition of the bulkheads. Unfortunately, no information is available concerning the condition of the storage sites when the mine was first pumped out in 1972. Evidently, the water that corroded the drums for 29 years was able to penetrate behind the first bulkhead constructed.

In the report of his visit, Charlton (1985) noted that the storage drifts do not intersect any underground water channels. Only one horizontal drill hole (No. 229) had to be plugged with an expanding cap and concrete. Charlton concluded that it would have been difficult to imagine how a solution could travel very far in undisturbed structural conditions such as those which exist at the 1,500-foot west level.

III. NATURE OF THE CONTAMINANT

3.1 IDENTIFICATION OF THE CONTAMINANT

Arsenic can be present in the natural environment, but generally only in very small amounts. Most of the time, arsenic is present as an impurity in other metal ores such as sulfides of copper, lead, iron, gold, silver and so on. Many sulfide minerals also contain significant amounts of arsenic in solid solution. The most common of these minerals is pyrite, which can contain up to 5 percent arsenic.¹⁶

Arsenic trioxide (As_2O_3) is considered a hazardous waste for regulatory purposes. This compound is a by-product of the roasting of sulfide ores, a process used in the recovery of gold (in this case, from arsenopyrite (FeAsS)). Arsenic trioxide is a very toxic compound used in the manufacture of insecticides, herbicides, rodenticides, mordants for the dye industry and as a decolourizing agent in certain types of glass.

In addition to arsenic, the arsenic trioxide residue contains very high levels of certain other chemical elements that were caught up with it when the exhausted gases cooled.

3.2 PHYSICAL PROPERTIES OF ARSENIC TRIOXIDE

Arsenic trioxide, As_2O_3 , or arsenous anhydride (most commonly written as As_4O_6) is a solid grey substance. It is sparingly soluble in water (approximately 2%), in which it dissolves slowly. The resulting solution is only weakly acidic (arsenous acid, H_3AsO_3). Solubility increases with increasing water temperature. Arsenic trioxide is also soluble in alcohol, hydrochloric acid and in an alkaline medium.

Arsenic trioxide is also nonflammable and non-explosive but it can react with hydrofluoric acid (HF) and fluorine. It is not volatile at room temperature, but this is not the case when it is exposed to heat.

3.3 CHEMICAL PROPERTIES OF ARSENIC TRIOXIDE

The arsenic trioxide residue stored in the drums was analysed for various chemical parameters, and the results are listed in Table 2. As these data suggest, the arsenic trioxide contains elevated levels of As, Cd, Sb and Sn.

The behavior and toxicity of these various contaminants in the environment are discussed in Appendix 1. Unfortunately, no leaching study was performed on this solid residue.

3.4 BIOCHEMICAL PROPERTIES OF ARSENIC TRIOXIDE

The various arsenic compounds can be transformed by a number of bacteria, some of which convert arsenites and arsenic trioxide to trimethylarsine by methylation. Under anaerobic conditions, other bacteria can reduce arsenates to arsenites, which can later be transformed to trimethylarsine by methylation.¹⁶ A number of these reactions will be dealt with later, in another section.

Table 2: Chemical composition of the arsenic trioxide compound

| <u>Parameter</u> | <u>Result of analysis</u> |
|------------------|---------------------------|
| Al (ppm) | 1,800 |
| As (ppm) | 25,232 |
| Cd (ppm) | 3,600 |
| Fe (ppm) | 7,201 |
| Mg (ppm) | 1,000 |
| Pb (ppm) | 100 |
| Sb (ppm) | 100 |
| Sn (ppm) | 3,358 |
| T.O.C. (ppm) | 151 |
| pH | 4.2 |

3.5 TOXICOLOGICAL PROPERTIES OF ARSENIC TRIOXIDE

Arsenic trioxide is highly poisonous to humans. Its effects on the body usually follow absorption; ingestion of as little as 0.1 gram can prove fatal. Arsenic trioxide can also be absorbed by inhalation of airborne dust. Current standards for arsenic trioxide in ambient air in the work environment have been set at 0.5 mg/m³.

