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ARSENIC CONCENTRATIONS IN SUSPENDED AND SETTLEABLE  
PARTICULATE MATTER IN YELLOWKNIFE, NORTHWEST TERRITORIES

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ABSTRACT

*For over three decades the City of Yellowknife has been subjected to arsenic particulate fallout from nearby gold milling operations. Environment Canada, in accordance with the Canadian Public Health Association task force recommendations and based on the government's concern for the health of the local population, has collected hi-vol suspended particulate, snow and settleable particulate samples as part of its ongoing arsenic monitoring program. This paper outlines the location of sampling sites, sampling procedures, analytical techniques, and results obtained. Comparison of recent results with the previously published results indicate that total suspended particulate levels and total particulate deposition rates have decreased marginally, however substantial reduction in ambient arsenic levels and total arsenic deposition rates have occurred. An overview of the industry's emission reduction strategy and federal mechanisms intended to regulate emissions from gold roasting operations is also presented.*

## Introduction

Since 1948, the residents of the City of Yellowknife in Canada's Northwest Territories have been exposed to concentrations of arsenic in the ambient air as a result of gold mining and milling operations in the City. Gold in the ore body is found in association with arsenopyrite. Recovery of the gold is achieved by roasting, causing the arsenic to be oxidized into arsenic trioxide and arsenic particulates which are emitted from the roaster stack. It has been estimated that up to 16,000 lbs of arsenic were released to the atmosphere per day during the early years of mining operation.

Presently only Giant Yellowknife Mines Ltd still continues to roast its ore. Con Mine Ltd. ceased its roasting operations in 1970; however, the arsenic storage ponds at Con Mine still constitute a lesser source of fugitive emissions.

The airborne arsenic has contaminated the snow and nearby lakes so that they can no longer be recommended as a source of drinking water; has raised questions about the quality of garden vegetables grown in the area and has been of considerable concern as a human toxin.

The arsenic trioxide and arsenate particulates enter the body by ingestion, inhalation, or by absorption through the skin. Once absorbed, trivalent arsenic reacts with sulphydryl groups (-SH) of proteins and enzymes to produce known or suspected harmful effects.

Since 1973, the Environmental Protection Service has monitored arsenic concentrations in Yellowknife. Considerable information has now been accumulated through deployment of dustfall cylinders, high-volume air samplers, snow samplers, stack emission surveys, as well as through discussions with mill personnel on emission inventories, production levels and emission control strategy.

A discussion of the air monitoring programs and review of the emission control strategies at Giant Yellowknife Mine, leading to the reduction in ambient arsenic levels is presented below.

