

CONTROLLING ARSENIC RELEASES TO THE ENVIRONMENT

IN THE

NORTHWEST TERRITORIES

Discussion of Management Options

For Consultation

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1.0 INTRODUCTION

Arsenic is a naturally-occurring substance found most often in compounds with sulphur, either alone or in combination with various metals. Arsenic is present in the environment because of natural processes, as well as human activities including metal processing, the use of arsenical pesticides, coal-fired power generation and the disposal of domestic and industrial waste materials.

Metal production facilities are the principal sources of arsenic released into the Canadian environment from human activities. Based on release data from the National Pollutant Release Inventory (NPRI) for 1994, 45 facilities reported total arsenic releases of 47.2 tonnes to water, 132.9 tonnes to the air, 3800.0 tonnes to underground, and 0.3 tonnes to land.

In 1994, "Arsenic and its Compounds (Priority Substances List Assessment Report)" was released by the Government of Canada. The report concluded that arsenic and its inorganic compounds are "toxic" as interpreted under section 11 of the Canadian Environmental Protection Act (CEPA).

In June 1995, the Government of Canada released its "Toxic Substances Management Policy" which outlines the steps which may be taken for the Priority Substances List (PSL) substances that were assessed and found to be "toxic". According to this policy, arsenic is to be managed as a "Track 2 toxic substance", and should therefore be subjected to "full life-cycle management" to "prevent or minimize" its release into the environment. Factors that must be considered during the development of control measures for Track 2 substances are:

- source contribution to total release;
- environmental/health effects;
- technological factors; and
- socio-economic factors.

Also in June 1995, the House of Commons Standing Committee on Environment and Sustainable Development released its report "It's About our Health! Towards Pollution Prevention". Chapter 13 of this report deals with "The North" and Recommendation No.107 in this chapter states: "The Committee recommends that the Minister of the Environment and the Minister of Health conclude their determination of the measures they plan to apply to arsenic by December 1995". While Recommendation No. 107 itself is quite broad, the information preceding the recommendation appears to restrict it to arsenic releases in the Northwest Territories.

Environment Canada assembled a technical task force in August, 1995 with expertise in pollution control technology, environmental modelling and sampling, health issues, economics, and legal issues. Staff of Environment Canada consulted representatives of the Government of the Northwest Territories, the Yellowknives Dene First Nation, and the mining industry, to obtain input in developing an action plan. The draft action plan was released for public consultation in December, 1995. Comments received on the draft were incorporated and the final report entitled "Reducing Arsenic Releases to the Environment

in the Northwest Territories - Action Plan to Develop Control Options" was released in May 1996.

The Task Force recognized the presence of some information gaps in the areas of technology and socio-economics, and engaged consultants to conduct studies and provide the required information.

This paper describes the results of studies conducted by the Task Force and by other agencies regarding arsenic in the Northwest Territories, and discusses technical and management options available for the reduction of arsenic releases in the Northwest Territories. Its purpose is to facilitate consultation with people of the Northwest Territories to decide on which of the options should be pursued.

The list of references at the end of this report provides the sources of the detailed information that was used in the preparation of this report.

2.0 ENVIRONMENTAL ARSENIC STANDARDS

There are no federal standards in Canada for atmospheric arsenic releases or for ambient air quality. Because of this, the Task Force examined other political jurisdictions around the world to determine the standards for arsenic being used elsewhere. The findings are summarized in Tables 2-1 and 2-2.

TABLE 2-1
ARSENIC RELEASE STANDARDS

Country	Emission Limit	Type Source of
France	1.0 milligrams per cubic meter	Incineration of municipal waste
Canada (British Columbia)	0.7 milligrams per cubic meter	Thermal treatment facilities
	7 - 11.5 milligrams per cubic meter	Control Objectives for Gaseous and Particulate Emissions
	0.1 Kilograms per tonne of copper or lead produced	Control Objectives for Gaseous and Particulate Emissions for Specified Processes (applicable to copper smelting and lead smelting and refining operations)
U.S.A.	11.6 milligrams per cubic meter (expressed as particulate)	National Emission Standards for Inorganic Arsenic Emissions from Primary Copper Smelters. Applicable to secondary hooding on primary copper smelter convertors which process greater than 75 kilograms per hour of arsenic, averaged on a monthly basis.

TABLE 2-2**AMBIENT AIR QUALITY STANDARDS FOR ARSENIC**

Country	½ hour	24 hour	annual
Canada (Ontario)	1.0 microgram per cubic meter (interim)	0.30 micrograms per cubic meter (interim)	
USA (Kansas)			0.000233 micrograms per cubic meter
USA (Montana)		0.390 micrograms per cubic meter	0.07 micrograms per cubic meter
USA (New York)			0.67 micrograms per cubic meter
USA (Oklahoma)		0.020 micrograms per cubic meter	
USA (Rhode Island)			0.002 micrograms per cubic meter
USA (South Carolina)		1.0 microgram per cubic meter	
USA (Virginia)		3.3 micrograms per cubic meter	
USA (Vermont)			0.00023 micrograms per cubic meter
Sweden		30.0 micrograms per cubic meter	

3.0 ARSENIC RELEASES IN THE NORTHWEST TERRITORIES

The major man-made sources of arsenic releases in the NWT are mines, mills and refiners. Arsenic is often found at substantial concentrations in metal-bearing rock (ore). When ore is mined and then processed to extract the metals, arsenic can be released to the environment. Two stages of the processing system - milling and smelting - are the major sources of arsenic releases to the environment.

Milling results in the production of "concentrate" that contains both the desirable metals and some portion of the host rock. Waste products or "tailings" contain arsenic among other substances. Typically, the tailings slurry is stored in a tailings pond where the solids are allowed to settle, and the liquid is released to the environment either with or without further treatment. This can result in arsenic releases to adjacent surface and sub-surface waters.

At most gold mines, the concentrate is further refined to recover almost pure gold. Refining results in the production of additional tailings which are usually mixed with the tailings from the milling process. The refining process can involve the use of heat and/or pressure (smelting) to remove wastes from the concentrate, and this can result in arsenic releases to the air.

At present, there are 8 metal mines/mills operating in the NWT.

Base Metal

- Nanisivik Mine, Baffin Island
- Polaris Mine, Little Cornwallis Island

Gold

- Colomac Mine, Steeves Lake
- Giant Mine, Yellowknife
- Lupin Mine, Contwoyto Lake
- Miramar Con Mine, Yellowknife
- Mon Mine, Discovery Lake
- Ptarmigan Mine, Yellowknife

All of these facilities have the potential to release arsenic into water because the ore is milled on site. Therefore, the discussion of arsenic releases to water will include all 8 mines.

The base metal mines do not operate smelters on-site, and therefore there is little potential for arsenic releases to the air. Of the gold mines, only Giant and Miramar Con utilize a smelting process for refining their concentrate. Therefore, the discussion of arsenic releases to the air will focus on these two facilities.

3.1 Releases to Water

Environment Canada has examined arsenic releases to water for all mines operating in

the Northwest Territories. This involved the review of existing regulatory controls and other initiatives that may be addressing this issue, and research on actual releases to water from operating mines.

As mentioned previously, the primary source of arsenic releases to water is the decant of water from tailings ponds. Other potential sources include surface runoff from contaminated soils, and the unique case of Giant Mine in Yellowknife where arsenic trioxide is stored underground in unused mine workings. There are concerns that the stored arsenic could be transported by groundwater and eventually enter Great Slave Lake.

Arsenic releases into water from the mines and mills operating in the NWT are controlled through the terms of Water Licenses issued by the NWT Water Board pursuant to the Northwest Territories Water Act or the Nunavut Water Board. Gold mines and mills using cyanidation (Colomac, Giant, Lupin, and Miramar Con) are bound by the provisions of subsection 36(3) of the Fisheries Act. All other metal mines and mills must comply with the Metal Mine Liquid Effluent Regulations (MMLER) pursuant to the Fisheries Act. In 1994, liquid effluent from each mine was in compliance with the arsenic levels specified in the Water Licenses and the MMLER.

The special situation of the arsenic trioxide stored underground at Giant Mine is addressed in the Mine's 1994 Water License, which requires that Giant Mine conduct and submit the studies on the technical and environmental feasibility of the storage system. These studies are scheduled for completion by the expiration of the Water License in 1998.

In 1994 and 1995, DOE obtained 4 samples of liquid effluent from Giant Mine and 2 samples of liquid effluent from Miramar Con Mine, and conducted bioassay testing using rainbow trout. Three of the four samples from Giant Mine passed the bioassay test, indicating that the effluent complies with the requirements of subsection 36(3) of the Fisheries Act. The 1994 sample from Miramar Con failed the bioassay test at the outfall pipe from the mill, however, the 1995 sample, taken at the end of the treatment system, passed the bioassay test, indicating that the effluent complies with the requirements of subsection 36(3) of the Fisheries Act.

The "AQUAMIN" Program has examined the effectiveness of the MMLER with a view toward amending the MMLER if the program finds that these Regulations do not adequately protect the environment. The final report from the AQUAMIN Program, released in September, 1996, recommends that these regulations be amended to apply to gold mines using cyanidation, such as Giant Mine and Miramar Con Mine. AQUAMIN did not recommend changes to any of the effluent quality parameters currently in the MMLER, indicating that the regulated limits for arsenic in liquid effluent from metal mines are adequate to protect the aquatic environment.

3.2 Releases to Air

Environment Canada has examined arsenic releases to the air from the mines operating smelters in the Northwest Territories. This involved the review of existing regulatory controls and other initiatives that may be addressing this issue, and research on actual releases to the air from these mines.

The only facilities in the Northwest Territories operating smelters are Miramar Con Mine Ltd.'s Con Mine and Royal Oak Mines Inc.'s Giant Mine, both located in Yellowknife. Con Mine operates a pressure leaching system or autoclave, while Giant Mine operates a gold roaster. With the use of a pressure leaching system, there are no atmospheric emissions. Therefore the only facility releasing arsenic to the air is Giant Mine.