Skin absorption of this product may cause a variety of skin diseases (dermatitis, etc.). Symptoms of severe arsenic trioxide poisoning include respiratory problems, severe abdominal pain, vomiting, diarrhea, limb and muscle pain, coldness of the skin, weak or rapid pulse, loss of consciousness, convulsions and even death.

Symptoms of chronic poisoning as a result of long-term exposure to low levels of arsenic are more difficult to diagnose because they can vary widely.

Arsenide trioxide is also known to be highly toxic to most forms of animal life. Plant damage has also been reported in the literature.

IV. SITE DESCRIPTION

4.1 HYDROGEOLOGY

Between 10 and 15 drinking-water wells that are sources of drinking water have been counted within a one-kilometre radius of the O'Brien-Darius mine site. The closest well is approximately 750 metres from the mine site.⁸ It is just under 17 metres deep, which makes it much shallower than the 450-metre depth of the arsenic trioxide storage drifts.

A description of drilling work done two kilometres southwest of the municipality of Cadillac indicates that the thickness of the overburden is approximately 30 metres. The overburden consists primarily of gravel and sand (and is intermittently rocky). In certain places, there are surface deposits of clay. No groundwater analysis is available.

V. ENVIRONMENTAL IMPACT

5.1 GROUNDWATER CONTAMINATION

In 1976, water was sampled at various depths in the mine by the Department of Energy and Resources (J.P. Lalonde, pers. comm.). These results postdate the first period during which arsenic trioxide was stored in the drifts (1956), and were obtained four (4) years before the concrete bulkheads sealing the drifts were demolished. With the exception of arsenic, they are not abnormally high (Table 3).

Table 3: Results of water sampling at the O'Brien-Darius mine

| Level | Hole No. | Cu | Zn | Pb | Ni | Cr | As | Cd |
|----------------------------------|----------|-----|-------|----|-----|----|------------|----|
| -115m. | basin | 12 | 84 | 6 | 24 | 1 | 27 | .6 |
| -180m. | 6F-West | 24 | 146 | 4 | 6 | .5 | <u>68</u> | .1 |
| -230m. | 7F-West | 32 | 144 | 6 | 1 | 2 | <u>119</u> | .1 |
| -300m. | 10H-East | 24 | 98 | 1 | 32 | - | 6 | .4 |
| Level B criteria ¹ | | 500 | 5,000 | 50 | 250 | 40 | 50 | 5 |
| Guidelines ² | | - | - | 50 | - | 50 | 50 | 5 |

N.B. Concentrations are in ppb

- 1: Grille^{***} des critères indicatifs de la contamination des sols et des eaux souterraines
(Guide to soil and groundwater contamination criteria)
- 2: Guidelines for Canadian Drinking Water Quality (Maximum Acceptable Concentration)

Two samples, taken at levels above the storage level (-450 metres), but in the same zone of the mine, have values exceeding those set for level B criteria, indicating contamination of

^{***} See entry No. 11 in the bibliography; should this read "Guide"? [TR]

groundwater and drinking water.¹¹ One of these values even exceeds the level C criterion for arsenic, which is set at 100 ppb.

In the absence of specific details concerning the source of the groundwater sampled, these excessive values cannot be attributed the presence of arsenic trioxide in the mine drifts (particularly since these water samples were not particularly high in cadmium). Water samples collected in close proximity to deposits containing arsenic-rich minerals (such as arsenopyrite) often contain high levels of arsenic (Jean-Pierre Lalond, pers. comm.). Inorganic arsenic is more mobile than organic arsenic and therefore represents a greater hazard since it can be transported by groundwater.⁹

At the -300-metre level, in a zone outside the storage zone, arsenic levels are once again below established groundwater contamination criteria levels.

5.2 OVERALL IMPACT ON THE AQUATIC ECOSYSTEM

Given the shortage of available data and the steps taken to confine the arsenic trioxide residue to the mine drifts, it is unlikely that these drifts, as they were sealed in 1985, could be a direct source of contamination of aquatic and terrestrial ecosystems. The arsenic observed in the surrounding environment in 1976 could have two sources: one natural, and one anthropogenic.