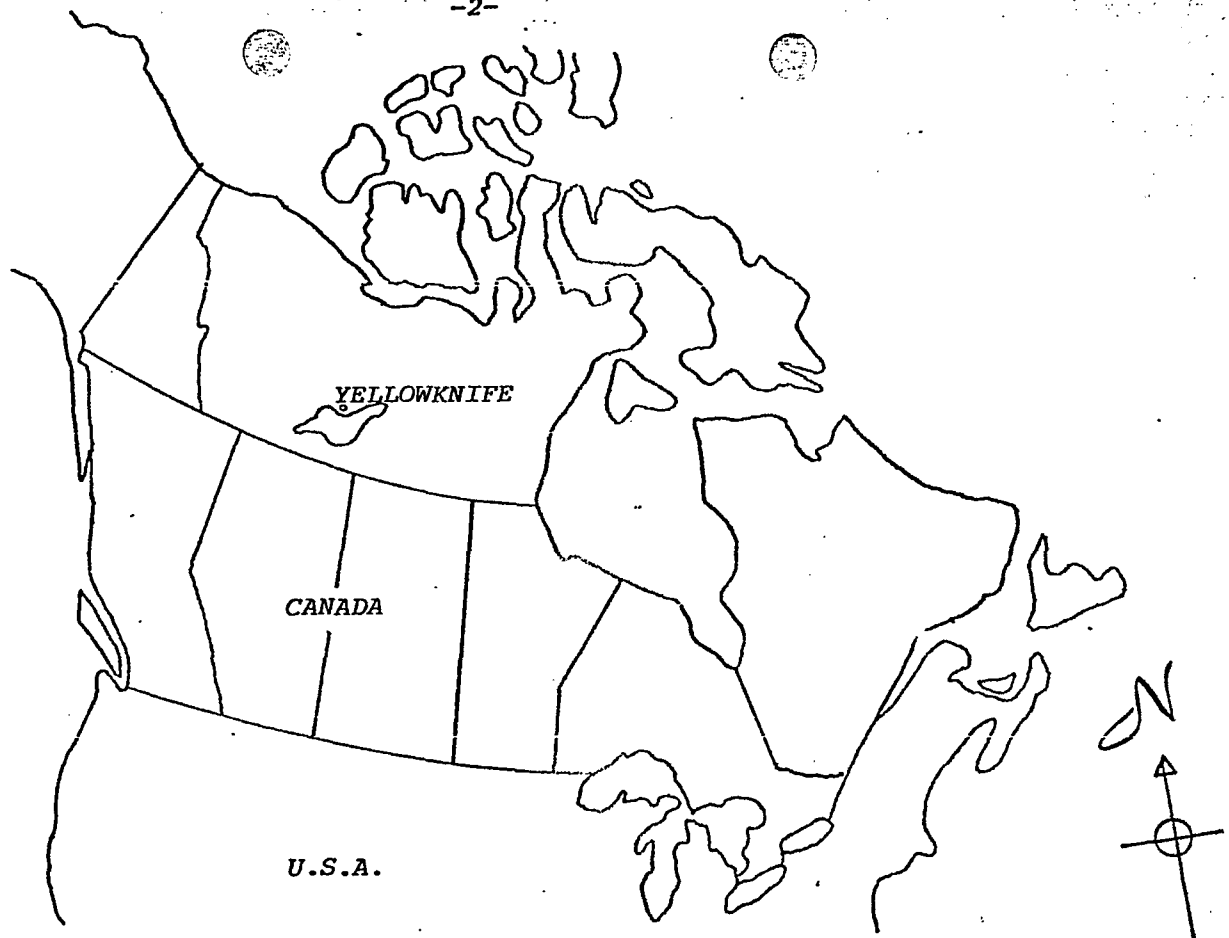


Figure 1. City of Yellowknife, Northwest Territories

#### Arsenic Sources

The City of Yellowknife situated on the north shore of Canada's Great Slave Lake (Figure 1.) is located between two gold producing companies: Giant Yellowknife Gold Mines Limited, 5.6 kilometers to the north, and Con Mine, a subsidiary of Cominco Limited, 0.8 kilometers to the south.

Historically both operations were sources of ambient arsenic. With the closure of Con Mines' roasting operation in November 1970, remaining sources of arsenic emissions considered important are from Giant's roaster operation and to a lesser extent fugitive dusts from Con's dry tailings and arsenic storage ponds. Details of Giant's roaster operation and arsenic emission control strategy are presented later in this paper.

#### Ambient Monitoring Program

Over the past six years ambient air in the Yellowknife area has been monitored for arsenic through deployment of dust-fall jars and automatic hi-vol samplers strategically located at varying distances from the major source, Giant Mines. In addition cored snow samples have been collected to assess winter deposition rates. An analysis of historical wind data has indicated prevailing wind direction during the summer (May-August) to be from the south to east quadrant whereas during the winter, from the northwest or east quadrant. Having identified the source and prevailing wind directions, the location of sampling sites were chosen (see Figure 2). Access to sites, availability of electricity, and topography imposed additional constraints.

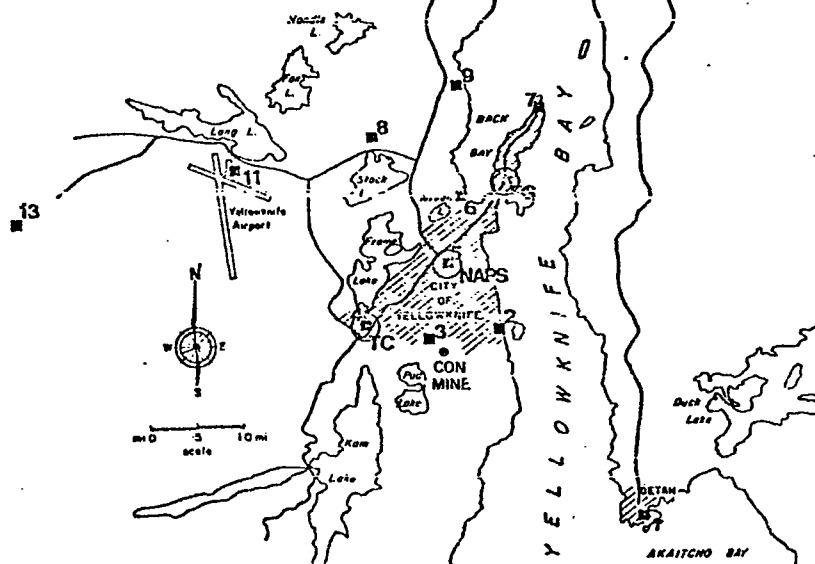
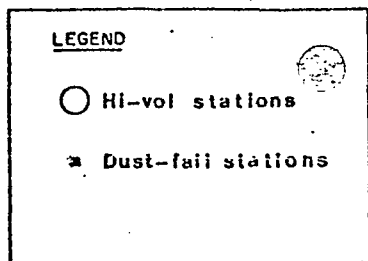