There are presently no regulations controlling the release of arsenic to the air in the NWT, although the statutory authority exists under both federal and territorial legislation. Environment Canada's primary legislation for dealing with arsenic releases to the air is the Canadian Environmental Protection Act.

3.3 Other Regulatory Initiatives

Under the federal "Strategic Options Process" (SOP), fourteen Issue Tables have been established to examine reductions of the releases of toxic substances to the environment. Four of these are examining the need for the management of arsenic, as well as other toxic substances being released from base metal smelters, coal-fuelled power plants, iron and steel plants, and wood preservation facilities. Gold roasters are not being addressed within the scope of work of any of the fourteen Issue Tables.

Prior to the formation of this Task Force, the Government of the Northwest Territories (GNWT) had begun the development of regulations to control releases of sulphur dioxide from gold roasters in the NWT. Frequent communications have taken place between Environment Canada and the GNWT to ensure compatibility of the two initiatives. It was critical that any measures proposed to reduce sulphur dioxide releases not result in increased arsenic releases, and vice versa. The GNWT's draft regulation was released for public consultation in May 1996.

3.4 Conclusions

Based upon the assembled information, the Task Force determined that releases of liquid effluent containing arsenic in the Northwest Territories, including issues related to the underground storage of arsenic trioxide at Giant Mine, could be adequately controlled through the water licensing processes of the NWT Water Board and the Nunavut Water Board.

Arsenic releases to the air in the Northwest Territories are not subject to regulatory control, and are not being examined by any other federal or territorial regulatory initiatives.

Because of this, the Task Force has determined that, in the Northwest Territories, atmospheric releases of arsenic from gold roasting warrant the highest priority for federal action.

The gold roaster at Giant Mine in Yellowknife is the only anthropogenic source of arsenic releases to the air in the NWT. Because the intent of CEPA is to control activities on a nation-wide or industry-wide basis, this examination of options for the reduction of arsenic releases considered releases from all gold roasters in Canada. Besides the gold roaster at Giant Mine, there is only one other gold roaster in Canada. It is located at Golden Bear Mine in British Columbia, and has been out of operation since 1994.

4.0 AIR QUALITY AND MONITORING

4.1 Releases to the Air from Gold Roasters

Historic Releases

Two gold roasters have operated in Yellowknife (see Figure 1). Con Mine (now known as Miramar Con Mine) began roasting in April 1942, but suspended operations in August 1943 because of World War II. Roasting operations resumed in July 1948 and continued until the roaster was decommissioned in November 1970. Giant Yellowknife Mine (now known as Giant Mine) began roasting in January 1949, and has operated the roaster continuously since then.

In the early years, there was no direct measurement of arsenic releases from the roasters. However, the mines did provide estimates based on mass balance calculations. Later, the mines did measure arsenic releases, but used an old method for stack testing until 1977. All of the available data up to and including 1977 are summarized in Table 4-1.

Examination of this data leads to the following observations:

1. From 1949 to 1951, approximately 7400 kilograms of arsenic were released per day to the atmosphere from the two roasters. Almost 99% came from Giant Mine.
2. From 1954 until 1958, approximately 3300 kilograms of arsenic per day were released to the atmosphere from the roasters. Almost 95% came from Giant Mine.
3. From 1959 until 1970, approximately 370 kilograms of arsenic per day were released to the atmosphere from the roasters. Approximately 50% came from each mine.
4. From 1971 to 1977, approximately 350 kilograms of arsenic per day were released to the atmosphere, and all of it was from Giant Mine.

Standard Method for Stack Testing

In about 1974, Environment Canada began developing a Standard Method for arsenic stack testing. Environment Canada tested the Giant stack in 1975 to assist in evaluating the new Standard Method, and in 1978 Giant Mine began sampling the stack emissions using the new Standard Method. The "Standard Reference Method for Source Testing: Measurement of Arsenic Emissions from Gold Roasters" was finalized in May 1979 and, it is widely accepted and used when testing atmospheric releases of arsenic.

In the Standard Method, a composite gas sample is withdrawn for a minimum of 5 minutes from a number of different points in the stack using a vacuum pump. Each sample passes through three water-filled impingers to collect the arsenic.

The number and location of sampling points is determined by the physical dimensions of each individual stack. For the roaster stack at Giant Mine, there are 32 sampling points, which results in a minimum sampling duration of 2 hours and 40 minutes. Ambient air temperature can affect the scheduling of sampling because of the use of water-filled impingers.

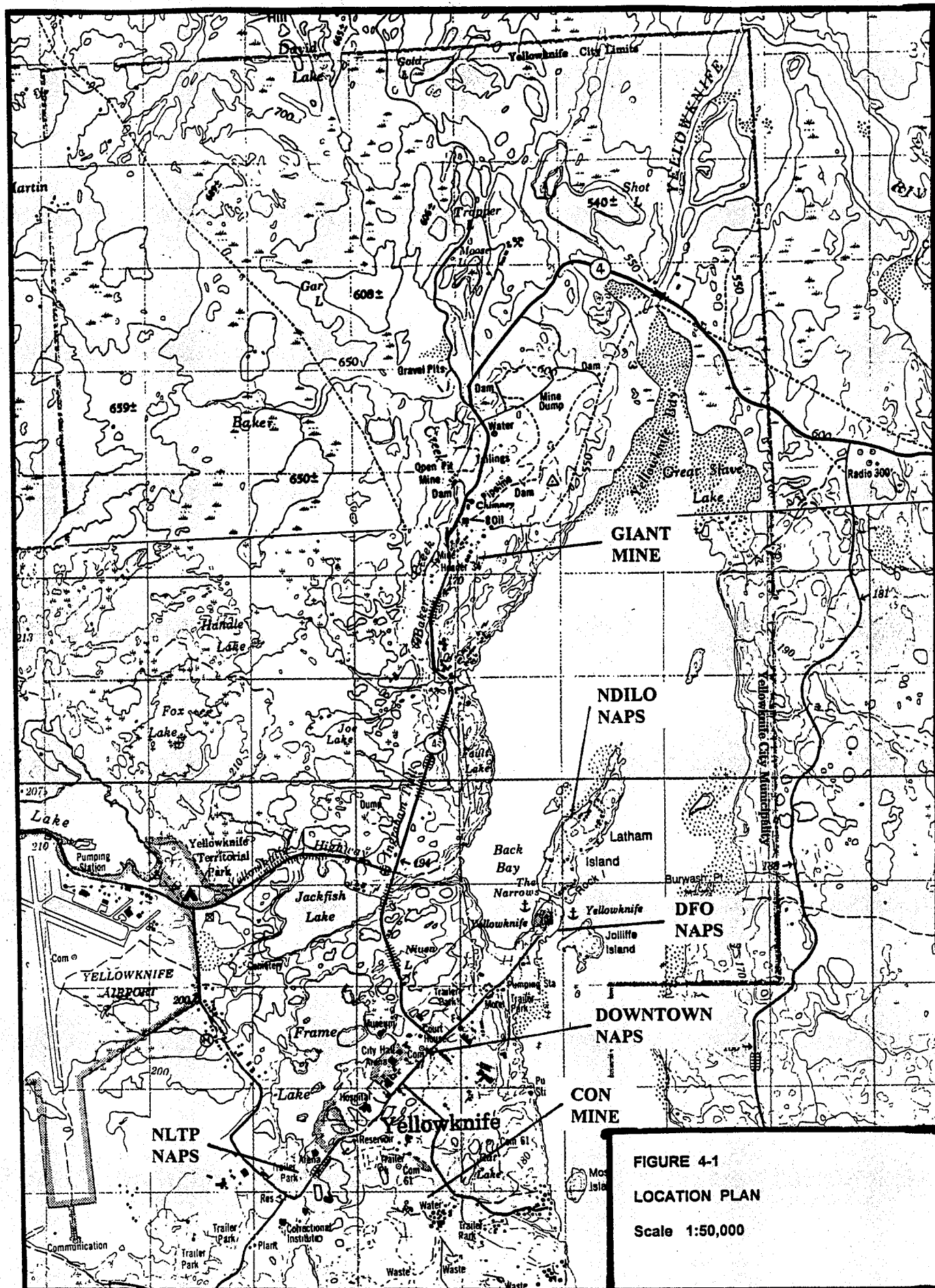


FIGURE 4-1
LOCATION PLAN
Scale 1:50,000

Modern Releases to the Air from Gold Roasters

While Environment Canada was developing the Standard Method, Giant Mine was examining new operation and maintenance procedures for the air pollution control system to improve atmospheric releases of arsenic from the roaster. The new procedures were implemented in 1977, and are still being used today.

The results of stack tests since 1975 using the Standard Method are summarized in Table 4-2, and the tests which did not follow the Standard Method since it was adopted are indicated. Examination of the data in Table 4-2 leads to the following observations:

1. Arsenic emission rates decreased substantially between 1975 and 1978 mainly as a result of changes that Giant Mine made to the operation and maintenance procedures for their air pollution control system in 1977.
2. With the exception of the two tests in 1988, releases have been relatively constant since 1978. Giant Mine has acknowledged that they experienced a number of operational difficulties in the air pollution control system during 1988.
3. The average concentrations and daily release rates of arsenic in 47 tests since 1978 (including the 1988 tests) are 24.1 milligrams/cubic metre (mg/m^3) and 30.5 kilograms/day (kg/day) respectively.
4. The six tests performed in 1983 by Environment Canada found the average concentration and daily release rate of arsenic to be 25.0 mg/m^3 and 27.0 kg/day respectively.