The lithogeochemistry of the Cadillac area is influenced by the presence of geologic formations containing levels of arsenic that are already fairly high because of the presence of arsenopyrite. As a result, the groundwater circulating in these formations may have locally high concentrations of arsenic. For the same reason, soils developed on these particular lithologies should have a higher arsenic content than soils in areas where these minerals are less common.

The high levels of arsenic observed in water at the O'Brien-Darius mine may also originate from the material stored in the -450-metre-level storage drifts. During the 1981 visit, the drums were observed to be in very poor condition. The abnormally high levels seen (119 ppb) could therefore also be partly the result of leakage of the material in these storage drifts.

VI. RISK ASSESSMENT

6.1 SHORT-TERM RISK

Given the economic constraints at the time, construction of an impermeable concrete bulkhead at the entrance to each drift was the safest, most effective solution to the problem of how to protect the resources of the environment from a migrating toxic product.

Despite the fact that the drums are in very poor condition, the short-term risk of arsenic trioxide and associated metals escaping from these drifts is minimal. Indeed, from a purely geological point of view, the lithologies surrounding the drifts were considered capable of adequately containing the arsenic trioxide compound. In all likelihood, there is very little possibility of the arsenic trioxide escaping from these drifts because the structure of the rock in which the 15-G-West and 15-F-West drifts would tend to prevent groundwater flow from reaching the drums of arsenic trioxide. In fact, when the drifts were inspected, no water channel was found to intersect them.⁷

If any material were able to escape the confines of this enclosure, the contaminant solution would be expected to follow the regional groundwater flow pattern and could reach the surface in this way via a network of fractures. The rate of dilution resulting from mixing with groundwater cannot be predicted, but it is unlikely that the resulting solution would be sufficiently concentrated to constitute a direct threat to public health or the environment.

6.2 LONG-TERM RISK

The nearby presence of the Cadillac Break (a few tens of metres) may constitute a long-term risk. Such a risk is inherent in any underground waste disposal project.

The reliability of this method of storage depends on the information available on the stratigraphy, structural geology and hydrogeological characteristics of the host rock. In an ideal setting, the porosity and permeability of the geological formation are low and there is no incompatibility between the host material and the waste itself.⁶

Generally speaking, areas that are strong candidates for safe burial of wastes must satisfy certain criteria including a lack of major faults which could permit leakage of a solution, freedom from seismic activity capable of causing damage to surrounding lithologies, and a low hydraulic gradient. The Cadillac region satisfies all these requirements fairly well, if it is accepted that seismic activity in the area is relatively non-existent.

In itself, underground disposal of waste does not constitute a permanent solution to the problem of the elimination of hazardous substances. It is generally regarded as a "temporary" solution capable, in a worst-case scenario, of causing practically irreversible pollution of the

environment at depth and on the surface.

The technique adopted at the O'Brien-Darius Mine has also been used at the Giant Yellowknife deposit in the Yukon, where arsenic trioxide has been stored in underground vaults since 1951. The storage drifts are located at between 30 and 75 metres depth. The company was required to plug all locations where leakage was possible (the integrity of the seal was even checked under pressure), carefully seal openings with impermeable bulkheads (massive concrete caps) designed to withstand shear stress, and keep the drifts dry. The method used at the time was by far the safest available.¹

A fundamental difference between the approach taken at the O'Brien-Darius Mine and that adopted by Giant Yellowknife Mines lies in the fact that at the latter's site, the drifts are kept dry at all times to prevent water from dissolving the arsenic trioxide residue. Since the deposit is still being mined, it is not known whether the workings will be flooded after operations cease or the storage drifts will have to be kept dry.

VII. CONCLUSIONS AND RECOMMENDATIONS

In 1985, approval was granted for the storage of 8,938 drums of arsenic trioxide inside two underground drifts at the former O'Brien-Darius Mine. This approval was based on studies showing this to be the safest, most effective method of disposing of the arsenic trioxide residue, because the economic climate at the time did not favour the sale of this type of material, and the poor condition of the storage drums meant made it impossible to recover all the contaminants at reasonable cost.

Because the arsenic trioxide residue is buried some 300 metres below the surface, it is now "practically" impossible to access the storage drifts. It is therefore essential that a program be set up to periodically monitor levels of arsenic, cadmium, tin and antimony in the immediate environment of the site, and thus to alert us to any leakage of contaminants from the storage drifts.