Figure 2. Dust-fall and hi-vol sampling sites around Yellowknife

#### Sample Collection Methods

*Dust-fall* measurements were made on the basis of monthly collection of dust into 15.2cm ID, 45.7cm tall, 6.9 litre nalgene jars normally mounted on stands or poles one to two meters above ground level; sometimes mounted higher where security requirements necessitated. Collected material combined with container washings were transferred to the laboratory in separate labelled plastic bottles for:

- Simple gravimetric analysis, expressed in terms of tonnes of particulates/square kilometer/month
- arsenic analysis utilizing the Vasak Sedivek (pyridine) and more recently the graphite furnace technique, expressed in terms of kilograms or arsenic/square kilometer/month.

*Hi-vol* suspended particulate samples were collected by passing metered ambient air through glass fibre filters over a continuous 24-hour period. Each sampler was automatically activated each sixth day of the survey and the filters later recovered for:

- gravimetric analysis, expressed as micrograms of particulate/m<sup>3</sup>, and
- arsenic analysis (Vasak Sedivak and graphite furnace techniques), expressed as micrograms of arsenic/m<sup>3</sup>.

*Snow Samples* were collected towards the end of the winter season by coring through an entire depth of snow to obtain composite samples. Samples were then subsequently transferred to individually marked plastic bags for laboratory analysis. Results expressed as milligrams of arsenic/litre of melted snow.

## Surveys Results

Data for surveys presented here were obtained from two earlier published reports prepared by the Environmental Protection Service, Northwest Region,<sup>2,3</sup> one unpublished paper<sup>4</sup>, and recent survey records collected and compiled by the authors.

### Dust-fall Surveys

During two five-month survey periods June - October 1975 and 1978, monthly dust-fall samples were collected from thirteen stations representative of the Yellowknife area.

A comparison of the geometric mean particulate deposition rate (expressed as tonnes/square kilometer/month) for the two periods is provided in Table Ia. A similar comparison for arsenic deposition (expressed as kilograms/square kilometer/month) is provided in Table Ib.

Table Ia      Particulate deposition rates during June - October at thirteen locations in the Yellowknife area (tonnes/km<sup>2</sup>/mo.)

	<u>June</u>	<u>July</u>	<u>August</u>	<u>September</u>	<u>October</u>	<u>Five-Month Average</u>
1975	3.45	4.82	2.70	1.77	0.96	2.37
1978	4.70	2.05	1.23	3.52	2.34	2.50

Table Ib      Arsenic deposition rates for stations reported in Table Ia (kg/km<sup>2</sup>/mo.)

	<u>June</u>	<u>July</u>	<u>August</u>	<u>September</u>	<u>October</u>	<u>Five-Month Average</u>
1975	0.53	0.89	1.10	0.70	0.66	0.77
1978	0.17	0.07	0.18	0.15	0.13	0.13

Although a marginal increase in average particulate fallout was recorded for the five month period compared, a substantial reduction in arsenic deposition has occurred. Dustfall samples collected June - August 1979 confirm a similar trend.

The annual geometric mean arsenic deposition from June 1978 to May 1979 was calculated to be 0.12kg/km<sup>2</sup>/mo.

# High-Vol Surveys

Various locations in the Yellowknife area have been monitoring suspended particulates for over five years using the high-volume air sampler techniques. Suspended particulate concentrations, including arsenic, were earlier reported by Hazra and Prokopuk. To maintain a continuous watch on the ambient concentrations of arsenic in the Yellowknife area, three sites used in earlier studies have continued to operate and supply information. One such location, in the centre of Yellowknife, contributes to the National Air Pollution Surveillance (NAPS) Network of stations<sup>5</sup> selected to monitor urban air in major cities across Canada.