TABLE 4-1**ESTIMATED ARSENIC RELEASES TO THE AIR
FROM GOLD ROASTERS IN YELLOWKNIFE 1949 TO 1977**

YEAR	GIANT (kg/day)	CON (kg/day)	TOTAL (kg/day)
1949	7300	NR	>7300
1950	7300	90	7390
1951	7300	90	7390
1952	NR	90	NR
1953	NR	NR	NR
1954	5500	180	5680
1955	2900	185	3085
1956	2700	190	2890
1957	3000	180	3180
1958	1500	175	1675
1959	52	200	252
1960	75	265	340
1961	150	200	350
1962	150	200	350
1963	150	200	350
1964	310	135	445
1965	NR	170	NR
1966	240	140	380
1967	130	155	285
1968	230	150	380
1969	300	195	495
1970	220	250	470
1971	880	0	880
1972	400	0	400
1973	400	0	400
1974	220	0	220
1975	215	0	215
1976	165	0	165
1977	135	0	135

NR indicates no results available.

TABLE 4-2

**ARSENIC RELEASES TO THE AIR FROM GIANT MINE ROASTER
RESULTS OF STACK TESTING, 1975 TO 1995**

	DATE	YEAR	EMISSION RATES		FLOW	TESTER
			(mg/m ³)	(kg/day)	(m ³ /h)	
		1975		76.1		EPS
(1)		1978	18.7	26.1		Giant
(2)		1979	10.7	14.6		Giant
	May 27	1981	6.7	8.8	54,500	Giant
	May 28	1981	6.7	7.5	52,500	Giant
	June 24	1981	4.4	6.5	61,300	Giant
	July 14	1981	5.5	8.3	63,200	Giant
	July 31	1981	5.8	8.1	58,400	Giant
	August 7	1981	18.4	27.2	61,500	Giant
	August 20	1981	18.9	24.0	53,000	Giant
	August 21	1981	9.3	11.2	50,100	Giant
	August 25	1981	14.1	17.3	51,000	Giant
(3)	Dec. 15	1982	10.2	13.2	54,200	Giant
	July 5	1983	15.8	17.0	44,900	EPS
	July 7	1983	19.0	21.8	47,700	EPS
	July 8	1983	37.0	40.8	46,000	EPS
	July 11	1983	29.7	28.1	39,400	EPS
	July 12	1983	23.0	25.7	46,400	EPS
	July 13	1983	25.3	28.8	47,400	EPS
(3)	Nov. 19	1985	14.4	27.1	78,000	Giant
	Nov. 8	1986	16.3	24.3	62,000	Giant
(4)	Sept. 28	1988	158.1	185.0	48,800	Giant
	October 5	1988	198.8	232.8	48,600	Giant
(3)	October 11	1989	24.0	26.4	45,300	Giant
(3)	August 17	1990	34.3	37.1	45,000	Giant
(3)	June 24	1991	16.3	15.2	38,700	Giant
(5)	August 29	1991	25.8	59.0	95,000	Contractor
	October 30	1991	23.0	25.9	46,900	Contractor
	October 14	1993	27.0	29.2	39,900	Giant
	Sept. 13	1995	3.2	3.2	45,000	Contractor

NOTES:

1. Average of 16 separate tests.
2. Average of 4 separate tests.
3. The Standard Method was not followed.
4. The results for the test of September 28, 1988 cannot be assessed because complete test documentation is not available.
5. Giant disputes these results for daily mass emissions and stack flow. They believe that the contractor erred by a factor of two.

4.2 Ambient Air Monitoring in Yellowknife

Monitoring to determine the concentration of arsenic in the air in Yellowknife has been conducted sporadically since 1973 and continuously since 1984 using high-volume (Hivol) air samplers. Hivol samplers use a vacuum pump to draw ambient air through a filter for a 24-hour period every six days. The filters are weighed to determine total particulates, and analyzed to determine concentrations of various substances.

By way of a brief history of ambient air monitoring for arsenic in Yellowknife, in 1973 and 1974, stations were operated at the Department of National Defence building in downtown Yellowknife, at Giant Mine, and at Yellowknife Airport. In 1975, six additional stations were established and operated for one year, including stations at the Department of Fisheries and Oceans warehouse in Old Town, and at a location in Northland Trailer Park which, at the time, was at the southern edge of Yellowknife. Monitoring was not done in 1976 and 1977, however some of the stations were reactivated in 1978. From 1978 to 1982, arsenic monitoring was done at the following locations:

- Federal Building in downtown Yellowknife
- Department of Fisheries and Oceans warehouse in Old Town
- Northland Trailer Park.

Arsenic monitoring was again suspended in 1983, but it resumed in 1984 from the station at the Federal Building in downtown Yellowknife. This station is part of the National Air Pollution Surveillance (NAPS) network, which monitors air quality in all major Canadian cities. Table 4-3 summarizes the results of the ambient air monitoring at the stations listed above. In April 1996, Environment Canada established another Hivol monitoring station in Ndilo approximately 1.5 kilometres from Giant Mine. Results from this station are not yet available. The locations of the monitoring stations are shown in Figure 4.1.

Observations based on the data in Table 4-3, indicate the following:

1. During the years when three monitors were operating within the City, arsenic concentrations were relatively similar at each monitoring location.
2. From 1973 to 1978, annual mean arsenic concentration in the ambient air fell by approximately 80% to 0.018 micrograms/cubic metre ($\mu\text{g}/\text{m}^3$).
3. The annual mean concentration of arsenic in the ambient air from 1978 to 1995 has ranged from 0.006 to 0.023 $\mu\text{g}/\text{m}^3$ and has averaged 0.013 $\mu\text{g}/\text{m}^3$.
4. The mean concentration of arsenic in the ambient air from 1989 to 1995 was 0.009 $\mu\text{g}/\text{m}^3$.
5. The highest concentration of arsenic measured over a 24-hour period in Yellowknife since 1989 was 0.251 $\mu\text{g}/\text{m}^3$.

TABLE 4-3

**YELLOWKNIFE AIR QUALITY MONITORING RESULTS
ARSENIC CONCENTRATIONS, 1973 TO 1995**

YEAR	DOWNTOWN		DFO		NLTP		OVERALL	
	MEAN	MAX.	MEAN	MAX.	MEAN	MAX.	MEAN	MAX.
1973	0.090	0.420					0.090	0.420
1974	0.080	0.540					0.080	0.540
1975	0.040	0.590	0.030	0.310	0.030	0.530	0.035	0.590
1978	0.018	0.108	0.021	0.244	0.020	0.223	0.020	0.244
1979	0.018	0.110	0.014	0.087	0.016	0.101	0.016	0.110
1980	0.007	0.027	0.005	0.050	0.005	0.035	0.006	0.050
1981	0.008	0.135	0.006	0.066	0.006	0.110	0.007	0.135
1982	0.007	0.028	0.005	0.025	0.004	0.049	0.006	0.049
1984	N/A	0.182					N/A	0.182
1985	0.021	0.288					0.021	0.288
1986	0.016	0.176					0.016	0.176
1987	0.021	0.238					0.021	0.238
1988	0.023	1.819					0.023	1.819
1989	0.010	0.047					0.010	0.047
1990	0.009	0.039					0.009	0.039
1991	0.006	0.037					0.006	0.037
1992	0.008	0.083					0.008	0.083
1993	0.015	0.251					0.015	0.251
1994	0.006	0.203					0.006	0.203
1995	0.011	0.141					0.011	0.141

Notes:

- All values have units of micrograms/cubic metre.
- N/A indicates not enough data to calculate a statistically significant mean.
- DFO stands for the Department of Fisheries and Oceans warehouse in Old Town.
- NLTP stands for Northland Trailer Park.

4.3 CONCLUSIONS

Voluntary control measures instituted at Giant Mine reduced arsenic releases from their gold roaster to the atmosphere from approximately 7300 kg/day in the early 1950's to approximately 30 kg/day by 1978. Atmospheric arsenic releases from Giant Mine have remained at this level since 1978. Also since 1978, the concentration of arsenic being released to the atmosphere has averaged 25 mg/m³.

The amount of arsenic released to the air varies due to a number of factors. Taking into account these variations, the existing air pollution control system at Giant Mine could be expected to consistently achieve an arsenic concentration of 30 mg/m³.

Arsenic levels measured in the ambient air in Yellowknife have improved substantially since 1975, and are now similar to the levels measured near arsenic point sources in other parts of Canada. The annual mean ambient concentrations of airborne arsenic measured in downtown Yellowknife over the period from 1978 to 1995 ranged from 0.006 to 0.023 µg/m³, averaging 0.013 µg/m³. From 1989 to 1995, the annual mean arsenic concentrations of airborne arsenic averaged 0.009 µg/m³. This compares with a mean annual concentration of 0.001 µg/m³ measured in cities across the rest of Canada, and a range of between 0.0086 and 0.22 µg/m³ measured near industrial arsenic point sources in Canada.

5.0 HEALTH EFFECTS OF ARSENIC

Arsenic is quite widely distributed on the surface of the earth, being the 20th most common trace element found within the earth's crust. It is usually found in association with other metals such as copper, cobalt, lead, zinc, gold, etc. In marine environments, it also occurs as part of organic complexes (some shellfish may contain as much as 10 mg/kg of arsenic).

Elemental arsenic and naturally occurring "bound" forms do not appear to pose a significant health threat to human beings. Therefore, most human or wildlife exposures to arsenic that are of concern occur in occupational settings or in the context of industrial activity. Arsenic trioxide (As_2O_3) and arsine gas (AsH_3) are the most toxic forms of arsenic.

Arsenic trioxide is a significant by-product of metal smelting and is also found in the production and use of some forms of pesticides, the production of opal glass and certain kinds of enamelling, some pharmaceuticals, paints and coatings, leather tanning and taxidermist products. For airborne particles, the optimum size for deposition into the lower tracheobronchial tree is within the 0.1 to 2 μm range. High temperature combustion sources (such as smelters) produce particles of 1 μm and less, which are readily respirable.

5.1 Priority Substances List Assessment

The primary concern related to the exposure of Yellowknife residents to airborne releases of arsenic relates to the potential carcinogenic risk associated with chronic exposure. This risk was identified in the "Priority Substances List Assessment on Arsenic and its Compounds" (PSL Assessment Report).