The program involves annual monitoring of the heavy-metal content of drinking water in wells situated near the former O'Brien-Darius Mine. Similar monitoring efforts have already been arranged under the GERLED drinking water program.

A sampling station south of the O'Brien-Darius Mine was selected because of its proximity to the site. Because this well is much shallower than the storage drifts, it is unlikely that contamination from the arsenic trioxide residue will be detected. Data from this well also show that the direction of groundwater flow is northward, toward the O'Brien-Darius Mine.

For these reasons, there is virtually no danger that drinking water sources will be contaminated by the arsenic trioxide residue. Results of analyses to date show that none of the parameter limits have been exceeded.

In order to enhance the reliability of the environmental follow-up at the site and to broaden the monitoring zone, the Quebec Department of the Environment should be notified of cases where chronic poisoning is the suspected source of health problems for residents of the municipality of Cadillac and the surrounding area.

APPENDIX

Fate and toxicity of arsenic and associated metals

1. THE FATE OF MAJOR CONTAMINANTS

1.1 Arsenic

The chemistry of arsenic is very similar to that of phosphorus.¹⁵ Arsenic in arsenate form (AsO_4^{-3}) is stable in oxidizing waters; however, arsenite (AsO_3^{-3}) may also be present in surface waters if arsenate oxidation is incomplete. An increase in pH, redox potential or level of dissolved oxygen tend to result in a predominance of species at a higher oxidation state (V). Conversely, under anaerobic conditions, As(III) predominates.⁸ Elemental arsenic and arsine (AsH_3) can also exist in such conditions.^{15,9}

Most of the arsenic in surface waters is present in a soluble form that may co-precipitate with hydrated oxides of iron and aluminum or bind in either adsorbed or chelated form with suspended organic matter or the organic matter in bottom sediments. As(IV) may also be fixed by adsorption on hydrated iron oxides, aluminum hydroxide and clays. As(III) displays a stronger affinity for sulphur; it is easily adsorbed on other metallic sulfides and co-precipitates with them.

In most conditions, dissolved arsenic is probably eliminated through co-precipitation or sorption on hydrated iron oxides.⁸ In fact, arsenic levels are always found to be higher in sediments than in the waters associated with them.¹⁶

In most natural waters, arsenic is present in inorganic form. Surface freshwater systems contain background levels of arsenic of between 0.001 and 0.01 ppm. Levels as high as 0.3 ppm are sometimes seen in the vicinity of arsenic-rich mineral deposits.⁹ In general, arsenic concentrations are higher in groundwater than in surface water. However, in water which has a high organic content, arsenic may be bound with humic colloidal material.^{4,9}

There are many micro-organisms in sediments and soils that are capable of creating reduced and methylated arsenic compounds, thus producing volatile arsines. A significant proportion of the arsenic removed by organisms from an aquatic environment is converted to lipid- or water-soluble organoarsenic compounds.⁹ As(III) and As(V) can form stable bonds with carbon to produce many organoarsenic compounds, some of which are very toxic. One environmentally significant group of such compounds, the methylarsines, is formed by biomethylation of inorganic arsenic compounds. The main arsenic species in the environment is dimethylarsenic acid ($(\text{CH}_3)_2\text{AsOOH}$), and it is ubiquitous. This acid resists oxidation, which suggests that it may have a long residence time in the environment.⁸

There are certain micro-organisms present in water and soil which can also reduce arsenates to arsenites, releasing arsine (AsH_3) into the environment. Arsine is a colourless gas with a garlic-like odour; it is sparingly soluble and highly toxic.⁴ Arsenic is generally considered to be an element with considerable geochemical mobility in rocks; for example, a slight enrichment is seen in sulfide minerals in igneous rocks. Average arsenic levels in rocks are 2 to 3 ppm. Levels of arsenic generally observed in surface soils are a function of the

geologic history of the area in question. In the case of soils developed over sulfide deposits, levels of the order of 8,000 ppm As have been seen.¹⁵ However, levels are most commonly between 0.1 and 40 ppm, with the average ranging from 3 to 6 ppm, depending upon the author. In oxidizing conditions, arsenic is fairly mobile in the surface environment.¹⁹ Inorganic arsenic is also more mobile than organic arsenic and, as a consequence, is a greater threat since it can be caught up in surface or groundwater.⁹