Recent survey information collected from July 1978 - June 1979 is compared to an earlier 1975 survey in Tables IIa and IIb below.

From Table IIa, stations FG and NAPS show a marginal decrease in average suspended particulate levels while stations TC and FG show a dramatic drop in the number of sample occurrences where Canada's Ambient Air Quality Maximum Acceptable level for suspended particulates ( $120 \text{ ug/m}^3$ -24 hour) are exceeded. The downtown Yellowknife NAPS station continues however to record elevated levels, which is not considered unusual.

From Table IIb all three stations show a substantial reduction in average arsenic concentration from 1975 to 1978 including a reduction in the number of occurrences where arsenic concentrations exceed  $0.10 \text{ ug/m}^3$ . Because many samples (34%) of the recent survey were analyzed at  $<0.01 \text{ ug arsenic/m}^3$  (the lower level of detection reported), the exact arsenic concentration is indeterminable.

Table IIa Comparison of hi-vol survey results for particulate concentrations

Survey Date	Station Location	Number Samples Collected	Maximum ( $\text{ug/m}^3$ )	Average ( $\text{ug/m}^3$ )	Occurance of Samples $>120 \text{ ug/m}^3$	% Frequency Occurance $>120 \text{ ug/m}^3$
1975	TC	47	451	74	20	42.6
1978-79	TC	45	102	27	0	0.0
1975	FG	44	261	32	6	13.6
1978-79	FG	36	123	30	1	2.8
1975	NAPS	50	425	73	10	20.0
1978-79	NAPS	45	439	52	12	26.7

TC - Trailer Court (See Figure 2)

FG - Fisheries Garage (See Figure 2)

Table IIb Comparison of hi-vol survey results for arsenic concentration showing reduction in contamination

Survey Date	Station Location	Number Samples Collected	Maximum ug/m <sup>3</sup>	Average ug/m <sup>3</sup>	Occurrence of Samples >0.10 ug/m <sup>3</sup>	% Frequency Occurrence >0.10 ug/m <sup>3</sup>
1975	TC	47	0.53	0.03	6	12.8
1978-79	TC	45	0.22	<0.02	2	4.4
1975	FG	45	0.31	0.03	10	22.2
1978-79	FG	36	0.11	<0.02	3	8.3
1975	NAPS	50	0.31	0.03	7	14.0
1978-79	NAPS	45	0.11	<0.02	2	4.4

TC - Trailer Court

FG - Fisheries Garage

#### Snow Surveys

Core samples are representative of all deposition and precipitation events occurring since the first snow cover of the season. Towards the end of the winter season in 1974-75 and again in 1977-78, samples of snow were collected and analyzed for a wide range of elements, including arsenic. At the time of the survey primary concern centered around the use of snow as a source of potable water.

An analysis of the data obtained from the surveys in comparison with the specifications of the Canadian Drinking Water Standards indicates the following:

- 1) for the 1975 survey (52 samples collected) the concentration of arsenic in 83% of the samples was greater than the maximum permissible level of 0.05 mg/l specified by the Standards, and 15% of the values were at least one order of magnitude greater than the limit; most samples (90%) did not fall within the range of pH specified by the Standards.
- 2) For the 1978 survey (54 samples collected) the concentration of arsenic in 50% of the samples exceeded the Standards and 1% of the samples were at least one order of magnitude greater than the limit; again most samples (85%) did not fall within the range of pH specified by the Standards.

It should be noted that the Canadian Public Health Association (CPHA) later recommended among other things that melted snow not be used as potable water, that the community be advised of the risk, and that adequate potable water be made available in unserved communities (Recommendations edited by authors).



From the analysis of snow core data and individual arsenic deposition isopleths (superimposed in Figure 3), two results are clearly evident:

- Giant Mines Limited continues to be the most significant source of arsenic to the Yellowknife ambient air, and
- a substantial reduction in arsenic deposition rates are observed in 1978 in comparison to 1975.

The geometric mean arsenic concentration in melted snow samples was determined to be 0.05 mg/ml in 1978, reduced from 0.17 mg/ml in 1975.