An association between inhalation of inorganic arsenic and respiratory cancer has been observed in several case reports and numerous epidemiological investigations of workers in smelters and arsenical pesticide production facilities. Ingestion of arsenic in drinking water or medicines has also been linked with skin cancer and cancers of various internal organs, including the bladder, kidney, lung and liver. Based primarily upon these reports, the PSL Assessment Report concluded that arsenic is a non-threshold carcinogen, meaning that it is assumed that there is some probability of carcinogenic potential at any level of exposure.

Based upon three studies conducted on smelter workers, the PSL Assessment Report estimated the respiratory cancer potency ($\text{TD}_{0.5}$) for airborne arsenic to be between 7.38 and 50.0 $\mu\text{g}/\text{m}^3$. The potency is an expression of the concentration of arsenic to which the workers were exposed which induced a 5% increase in the incidence of respiratory cancer in the population of smelter workers. An exposure/potency index (EPI) can then be calculated for the inhabitants of Yellowknife, defined as the ratio of their exposure to the levels which induced cancer in the smelter workers. Such a ratio provides an indicator of where the population exposure falls, relative to the $\text{TD}_{0.5}$. In this case, the EPI would range from 1.14×10^{-3} to 1.8×10^{-4} , that is, the public is exposed to concentrations of

arsenic at levels between approximately one thousand and twenty thousand times lower than those which induced cancer in 5% of exposed smelter workers.

Another way to consider the cancer risk is to extrapolate from exposure levels experienced in the industrial exposure studies, down to the exposures experienced in the community. Although there is a wide range of inherent uncertainty around such extrapolations, they provide a useful reference point.

Assuming a linear dose-response relationship, the existing ambient air levels would be expected to create an increased cancer risk ranging between 9×10^{-6} and 5.74×10^{-5} over normal expected rates of cancer. Put differently, if one million people were exposed to this range of airborne arsenic over an average 70 year lifetime, 9 to 57 additional deaths due to lung cancer would probably be observed over what would otherwise occur. Assuming a population for Yellowknife of 15,175 (Statistics Canada 1993), this translates to between 0.14 and 0.86 additional deaths due to lung cancer attributable to exposure to airborne arsenic via inhalation over the 70 year lifespan of the exposed population.

While these risk estimates put the cancer risk into numerical perspective, it must be noted that arsenic was designated a non-threshold carcinogen (as noted above), and, therefore, there is some level of risk at any exposure level. It should also be noted that numerical estimates of risk carry with them inherent uncertainties which may extend over orders of magnitude.

5.2 Conclusions

Although the health risk to the population of Yellowknife from exposure to current levels of airborne arsenic would be considered low relative to the risks encountered in day-to-day life, they are considered to be high in comparison with the risks generally associated with other environmental contaminants.

6.0 GIANT MINE MILL PROCESS AND AIR POLLUTION CONTROL

6.1 Introduction

The Giant Mine is located just north of the city of Yellowknife in the Northwest Territories. The property was discovered in 1937 and the Mine commenced production in 1947. Previous owners include Falconbridge Nickel Mines Limited and Pamour Resources Limited. Royal Oak Mines Inc. has owned and operated the mine since 1990. The head office for Royal Oak Mines Inc. is located in Kirkland, Washington.

The Giant Mine site is on Commissioner's Land, meaning that a Land Lease (#L-3668T) for the site has been issued by the GNWT's Department of Municipal and Community Affairs.

6.2 Milling

Gold present in the Giant ore is associated with the arsenic-bearing sulphide mineral arsenopyrite. The ore is refractory, meaning that the arsenopyrite mineral structure must be broken down and oxidized to allow the effective recovery of the contained gold. The arsenopyrite and other sulphide minerals are first concentrated by flotation. The flotation concentrates are then roasted and leached in cyanide to achieve an overall gold recovery of 87.5 %. The milling capacity of the ore processing plant at the Giant Mine is 1200 tonnes per day with a roasting capacity of 180 tonnes per day of flotation concentrate.

Simplified mill flowsheets are shown in Figures 6.1, 6.2, 6.3, and 6.4 for the following circuits:

- i) Grinding - Flotation Circuit;
- ii) Roaster Calcine Leach Circuit;
- iii) Roaster Dust Treatment Circuit; and
- iv) Roaster Gas Cleaning Circuit.

Ore is crushed underground in a primary jaw crusher and then hoisted to surface through "C" shaft to a surface coarse ore storage bin. Additional ore is truck-hauled to surface through several underground ramp systems. The combined ore is then crushed and screened at a three stage surface crushing plant with material smaller than 10 millimetre being conveyed into the mill fine ore storage bins. Ore is drawn off the mill storage bins into two parallel primary grinding lines each consisting of a 2.4 metre diameter x 3.0 metre long ball mill working in closed circuit with a spiral classifier. Water is added to the ore at the feed end of the two ball mills. The spiral classifier is a particle sizing device using the size and specific gravity of the ground ore particles to separate fine particles from coarse particles. The coarse particles are returned to the primary ball mill to be ground again while the fine particles overflow the spiral classifier. The combined overflow from both spiral classifiers is then screened to remove wood chips and other debris that may interfere with later process equipment.

The screened classifier overflow is then subjected to a processing step called flotation where, under controlled conditions, the sulphide minerals are separated from the ground ore slurry. The sulphide minerals contained in the Giant ore are primarily arsenopyrite and pyrite. The surface of these sulphide minerals is coated with copper sulphate which is added at the feed end of the ball mill. The copper ions selectively coat the surfaces of the sulphide minerals. A chemical flotation collector called xanthate is added at the classifier overflows and attaches itself to the coated sulphide mineral. The xanthate has a high affinity for air which is bubbled through the flotation cells. A commercial frothing agent (Dowfroth) is added to the slurry at the chip screen and provides a strong stable froth when air is bubbled through the slurry. The xanthate and the attached sulphide minerals attach themselves to these air bubbles and float to the surface of the flotation cell. At the surface of the flotation cell, this sulphide-mineral-rich froth is skimmed into a concentrate launder and collected for further processing.

The flotation circuit is broken into two sections set in series. The first section is called the rougher circuit. Material that did not float off in the rougher circuit is reground in two parallel regrinding circuits each consisting of a ball mill working in closed circuit with a set of cyclone sizing devices. The fine particles contained in the cyclone overflow from these two regrind circuits are combined and subjected to a second flotation circuit called the scavenger circuit. Additional copper sulphate, xanthate, and Dowfroth are added to the regrind circuits.

The flotation circuit is essentially a pre-concentrating step enabling Royal Oak to recover 95 % of the gold contained in the 1200 tonnes per day of ore milled into a sulphide mineral concentrate that weighs 180 tonnes per day. The remaining 1020 tonnes per day containing 5 % of the gold are rejected to the tailings impoundment area as what are called flotation tailings.

The flotation concentrates from both the rougher and scavenger circuits are combined and dewatered in a circuit using a dewatering cyclone and a thickener. The water is returned to the grinding circuit as a recycle stream. The principal gold-bearing mineral contained in this flotation concentrate is arsenopyrite, which is an arsenic-iron sulphide. The gold is interstitially locked inside the arsenopyrite mineral matrix making it resistant to recovery without first destroying the arsenopyrite structure, hence the term refractory gold.

6.3 Roasting

The ore at Giant Mine is refractory, meaning that a considerable portion of the gold is locked in pyrite and arsenopyrite minerals and is not amenable to conventional cyanide leaching processes. Roasting operations commenced in 1949 with an Edwards-type hearth roaster which was replaced in 1952 by a two-stage slurry roaster. In 1958 a larger two-stage fluid bed slurry roaster was installed with a baghouse for improved collection of arsenic. Mill tonnage approximated 910 tonnes/day with the flotation concentrate comprising the feed to the roasters.

Flotation concentrates are thickened to 75% solids and sprayed into the first stage of the roaster. Air is introduced through tuyeres at the bottom of the roaster to oxidize sulphide and sulphide-arsenide minerals at low oxygen partial pressures. At a temperature of 495 °C, arsenopyrite is decomposed and most of the arsenic is volatilized as arsenic trioxide. The roast is autogenous with no additional heat required.

The first stage calcine is transferred to the second stage where the temperature is held at 495 °C using spray water, and additional air is supplied to oxidize sulphur associated with pyrite and other minerals.

6.4 Leaching

The material left after roasting the flotation concentrates is called calcine. Roaster calcines are the gold-bearing remains of the pyrite and arsenopyrite after the majority of the sulphur and arsenic have been driven off as gas. These calcines consist of iron oxides, principally hematite and magnetite. The roaster calcines are water quenched and then ground in the two ball mills which work in closed circuit with cyclones. The ground calcines are water-washed in a thickener to remove excess acidic water and to increase the slurry density for subsequent gold leaching. The wash thickener overflows are rejected to the tailings impoundment area. The regrind breaks down the size of the iron oxides contained in the roaster calcine, exposing the contained gold for later recovery using lime and sodium cyanide.

The alkalinity of the washed calcine is then adjusted to a pH of 11.0 using lime. Sodium cyanide solution is added to the calcine. The contained gold is then leached from the calcine by the cyanide in a two-stage agitated leach circuit. The gold is dissolved into solution as a gold cyanide complex. After the first stage of leaching, the calcine is partially dewatered in a thickener. The dewatering solution contains dissolved gold and is therefore captured for subsequent gold recovery. Fresh cyanide solution is added to the thickened calcine which in turn is leached in a second stage of agitated leaching. The slurry from the second stage leach is dewatered in a thickener with the solution recovered for subsequent processing. Thickened slurry is then filtered to remove all gold bearing solutions which are again recovered for subsequent processing. The filtered solids are called the calcine residue and are rejected to the tailings impoundment area.