Oxidation of organic matter may result in the release of a certain amount of arsenic into the soil solution, thus making it available to plants. A plant absorbs arsenic through its roots and foliage. It is then transported by the vascular system. Concentrations observed vary according to species, rate of application, the nature of the compound and temperature (an increase in temperature would cause the plant to absorb more arsenic). Arsenic concentration in plants correlates very well with concentrations in the soil.⁹ Terrestrial plants usually contain between 0.002 and 10 ppm total arsenic (with an average of 0.45 ppm). Some plants, particularly those in ore zones, can contain very high concentrations of arsenic.

Arsenic can accumulate and persist for years in vegetation, with greater accumulations seen in aquatic than terrestrial plants. Plant roots are also observed to contain higher levels than their foliage. Plant sensitivity to arsenic depends on their ability to eliminate it.⁴

The amount of available arsenic in cultivated soil is generally considered to be one-tenth of the total arsenic content.¹⁶ In soils, as in water, arsenic persistence and availability to organisms is a function of its degree of fixation by organic matter, clay and sesquioxides of iron and aluminum. The half-life of arsenical compounds in soils is estimated to be between 6.5 and 16 years.^{4,9}

Finally, fine particles of inorganic arsenic oxides and arsenates may be present in the air. In this case, particle size will have a significant effect on rate of penetration of the respiratory system.

1.2 Antimony

The chemical and biological properties of antimony are similar to those of arsenic.⁸ In moderately oxidizing conditions, antimony is found in the hydrated trioxide form ($\text{Sb}_2\text{O}_3 \cdot (\text{H}_2\text{O})_n$). Unlike arsenic, which forms arsenous acid (H_3AsO_3) in slightly oxidizing conditions, an acid containing trivalent antimony is relatively rare. However, antimony salts are quite common.

Because of the relative stability of antimony compounds, given the redox conditions routinely observed in surface waters, most of the antimony that enters the aquatic environment is transported in a dissolved state. While antimony is known to have an affinity for clay and mineral surfaces, it is not known to what degree its concentration in water is reduced by sorption. Antimony also co-precipitates with iron, manganese and aluminum hydroxides. A number of

field studies have shown that antimony may also be bound to sediments, but how often this occurs and to what degree is not known.

To date, few studies have dealt with the bioaccumulation of antimony in aquatic environments. However, bioconcentration factors ranging from 40 to 16,000 have been identified for fresh-water invertebrates and fish, respectively. Although biomethylation has not been observed in the case of antimony, in view of the fact that it occurs in the case of elements close to antimony on the periodic table (ex.: Sn, Pb, As, Se and Te), its occurrence is entirely plausible.⁸

Rocks generally contain 0.2 ppm antimony, while levels in soils are approximately 5 ppm. Concentrations of antimony in Canadian surface waters range from 0.001 to 9.1 mg/l.⁸

High Sb concentrations have generally been associated with high arsenic concentrations above sulfide deposits.¹⁵ Very little data is available concerning the extensiveness of mobilisation and adsorption of antimony in soils. However, this element is generally considered to be weakly mobile in the secondary (surface) environment.¹⁹ Antimony probably exists in a soluble form as an antimonate, while humic complexes are also possible. Antimonates are probably adsorbed onto the same minerals which form bonds with phosphates and arsenates. As yet, nothing is known about the existence of organic derivatives of the biotransformation of antimony in the environment.

1.3 Cadmium

The study of the various cadmium species and of the fate of cadmium in water is complex. Speciation of this element is a function of the pH and hardness of the water as well as the presence of ligands and metallic cations. In fresh water, cadmium exists primarily as a free ion (Cd²⁺), and in the form of cadmium chloride and cadmium carbonate. Up to a pH of approximately 9.0, much of the dissolved cadmium exists as a bivalent cation. However, at pH levels higher than this, its solubility decreases because of the formation of cadmium hydroxide. In reducing conditions, and in the presence of sulphur, insoluble cadmium sulfide is produced.