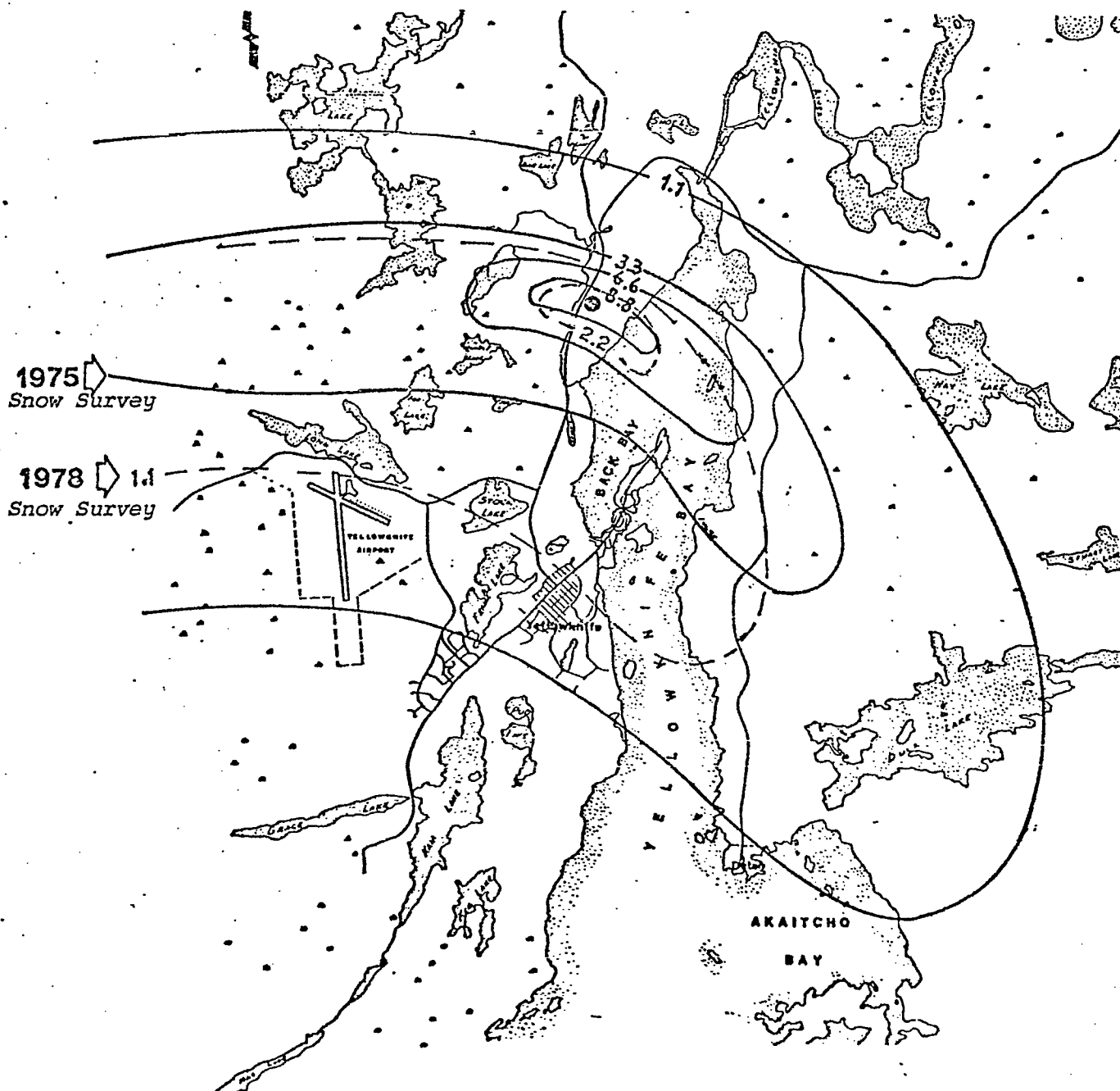


Figure 3. City of Yellowknife and surrounding lakes showing arsenic deposition isopleths ( $\text{kg}/\text{km}^2/\text{mo.}$ )

## Summary of Survey Results

It is clearly evident that between 1975-1978 substantial reductions occurred in arsenic concentrations in the ambient air around Yellowknife.

From Table Ib average arsenic deposition rates are shown to have declined eighty-three percent during the five month interval compared. From Table IIB annual average arsenic concentrations in suspended particulates are shown to have declined by at least thirty-three percent, with the majority of 1978 samples analysed at or close to the lower detection limit. From winter snow surveys the geometric mean arsenic concentration in melted snow samples declined seventy-one percent. It is believed these reductions are a direct result of improved emission controls at Giant Mines Ltd., described later in this paper.