All of the gold-bearing solutions (pregnant solutions) recovered from the calcine leach circuit are combined and then filtered in a leaf clarifier using canvas bags coated with diatomaceous earth. The clean pregnant solution is then deoxygenated in a Merrill Crowe Tower. Zinc dust is added to the deoxygenated solution allowing the gold cyanide complex contained in solution to "precipitate" onto the zinc dust (actually a plating reaction). The zinc dust is then filtered from the solution using a filter press. Lead nitrate is added to the pregnant solution at the clarifier to enhance the precipitation of gold onto the zinc dust by complexing competing ionic species.

The gold-bearing filtered zinc dust is periodically removed from the press and melted to form a gold dore bullion. The solution that passes through the presses is returned to the

circuit as barren solution. The barren solution is recycled to the leach circuit to make effective use of the contained unreacted cyanide. A portion of the barren solution is bled to the tailings impoundment area to control the build up of impurities that inhibit the cyanide dissolution of gold.

6.5 Gas Cleaning Circuit

The gas cleaning circuit is shown in Figure 6.4.

The tail gas from the roasters is combined, cycloned to remove coarse particulate and then passed through an electrostatic precipitator (ESP). Arsenious oxide in the vapour state passes through the ESP at 315 °C. The ESP is a Type K, rod curtain collector. The dust settles in the collection hoppers and is discharged by screw conveyors to the quench tank for subsequent gold recovery. Tail gas from the precipitator is cooled by dilution with ambient air causing arsenious oxide to condense as fine particulate from the gas phase. The tail gas is then filtered in a Dracco baghouse to remove particulate arsenic trioxide. Each of the eight compartments contains 300 filtration bags which are 127 millimetres in diameter and 3.2 metres long. Arsenic trioxide shaken from the bags is collected in V-shaped hoppers and discharged by means of 4 screw conveyors. The filtered gas is drawn into a variable speed fan and discharged to the atmosphere via an acid-brick lined stack that is 2.7 metres in diameter and 45.7 metres tall.

The efficiency of particulate collection in the baghouse is dependent on several variables namely, bag quality, shaking cycle, temperature in the baghouse, and maintenance of the system. A number of different types of bags have been tried over the years, and presently Giant Mine is using a homopolymer Acrylic Dralon T bag.

In 1977, changes to the later three variables were made at Giant Mine. The shaking cycle was changed from a timed 45 minute control to a pressure drop control. When the pressure drop across the baghouse reaches 2 inches of water, the individual compartments are shaken in sequence. The frequency of shaking was reduced from 32 to 4 cycles per day, reducing the amount of fine arsenic trioxide which passes through the bag during the shaking cycle.

Up until 1977, the gas was cooled to 110 °C which limited the arsenic trioxide concentration in the vapour phase to about 15 mg/m³. Since 1977, the temperature has been lowered to about 105 °C, lowering vapour concentration of arsenic trioxide to about 10 mg/m³. Because of this, a greater amount of arsenic is present as dust, and is therefore able to be collected by the bags.

Finally, a program to regularly replace all of the bags was instituted, thereby reducing excessive arsenic releases due to bag failure.