Most cadmium is eliminated by sorption. In natural waters, cadmium co-precipitates with iron, aluminum and manganese oxides. Cadmium can also be eliminated from solution by substitution of cadmium by calcium ions^{****} in the crystal structure of carbonate minerals. Adsorption of cadmium onto humic substances and other complexing organic agents can play an important role in water with a high organic content.⁸

A study of sediments in the Rouyn-Noranda² area shows the "normal" content in sediments to be less than 0.2 ppm. As in the case of arsenic, evidence of contamination by this

**** Should this read "...substitution of calcium by cadmium ions..."? [TR]

element in surface sediments has been observed (in excess of 100 ppm Cd).

The cadmium concentration of various rocks is generally the same as that of antimony (0.2 ppm). Soils contain between 0.01 and 7 ppm cadmium, with average levels around 1 ppm. Cadmium is relatively immobile in soils and tends to accumulate.¹⁵ A study of Canadian drinking water supplies indicates maximum average values for raw and supply water from lakes and rivers of 0.01 mg/l.⁸

1.4 Tin

In the aquatic environment, tin is generally found as Sn(IV). It is sometimes found in the bivalent form in anaerobic sediments and water with a low redox potential. Sn(IV) can form many inorganic and organometallic compounds. It is strongly adsorbed by the clay fraction of soils.¹⁵ The most common Sn(IV) species in natural water include Sn(OH)_4 , SnO(OH)_2 and SnO(OH)_3^- , with SnO(OH)_2 predominating at pH levels below 7.

Little reliable data is available concerning the fate of inorganic tin in aquatic environments. In general, concentrations of tin increase as follows: water < surface microlayers < sediments.

Methylated tin can be found in aqueous systems. Methyltin may be formed from Sn(II) and Sn(IV) in the presence of certain bacteria (*Pseudomonas* sp.). Sn(IV) can also be methylated in a nutrient medium or in mixtures of water and natural sediments.⁸

Tin levels in soils generally range from 1 to 10 ppm, but are usually less than 5 ppm. In the secondary environment, tin is immobile and moves mainly in detrital form.¹⁹

2. TOXICITY OF CONTAMINANTS

2.1 Arsenic

Arsenic trioxide is a powerful poison which is highly toxic to most life forms, including humans. This product can enter the body by ingestion, inhalation of dust and skin absorption.

It is difficult to assess the overall toxicity of arsenic because it is a function of an individual's tolerance, the nature of the compound and the route of exposure. Toxicity of the various arsenic compounds decreases in the following order: arsine (-III) > organo-arsine > arsenites (III) > arsenoxides (III) > arsenates (V) > pentavalent (V) organic compounds > arsonium compounds > metallic arsenic (0).⁹ In general, trivalent compounds are considered more toxic than pentavalent compounds.^{15,9} Similarly, inorganic compounds are usually more toxic than organic compounds.^{4,9}

Humans are more sensitive than aquatic organisms to arsenic.⁸ However, there is strong evidence of the methylation and/or oxidation of trivalent inorganic arsenic in the human body. Such conversions may constitute the body's detoxification mechanisms.⁹

Arsenic is a cumulative poison, even at low doses, and the respiratory and nervous systems as well as the skin are the critical targets of chronic exposure. Barely a day following exposure, most of the arsenic is in the liver, kidneys, spleen, lungs, muscles and skin, with small amounts in the brain, heart and uterus. Several weeks following initial exposure, arsenic accumulates in ectodermal tissues (hair and nails) because of the high concentration of sulphur-containing proteins in these tissues.⁹

Symptoms of acute poisoning include difficulty breathing, abdominal pain, vomiting, diarrhea and muscle cramps. In more severe cases, the skin is cold, the pulse becomes rapid and weak and there may be loss of consciousness, convulsions and finally death. The liver and kidneys are the organs most sensitive to acute arsenic poisoning.