Between 1975-1978 total suspended particulate concentrations were only marginally reduced. The bulk of suspended or settleable particulates measured are believed derived from natural or man-made sources not associated with gold recovery operations. As a result little if any reduction in suspended or settleable particulate concentrations are anticipated for the future.

### The Giant Mine Process

As reported earlier the bulk of arsenic contamination to the Yellowknife atmosphere is due to gold roasting operations at Giant. Here gold is extracted using conventional mining and milling processes as depicted in the process flow diagram in Figure 4.

In the operation ore is hoisted to the surface from underground mines or excavated from open pits near the mill and reduced in size through simple crushing and milling operations.

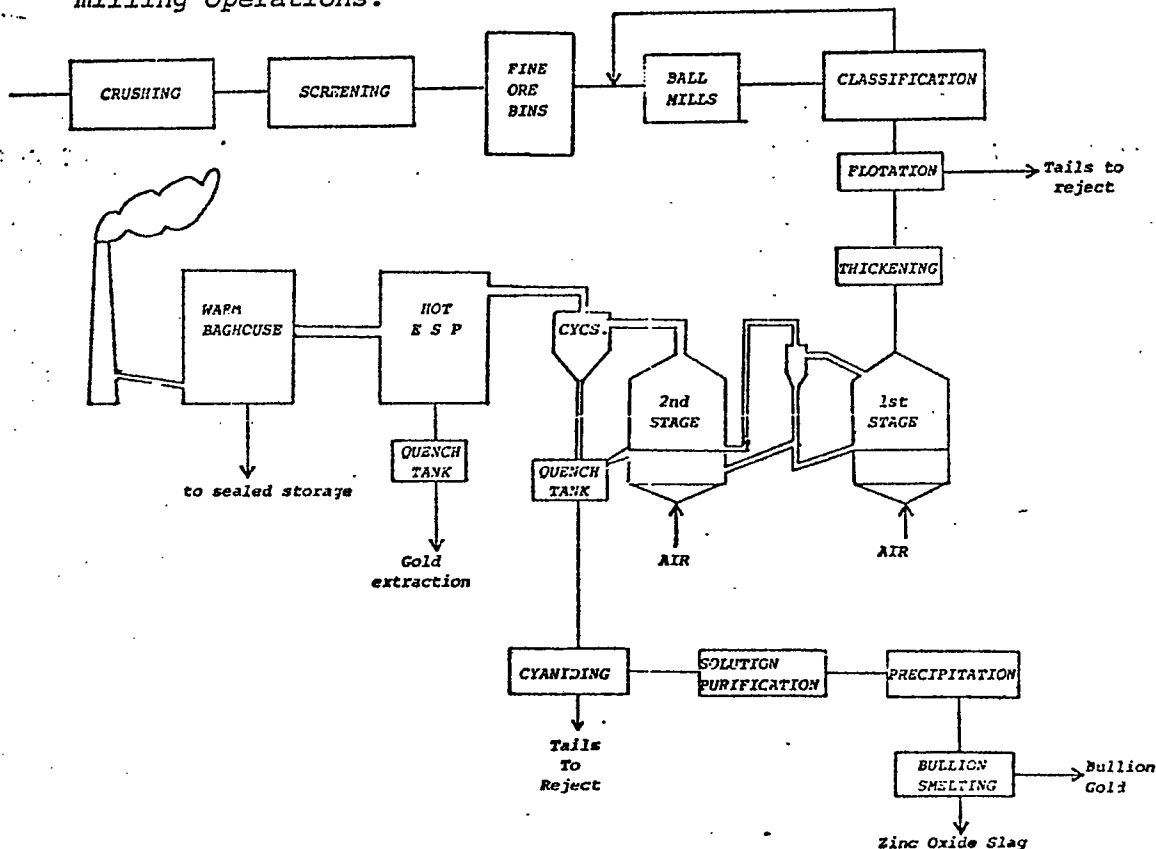


Figure 4. The Giant Mine Process

Following size reduction, a flotation process separates out waste rock to retain a more concentrated mixture of gold and sulphide mineral. The concentrate is then roasted at 480°C to remove arsenic, sulphur and antimony creating a porous calcine which is treated in a cyanidation circuit to precipitate the gold, later recovered in a small gold-bullion furnace.