FIGURE 6.1

GIANT MINE SIMPLIFIED MILL FLOWSHEET

Grinding - Flotation Circuit

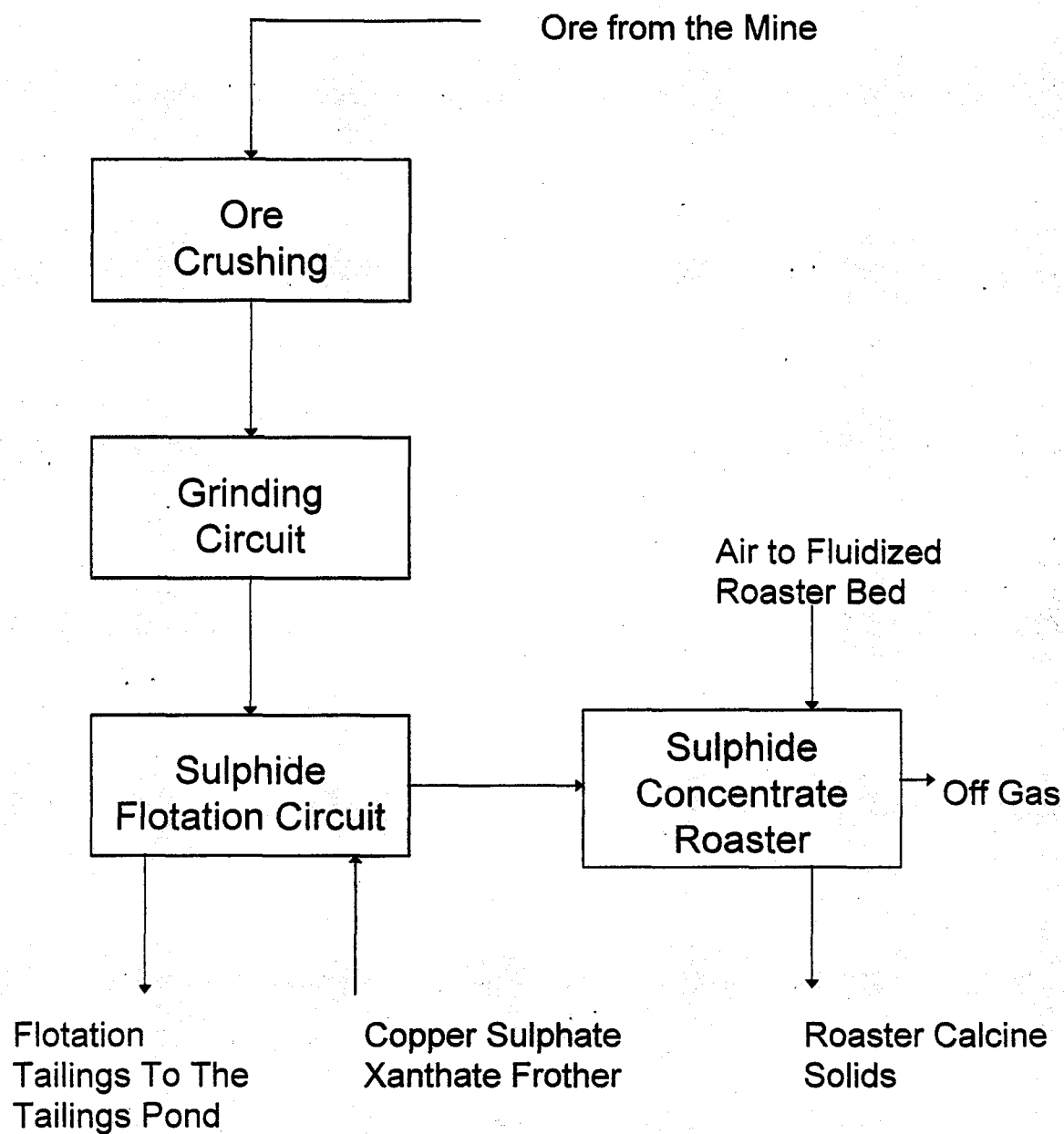


FIGURE 6.2

GIANT MINE SIMPLIFIED MILL FLOWSHEET

Roaster Calcine Leach Circuit

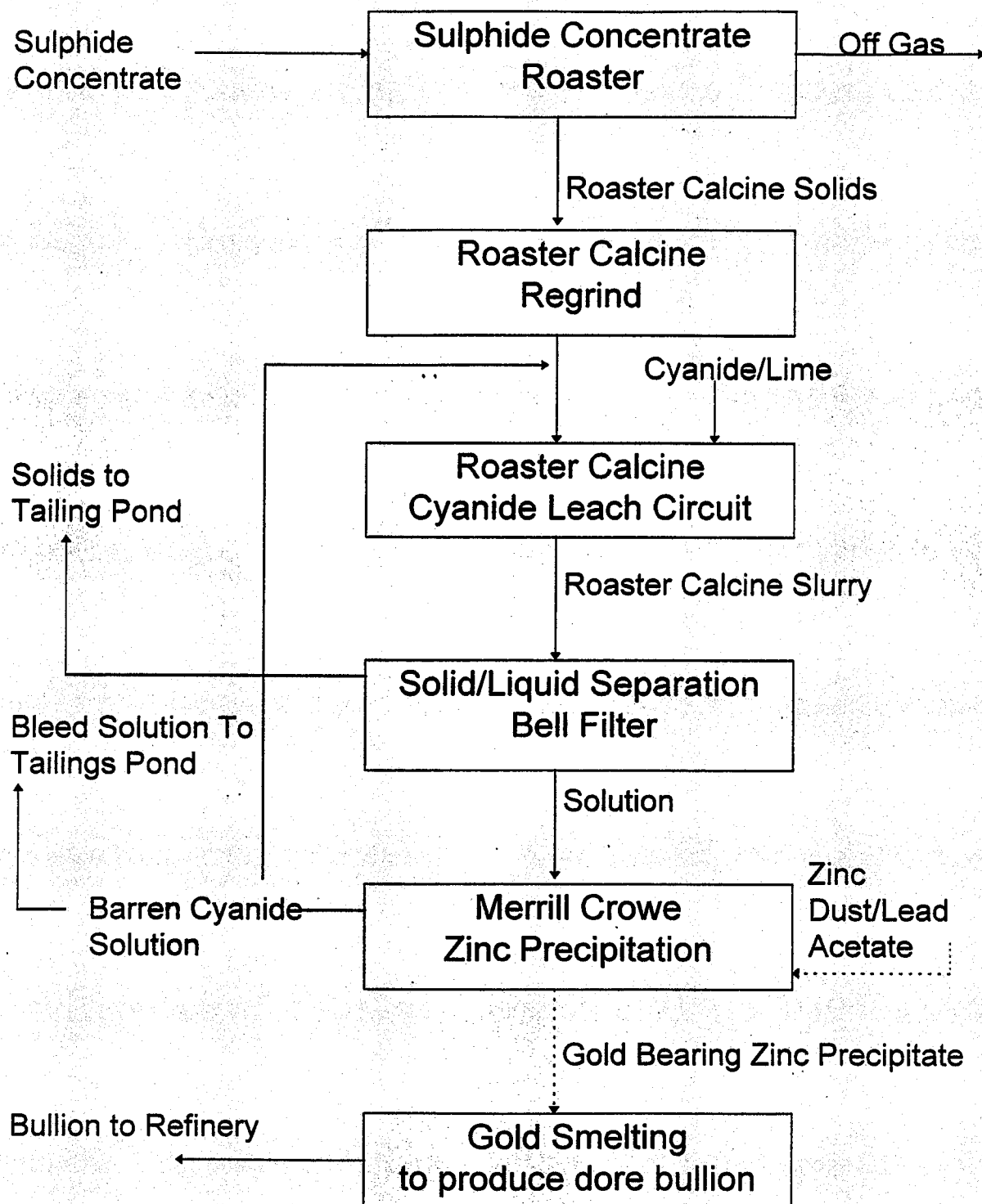


FIGURE 6.3

GIANT MINE SIMPLIFIED MILL FLOWSHEET

Roaster Dust Treatment Circuit

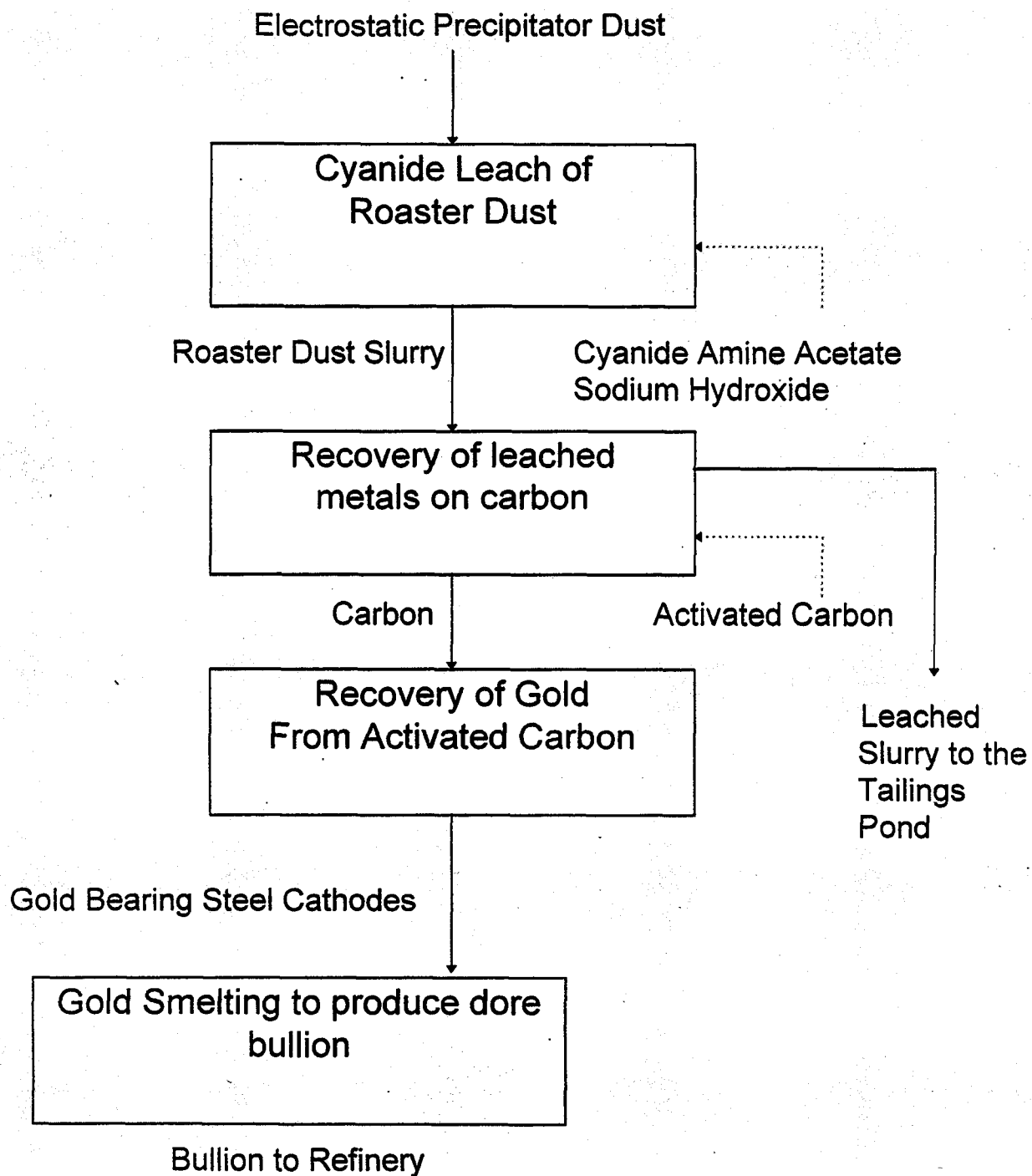
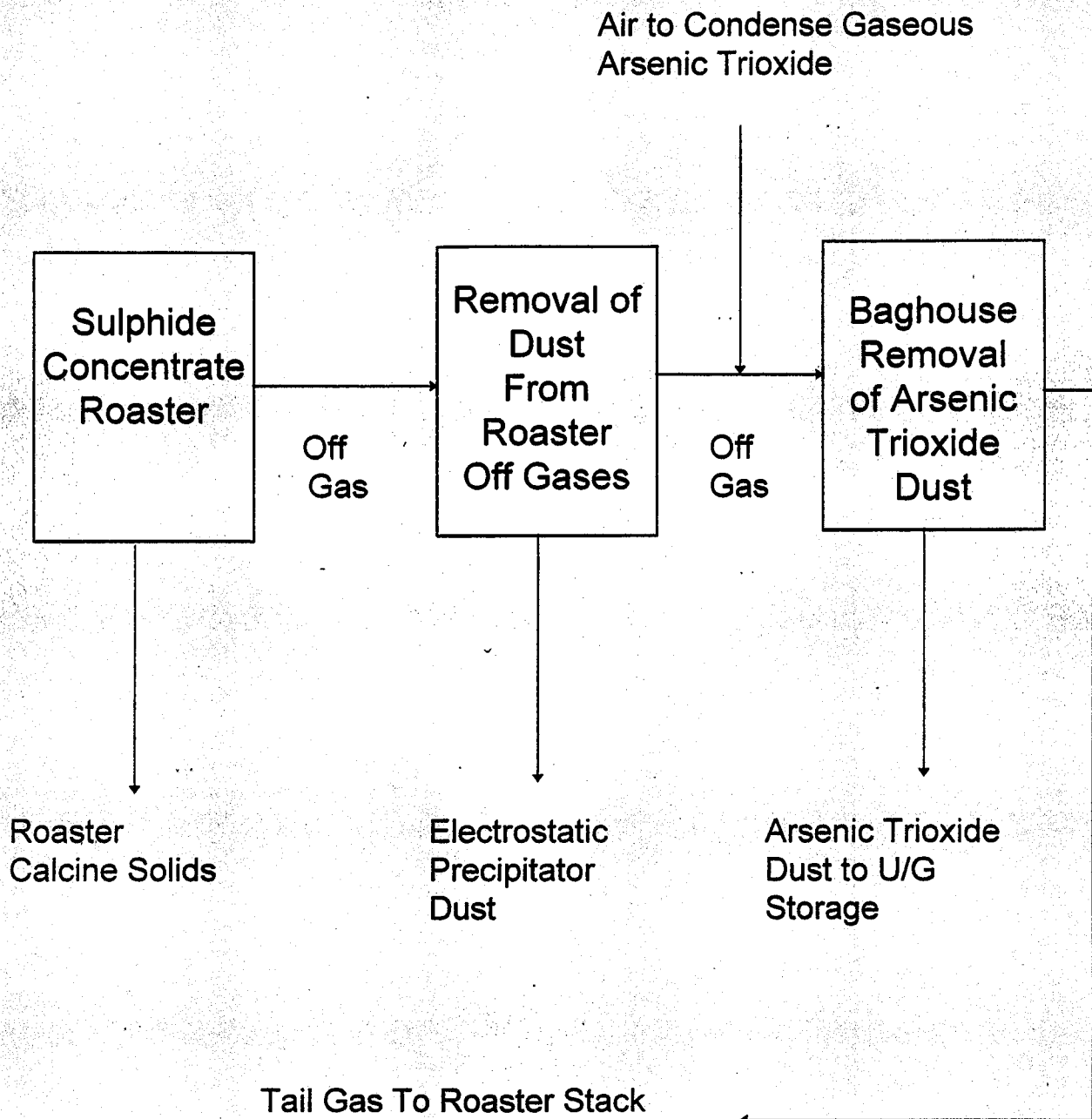


FIGURE 6.4

GIANT MINE SIMPLIFIED MILL FLOWSHEET

Roaster Gas Cleaning Circuit



7.0 TECHNOLOGICAL OPTIONS FOR REDUCING ARSENIC AIR EMISSIONS

Arsenic control options are divided into three principal categories:

- processes which are alternative technologies to roasting;
- processes which treat the roaster tail gas; and
- improvements to the existing air pollution control system at Giant Mine.

7.1 Alternative Technologies for Gold Recovery from Refractory Ore

Background

The following alternatives to the roasting of refractory minerals, which improve gold recovery and/or reduce atmospheric emissions of arsenic, have been investigated and reported.

- Pressure Leaching
- Biological Leaching
- Atmospheric Leaching
- Fine Grinding

The first three operations have been commercially demonstrated and are discussed below. Fine grinding is an approach reported by Metprotech in South Africa. Commercial applications could not be identified, hence this approach will not be discussed further.

Pressure Leaching

A number of gold mills employing roasting to treat refractory minerals have evaluated or switched to a hydrometallurgical approach. Table 7.1 lists examples of gold mills which have adopted pressure oxidation to treat refractory feeds. As with roasting, the main purpose of pressure leaching is to break down arsenic-bearing sulphide minerals to permit conventional leaching of gold.