An acute dose of inorganic arsenic may cause extreme weakness, gastro-intestinal and nervous-system problems as well as damage to the kidneys and ataxia. Chronic poisoning causes a general fatigue, skin changes (dermatitis, etc.) and changes in the kidneys, liver and nervous system. A decrease in growth rate has also been observed.^{4,8,9}

In studies conducted in areas of Chile and Nova Scotia where inorganic arsenic concentrations in the drinking water were 0.05 to 0.96 ppm (with an average of 0.6 ppm) and 0.06 to 0.09 ppm, respectively, it was shown that prolonged use of the water for drinking or cooking produced symptoms of chronic poisoning.⁹

In addition to being considered a teratogen, arsenic is thought to be co-carcinogenic and to increase the risk of cancer among smokers. Significant evidence exists of a link between exposure to arsenic and skin cancer and cancer of the respiratory system. The risk of cancer is increased if, in addition to arsenic, an irritant such as sulphur dioxide or a carcinogenic mixture such as cigarette smoke is present in inhaled air.

The cells of the body absorb arsenic via an active transport system which normally carries phosphate. In this way, arsenic compounds compete with phosphorus for chemical reaction sites and interfere with certain biological processes. Arsenic also interferes with the body's metabolism of selenium.

Arsenic also has an affinity for SH groups found primarily in ectodermal tissues such as hair and nails;⁴ as a result, these groups are good indicators of an excessive intake of arsenic. In fact, there is a significant statistical relationship has been shown to exist between arsenic in water and the level of arsenic in hair; a concentration above 0.05 ± 0.03 mg/l would begin to be stored in the body (hair).¹³

Aquatic animals absorb arsenic through their gills and digestive system. Arsenic from

environmental pollution seems to be absorbed two to three times faster by fish than arsenic from natural sources. Young fish contain proportionately more arsenic than older fish.⁹ A substantial proportion of the arsenic ingested by these aquatic organisms is converted to water- and lipid-soluble organic arsenic compounds. The organic and inorganic compounds are then excreted in bile.

Toxicity of arsenic to aquatic species is a function of the age and type of species, the chemistry and concentration of the arsenic compounds, the exposure time and the physico-chemical conditions (pH, temperature, dissolved O₂, etc.). It is reported that elevated temperatures promote absorption of arsenic by fish and seem to increase the toxicity of the product. The hardness of the water has little effect on the toxicity of arsenic.

Fresh-water invertebrates are generally more affected by arsenic than adult fish. Prolonged exposure to low dosages may cause histopathologic changes in various species; bleeding, cellular necrosis in the heart and liver and ruptured cells in the ovaries (causing a decrease in reproduction rate) have been reported. An increase in the cancer rate among certain species has also been noted.^{4,5,8} Fish living at or near the bottom of a body of water are most likely to concentrate arsenic.

Arsenic accumulates and persists in a broad range of organisms, particularly those at the lower levels of the food chain (algae, coelenterates, mollusks and crustaceans).⁹ Arsenic (V) seems more toxic in plants than arsenic (III). Lower forms of aquatic life (mollusks, crustaceans) can accumulate larger quantities of arsenic than fish. Background levels in aquatic plants have been assessed at 1 mg/kg, while the standard for consumption of marine mollusks is set at 0.4 mg/kg.

Terrestrial wildlife can also be exposed to arsenic through ingestion of food or water, or by inhalation or skin absorption of products containing arsenic. Arsenic accumulates in the liver, kidneys and lungs of almost all mammals. How such compounds are metabolized and eliminated depends upon the species, the route of exposure, the physical and chemical form of the compound and the dose received. Large animals eliminate these compounds more slowly, and organic compounds are eliminated more quickly and more completely than inorganic compounds. Consequently, in contrast to mercury, organic arsenic compounds are considered less toxic than inorganic compounds. Although oxidation and biomethylation of inorganic arsenic has been observed *in vivo*, organic arsenic is not transformed. The urinary tract is the main pathway of elimination, especially for organic compounds.