#### Emission Control

Of primary concern is the cleansing of arsenic laden gases driven off during fluosolids roasting. To maximize arsenic removal, the hot gases from the roaster are first passed through a hot electrostatic precipitator (Cottrell), cooled with ambient air and then passed through a warm (104°C) baghouse (Dracco) before exiting the stack. It is in these controlled cleaning stages that many pioneering and significant refinements in arsenic emission control technology have been made at Giant. Table III provides a chronological history of emissions and emission control developments at Giant. The key to efficient arsenic containment appears to rest with controlled cooling of the hot arsenic laden vapors to form a collectable particulate at temperatures as close to the acid dew point as possible; above the dew point arsenic vaporization continues and loss of collection efficiency results, below the dew point acid attack deteriorates filter bags, baghouse, flue system and stack also resulting in a loss of collection efficiency.

For the past several years gold roasting operators in Canada, such as Giant, have been aware of the federal government's ongoing development of national emission regulations to limit arsenic emissions from their plants. In concert with this, added recommendations to Giant from the CPHA Task Force to "take immediate steps to reduce arsenic emissions by commencing application of the best available technology" are believed to have caused arsenic emission levels to drop, as recorded in emission testing <sup>6,7,8</sup>.

The most significant refinements in the arsenic emission reduction strategy appear to have centered around:

- increased awareness of the importance in arsenic vapor cooling;
- introduction of improved filter bags having greater acid resistance;
- 80% reduction in baghouse shaking frequency by using photohelic pressure sensors;
- controlled shaking to one inch pressure drop to retain an all important filter cake to enhance collection;
- increased baghouse inspections.

Table III Giant Yellowknife Mines History of Emissions and Control Strategy

<u>Date</u>	<u>Emission Estimates (kg/day As)</u>	<u>Sources</u>	<u>Developments in Emission Control</u>
1948	7200	a	Operations began
1949			Allis Chalmers "Edwards" type hearth roaster installed
1951			two unit cold Cottrell ESP installed
1953	3100	b	2.7m diameter 45.7m high stack installed
1955			Two unit hot EPS installed
1958			Dracco baghouse installed new fluosolids roaster installed
1962	70-900	a,b,c	Cold ESP converted to hot mode
1977			baghouse controls upgraded, sur- veillance improved and inspections increased; improved stack testing procedures implemented by company
1978			bag quality improved through replace- ment campaign; average emissions approximately 20mg/SCM (from c)

Sources: a. Estimated values from company production data  
b. Company emission data as given to Health and Welfare Canada  
c. Company emission reports  
d. Environmental Protection Service emission testing

References (2,6,7,8)

### *Impact of Proposed Regulation*

The federal government through Environment Canada and upon the recommendation from the Minister of National Health and Welfare, has determined that control of arsenical compounds emitted from gold smelters to the ambient air is required pursuant to the Federal Clean Air Act. A proposed regulation with an effective date of July 31, 1980 is now being considered.

In December 1977 the federal government announced that all new federal regulations in the area of health, safety, and fairness that could have a significant effect on the Canadian economy would be subject to a Socio-Economic Impact Analyses (SEIA) as part of the basis for deliberation on a proposed regulation. A SEIA of the proposed federal regulation on arsenic from gold roasting has therefore been prepared in draft form and the impact of the regulation on Giant Mines Ltd. is clearly identified!.

The new regulation would limit the emissions from gold roasting operations, such as at Giant Yellowknife Mines Limited, to a level of:

- a) 20 mg per standard cubic meter measured in the stack;
- 7 X X b) 20 mg per standard cubic meter for handling operations associated with the disposal of collected arsenic dust.

Laboratory experiments on pure arsenic trioxide suggest that at the minimum baghouse inlet temperature of 104°C currently maintained by Giant, approximately 9 mg As/SCM exist as gaseous arsenic trioxide; the baghouse must therefore effectively limit arsenic particulate emissions to approximately 11 mg As/SCM to meet the proposed Regulation.

At Giant, stack emission surveys conducted by the Environmental Protection Service (August 1978) and the Company (twenty-five surveys since September 1977) indicate average emission levels range at 20-30 mg As/SCM. With the Company's continued attention to emission control operations coupled with their ongoing bag filter replacement program, it is felt that Giant could meet the proposed regulations, once promulgated.

## References

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