Pressure leaching involves reacting feed with oxygen at 1800 to 2200 kilopascals (kilopascals (kpa)) and temperatures in the range of 180 to 210 °C. in autoclave reactors. The solid residue after oxidation contains a mix of ferric arsenate, ferric oxide, basic ferric sulphates, jarosites, arsenic in ferric oxyhydroxides, gangue, precious metals and sometimes elemental sulphur. Arsenic in solution is treated in a neutralization circuit. The ultimate tailings from this process contain ferric arsenate, calcium arsenate, complex arsenates and adsorbed arsenic on ferric oxyhydroxides.

The stability of arsenic in gold mine wastes produced by pressure leaching has been investigated. The precipitation of a range of compounds such as ferrous and ferric arsenate, barium arsenate, titanium arsenate, magnesium-ammonium arsenate, and arsenic sulphide have been suggested for removing arsenic from waste water. The two major compounds which form in commercial operations are calcium and ferric arsenate. The other major compound is ferric oxyhydroxide.

Capital costs relating to the installation of pressure leaching circuits are documented. The Campbell Red Lake retrofit projected capital costs at \$23.6 million (C) (1990) including licensing and tailings area preparation. Capacity was rated at 71 tonnes of concentrate per day. Major capital expenditures are involved in converting from roasting to pressure leaching of refractory gold concentrates. A thorough study of capital and operating costs must be carried out along with studies to determine gold recovery.

Biological Leaching

An alternative to chemical leaching is biological leaching which employs bacteria to modify the refractory minerals for gold leaching. Oxidation of sulphides by *Thiobacillus Ferrooxidans* is a natural phenomenon and can be observed in most sulphide ore bodies. The bacteria behave as catalysts and, under ambient conditions, can accelerate the oxidation reaction by factors of several hundred thousand to a million.

In bacterial oxidation, selective oxidation is well documented. High gold extractions are possible with only partial oxidation of arsenopyrite and little oxidation of pyrite.

Observations of bacterial attack along grain boundaries, where gold often resides, may explain this. Selective oxidation bacteria can reduce requirements for oxygen, lime and limestone. A consequence of this phenomenon is that unoxidized sulphides are disposed of in tailings compounds. Long-term stability of sulphides in tailings needs to be ensured so that acids are not formed leading to acid drainage.

In bio-oxidation as in pressure oxidation, the sulphide minerals are reacted to form a variety of compounds, such as sulphates. Oxidation of one ton of sulphur requires two tonnes of oxygen. This oxygen requirement is the same for whole ore or concentrate treatments. For concentrates, considerable cooling or pulp dilution is necessary to maintain the process temperature in the range of 32 to 37 °C for *Thiobacillus Ferrooxidans*. The cooling requirement can negate the advantages of treating concentrates instead of ore. A further design consideration is the oxygen mass transfer. In bio-oxidation, oxygen transfer is slow compared to other processes. The implication is that power costs to provide oxygen increase more rapidly with increasing sulphur in the feed than for other processes. Neutralization costs at an Australian bio-leach plant were over 35 percent of the total operating costs.

The optimum form of arsenic for stable storage is the pentavalent species. This form produces a more stable, crystalline ferric arsenate. Bio-oxidation can produce a trivalent arsenic for disposal which requires an additional process step to produce pentavalent arsenic in a stable form for tailings disposal.

A summary of bio-oxidation plants is shown in Table 7.1. Plants have been built in the United States, Brazil and South Africa and considered for other sites. Bio-leaching was evaluated for Dickenson Mines in northern Ontario. Operations in Nevada, at U.S. Gold, were maintained through both summer and winter seasons. There are no reports of bioleaching in colder regions.

Successful operations have been reported at Fairview in South Africa where bio-leaching replaced roasting. At Sao Bento, near Belo Horizonte, Brazil, the capacity of the existing pressure leach plant will be supplemented with a bio-oxidation facility installed in tandem with the autoclaves to take advantage of the synergisms between the two processes.

The cost of a bio-leaching plant, to replace the existing roasting operation at a site such as Giant Mine, would be approximately \$35 million. Operating costs are estimated to be similar to current costs plus the costs of tailings neutralization which would increase the pre-treatment cost to \$98 per tonne from \$78 per tonne.

Atmospheric Leaching

Low pressure or atmospheric leaching has been developed as an alternative to pretreatments previously discussed. Process equipment is simplified by avoiding, for example, the use of autoclaves. Examples of this pre-treatment approach are the Nitrox Process and the Redox (formerly Arseno) process. Both of these processes are based on nitric acid as the leaching agent.

Many reviews of pre-treatments for refractory minerals describe atmospheric leaching as a process which holds potential but has not been demonstrated beyond the detailed feasibility study stage. The Redox process was proposed to be used at the Cinola site in British Columbia and at Snow Lake in Manitoba.

The overall chemistry of the two process cited above is similar but there are distinctive differences in operating temperatures, pressure and the means of recirculating nitric acid. The Nitrox process uses soluble calcium nitrate to recirculate nitric acid. On lower sulphide feeds, the Redox process uses air regeneration of nitric acid and atmospheric leach vessels. A summary of operations using this technology is shown in Table 7.1. Capital costs for commercial plants have not been reported in the literature. Estimates suggest that the cost for a Nitrox plant for a facility such as Giant Mine would be 1.2 times the capital cost of a pressure leach plant.

TABLE 7.1
ALTERNATIVE TECHNOLOGIES
FOR GOLD RECOVERY FROM REFRACTORY ORE

Examples of Operating Facilities

TECHNOLOGY	OPERATION	LOCATION	FEED	CAPACITY (Tonnes/Day)
Pressure Leaching	Campbell Red Lake	Red Lake Ontario	Gold Concentrate	71
	Miramar Con	Yellowknife NWT	Gold Concentrate	96
	Goldstrike	Carlin Nevada		1363
	McLaughlin	California		
	Sao Bento	Brazil		
	Getchell	Nevada		
Biological Leaching	Fairview	South Africa		12
	U.S. Gold	Tonkin Springs Nevada		1500
Atmospheric Leaching	Cinola	Queen Charlottes B. C.	Ore	Proposed Pilot
	Snow Lake	Manitoba	Tailings	Pilot

7.2 Alternative Technologies for Treating Roaster Tail Gas

Treating the tail gas is a viable option. Current technologies designed to address the removal of residual amounts of contaminants from process gas streams are well established. The technologies investigated were:

- Scrubbing
- Gas conditioning followed by electrostatic mist precipitation
- Activated carbon adsorption

Scrubbing

Tail gas scrubbing offered by Turbotak in Waterloo, Ontario was considered due to the compact, high intensity sprays available in their equipment. Scrubbing inherently cools the gas to precipitate the arsenic and collects about 80 percent on fine water droplets. The main energy consumer in this form of scrubbing is compressed air used for water atomization. The scrubbing step is followed by mechanical mist elimination. The process gas proceeds to the stack via a booster fan. A stack liner is required due to the reactive and corrosive nature of the gas. Table 7.2 compares arsenic recoveries using tail gas scrubbing with the other options. Capital and operating cost are presented in Section 7.4. Turbotak have indicated a willingness to operate a pilot scrubber at a site such as Giant Mine to confirm their predictions.

Electrostatic Precipitation

Significant tail gas arsenic removal is possible by cooling the gas in a low pressure drop venturi scrubber followed by treatment in a wet electrostatic precipitator. Gases from the wet mist precipitators proceed to the stack using a booster fan. A stack liner is also needed in this type of system. The tail gas recovery of arsenic following baghouse collection is estimated at 95 percent using this technology producing an overall arsenic recovery of >99.9% and an arsenic trioxide concentration of <1.0 mg/m³ in the stack gas. By adding additional mist precipitator modules, the arsenic recovery from the tail gas could be increased to 97 percent. Collecting the acid mist will be a bonus using this approach. A version of this equipment is offered by Environmental Corrections Inc. (California) as shown in Table 7.2.

A second version of the gas conditioner-mist precipitator combination is available from Biothermica in Montreal. This is an integrated design from France that is used on municipal incinerators. The arsenic recovery after baghouse collection forecast is 90 percent as shown in Table 7.2.

Activated Carbon Adsorption

Arsenic in the vapour state can be removed by passing the tail gas through a slurry of activated carbon. The forecast arsenic recovery is over 90 percent as shown in Table 7.2. Operating costs are highest for this option since the carbon must be replaced on a regular basis. An additional scrubbing tower using an activated carbon slurry added to the Biothermica unit provides for an extra degree of arsenic removal. Capital costs were

developed based on vendor equipment budget quotations to treat gases from a site such as Giant Mine. These costs are presented in Section 7.4.

7.3 Improvements to the Existing Air Pollution Control System at Giant Mine

The existing air pollution control system and operating procedures at Giant Mine have not changed significantly since 1977. Only minor improvements in arsenic releases to the air would be possible using the existing equipment. With improvements in bag technology and management practices, arsenic concentrations could potentially be reduced to 20 mg/m³. Stack emission testing would be required to confirm whether this concentration could be attained on a consistent basis.

7.4 Capital and Operating Cost Estimates

Estimated capital and operating costs for the alternatives examined are summarized in Table 7.3.

TABLE 7.2
ALTERNATIVE TECHNOLOGIES
FOR TREATING ROASTER TAIL GAS

TECHNOLOGY	MANUFACTURER	ESTIMATED ARSENIC REMOVAL	ESTIMATED ARSENIC RELEASE (mg/cu. m.)
Wet Scrubbing	Turbotak Inc. Waterloo, Ont.	90 %	Less than 1.0
Wet Electrostatic Precipitation	Environmental Corrections Sun Valley, Cal.	95 %	Less than 1.0
	Biothermica Inc. Montreal, Que.	90 %	Less than 1.0
Wet Electrostatic Precipitation plus Carbon Adsorption	Biothermica Inc.	Greater than 90 %	Less than 1.0

NOTE:

- Listing of manufacturers is for illustrative purposes only. This list does not purport to be an exhaustive list of all possible alternative technologies. Inclusion on this list does not mean that the Government of Canada endorses the products of any of the manufacturers listed. The Government of Canada assumes no responsibility for the accuracy or reliability for the quality of the products or services listed herein.