The phytotoxicity of arsenic is a function of plant species, level of arsenic present in the soil and its physico-chemical characteristics, type of compound and its application rate, level of arsenic in the plant and temperature and moisture conditions. Inorganic arsenic compounds have proven more phytotoxic than organic compounds.⁹

2.2 Toxicity of other heavy metals associated with arsenic

In general, the toxicity to aquatic wildlife of heavy metals associated with arsenic trioxide depends on the concentration, duration of action and species of the toxic material, the physiologic condition and age of the specimen and the physico-chemical parameters of the environment (pH, temperature, level of dissolved oxygen and amount of organic material). All of these physical and chemical parameters affect the way in which such compounds impact on health. These parameters also affect chemical equilibria and, in turn, the liberation and fixation of metal ions. Heavy metal toxicity generally declines with an increase in water hardness.⁵

2.2.1 Antimony

Antimony is not considered essential to life or health in the case of humans or animals. By comparison with other foods, drinking water is generally considered to be a source of only negligible amounts of antimony.⁸

The properties of antimony are similar to those of arsenic, although it is generally considered to be much less toxic. The usual results of prolonged inhalation of antimony are lung disease and skin irritation.

Aquatic plants appear to be more at risk of damage caused by antimony than fish and invertebrates.⁸ Suppression of chlorophyll and a reduction in the number of cells in certain algae species have been observed in affected plants. Data currently available concerning bioconcentration of antimony in the aquatic environment is still incomplete.

2.2.2 Cadmium

Food is considered to be the main source of cadmium in humans. Since it is difficult to limit its intake from this source, it is suggested that as little as possible be ingested in water.⁸

For aquatic biota, acute cadmium toxicity depends upon water hardness, pH, temperature and the presence of organic material, selenium and metal mixtures. For some aquatic species, cadmium toxicity decreases in the presence of calcium (but not magnesium) and selenium, while other elements such as zinc can accentuate this toxicity. It has also been shown that hardness may affect chronic toxicity, with cadmium toxicity varying inversely with hardness. Cadmium is considered to be an extremely toxic, but relatively common element in the environment. A dose of less than 0.01 mg/l is lethal.¹²

Depending on its availability to flora and fauna, cadmium may accumulate in a number of aquatic organisms such as macrophytes, phytoplankton, zooplankton, invertebrates and fish. Compared with the amount of cadmium that accumulates in most other tissues and organs of fish, only a small amount builds up in muscles. Cadmium may also be absorbed in large quantities by aquatic plants, although very little evidence of bioamplification has been found. Bioaccumulation of cadmium generally increases with temperature⁸ and decreases with trophic

level.

At high concentrations, cadmium is not only toxic to terrestrial fauna, but may also be teratogenic and even mutagenic and carcinogenic. Because cadmium accumulates primarily in the liver and kidneys, these organs should be consumed with caution.

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[Page 63: Key to numbered translations]

- 1) Borehole No. 229
- 2) CONCRETE CAP 1
- 3) End of 15-G-West drift at 710 W (90' from this point)
- 4) Drums of arsenic trioxide
- 5) CONCRETE CAP 2
- 6) End of 15-F-West drift at 2240 W (1620' from this point)
- 7) Expanding concrete plug
- 8) Old stope
- 9) Scale: 1"=20'
- 10) Borehole No. 229
- 11) concrete plug in this borehole
- 12) No. 3 SHAFT, 1,500 level
- 13) CONCRETE CAP 1
- 14) PLAN VIEW
Scale: 1"=10'
- 15) CONCRETE CAP 2
- 16) PLAN VIEW
Scale: 1"=10'
- 17) LONGITUDINAL CROSS-SECTION A-A'
- 18) Roof
- 19) Floor
- 20) LONGITUDINAL CROSS-SECTION A-A'

- 21) Roof
- 22) Floor
- 23) TRANSVERSE CROSS-SECTION B-B'
- 24) TRANSVERSE CROSS-SECTION B-B'
- 25) TRANSVERSE CROSS-SECTION C-C'
- 26) TRANSVERSE CROSS-SECTION C-C'
- 27) NOTE: The concrete to be used in these caps will 3000 psi 3/4" aggregate.
Box 1 - Slashing required
Box 2 - Concrete
- 28)

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|---|---------------------------------|---|
| <div style="display: flex; justify-content: space-between;"> <div><i>SULPETRO MINERALS LIMITED</i></div> <div><i>March 7, 1985</i></div> </div> | | |
| Plans for two proposed concrete caps to seal arsenic trioxide inside the O'Brien Mine | | |
| Scales: as indicated | Cadillac Township NTS 32/D/1 | Drawing: J.D. Charlton. Approved: E.S. Short |