TABLE 7.3**COST ESTIMATES FOR ALTERNATIVE TECHNOLOGIES
FOR REDUCING ATMOSPHERIC RELEASES OF ARSENIC AT GIANT MINE**

TECHNOLOGY	CAPITAL COST	ANNUAL OPERATING COST
Pressure Leaching	\$ 35 million	Unknown
Biological Leaching	\$ 35 million	Unknown
Atmospheric Leaching	\$ 42 million	Unknown
Wet Scrubbing	\$ 1.2 million	\$ 200,000
Wet Electrostatic Precipitation	\$ 2.0 million	\$ 170,000
Wet Electrostatic Precipitation plus Carbon Adsorption	\$ 2.2 million	\$ 210,000

NOTES:

- Capital and operating cost estimates are rough order of magnitude.
- Cost estimates make no allowance for loss of production during conversion to new technologies.
- Annual Operating Cost represents the incremental cost in addition to the present cost for operation of the existing air pollution control system.

7.5 Conclusions

Alternative processing technologies which could replace roasting are commercially available and would completely eliminate atmospheric emissions of arsenic. Installation of one of these processes would require significant capital expenditures, and operating costs at least as expensive as those associated with roasting. These processes would also require significant development to ensure that acceptable gold recovery from the concentrates at a specific mine could be achieved.

Roasting technology for treating refractory gold concentrates has been practised for over 50 years. Proven, commercially-available treatment technology could reduce atmospheric arsenic releases from Giant Mine from the present 30 kg/day to approximately 1 kg/day, by reducing arsenic concentration in the tail gas from 30 mg/m³ to less than 1.0 mg/m³. Operating costs are modest and would include the marginal costs associated with operating the existing tailings disposal facilities.

It may be possible to slightly reduce arsenic releases from the roaster at Giant Mine using the existing pollution control system. This would involve using different filter bags and changing some operating procedures. Increased costs would be low, but arsenic reductions would probably be small.

8.0 AIR DISPERSION MODELLING

8.1 Introduction

Dispersion Modelling is often used to predict the levels of various contaminants in ambient air, based on emission levels from point sources and on atmospheric conditions. This is particularly useful if actual measurements of emission levels and ambient air quality are available to calibrate the results calculated by the models. Once a model has been calibrated, it can be used to predict what the ambient air quality will be under various different conditions, such as reduced emissions, increased dispersion, or special atmospheric phenomena such as inversions.

8.2 Previous Air Dispersion Modelling

In 1995, the Government of the Northwest Territories undertook air dispersion modelling on the Giant Mine roaster stack to calculate the theoretical levels of sulphur dioxide and arsenic in the ambient air around Yellowknife that would be contributed by the roaster. The theoretical levels were then compared to the NWT Guideline for sulphur dioxide and to the Ontario Guideline for arsenic. Further model runs were completed to assess the effect of varying stack parameters on the ambient levels of sulphur dioxide contributed by the roaster.

The report "Air Dispersion Modelling of Roaster Stack Emissions" of May, 1995 by M. M. Dillon Limited, demonstrated that a complex terrain model was not necessary, that the Gaussian plume technique was the most refined method, and that most conditions at Yellowknife were non-fumigating. For these reasons, the United States Environmental Protection Agency (US-EPA) model ISCST2 (Industrial Source Complex Short Term) was selected for the modelling.

Dillon used the results of the October 1993 stack test at Giant Mine in the modelling. The parameters used were:

Stack Height	45.7 metres (m)
Stack Cross-sectional Area	5.91 square metres (m ²)
Gas Flow Rate	40,000 cubic metres/hour (m ³ /hr)
Gas Flow Velocity	2.70 metres/second (m/s)
Gas Temperature	385 degrees K (°K)
Arsenic Concentration	27.5 mg/m ³
Arsenic Emission Rate	0.306 grams/second (g/s)

The results of the modelling predicted that the Ontario Guideline of 0.300 µg/m³ for arsenic in the ambient air would not be exceeded in populated areas of Yellowknife, Ndilo or Dettah under these operating conditions.

8.3 Environment Canada Dispersion Modelling

In 1996, dispersion modelling was conducted by Environment Canada staff for a range of physical and operational parameters to assess what effect various combinations of these parameters may have on arsenic levels in the ambient air around Yellowknife that would be contributed by the roaster. Based on the 1995 work by Dillon, the United States Environmental Protection Agency (US-EPA) model ISCST2 (Industrial Source Complex Short Term) was selected for the modelling. The results of this model predict the "average 24-hour concentrations" of arsenic, and these predicted concentrations could be exceeded for shorter periods of time during the day.

Model Description

Meteorological input data were obtained from Environment Canada's Climate Services in Edmonton. The stations selected were Yellowknife for surface reports and Fort Smith for upper air reports. The model runs were conducted over the time span of 1991 to 1995 and the results shown in this report are the compiled results for this period. To investigate any seasonal differences, data were segregated into winter (November to April) and summer (May to October) periods. These periods roughly correspond to the open and closed-water seasons of Great Slave Lake which would affect the overall meteorology of the area.

Physical Parameters

The only physical parameter that was varied for the model runs was the stack height. Under the GNWT's draft sulphur dioxide regulation, gold roasters are required to maximize dispersion as an interim measure. The different stack heights used are provided in Table 8-1.

Operational Parameters

The operational parameters that can be controlled in the pollution control system at Giant Mine are gas flow rate and gas temperature. The results from stack testing (see Chapter 4.0) were examined to determine the operating range of these parameters. In the acceptable stack tests since 1981, gas flows have ranged from 39,400 m³/hr to 68,000 m³/hr, and gas temperatures have ranged from 350 °K to 385 °K. The gas flows and temperatures used in the modelling are provided in Table 8-1.

Emission Levels

The final parameter to be determined was the arsenic concentration in the stack gas. As concluded in Chapter 4.0, it would be reasonable for the existing pollution control system on the roaster to consistently achieve an arsenic concentration of 30 mg/m³.

One of the options discussed in Chapter 7.0 was improvements to the existing pollution control system to optimize removal efficiency. This optimization could result in the system achieving an arsenic concentration of approximately 20 mg/m³.

The other option discussed in Chapter 7.0 was installation of a new pollution control system to further treat gas from the existing system. The systems described could theoretically reduce arsenic concentration to less than 1.0 mg/m^3 , therefore in practice the operating system could reasonably be expected to achieve an arsenic concentration of 1 mg/m^3 .

The arsenic concentrations used in the modelling are summarized in Table 8-1.

TABLE 8-1
INPUT DATA FOR DISPERSION MODELLING

PARAMETER	VALUES		
Stack Height (m)	45.7	60.6	83.3
Gas Temperature ($^{\circ}\text{K}$)	350	375	
Gas Flow Rate ($\text{m}^3/\text{hr.}$)	40,000		60,000
Arsenic Concentration (mg/m^3)	1	20	30

The combination of two gas flow rates and three arsenic concentrations gives six possible emission rates which were all input into the model.

In summary, the model was run over the following cases: 5 years x 2 seasons x 3 stack heights x 2 exit temperatures x 6 emission rates. This gives a total of 360 individual runs on the computer. Averaging 5 years worth of results over 2 seasons reduced the number of unique results to 72. A receptor grid was defined for the model outputs. The emission stack was situated at the centre of the square grid with sides of 12 kilometres in length. This space was divided into $300\text{m} \times 300\text{m}$ squares comprising 41 nodes east to west and 41 nodes north to south. In total, this is equivalent to 1681 defined receptor points. All occurrences of a 24-hour averaged value of concentrations exceeding $0.020 \text{ } \mu\text{g/m}^3$ were saved at each receptor point. Approximately 60 combinations of stack parameters produced output concentrations exceeding the value of $0.020 \text{ } \mu\text{g/m}^3$.

8.4 Model Results and Discussion

Seasonal Variation

Higher values of arsenic in the ambient air are predicted overall in the summer though they tend to lie to the north of the site. There is a slight shift in the dominant wind direction with the season as the summer winds show a greater spread in the north to south direction while the winter winds show spread east to west. Although it is recognized that the areas north of the site are likely not well modelled by ISCST2 because of the impact of the Great Slave Lake, the wind fields indicate that Yellowknife may observe its largest concentrations in the summer months. The averages of the NAPS data (if the particularly high value found 28 March 1988 is removed) are $0.0244 \mu\text{g}/\text{m}^3$ for the summer and $0.0238 \mu\text{g}/\text{m}^3$ for the winter with an annual average of $0.0243 \mu\text{g}/\text{m}^3$ indicating that there is very little seasonal variability, which the model also suggests.

Temperature Variation

The small changes in exit temperature modelled here (350°K to 375°K) are not sufficient to produce any significant change in the dispersion even at the highest emission rates. This is especially true further from the site for, while small differences are evident near the stack, these differences are lessened with distance.

Stack Flow Variation

A change in stack flow ($40,000 \text{ m}^3/\text{hr.}$ to $60,000 \text{ m}^3/\text{hr.}$) shows more change in the dispersion patterns than was observed with a change in temperature and, again, as distance from the source increases, the impact of the change of emission velocity decreases. Generally, higher emission velocity results in greater dispersion of the emissions such that the ground-level concentrations near the stack are lowered.

Stack Height Variation

The model demonstrated a clear decrease in the ground level concentration with increased stack height from 45.7 m through 83.3 m . While the air concentrations near the stack are greatly decreased, the dispersion to other regions through long-range transport is increased, spreading the pollutant further afield.

Arsenic Emission Rate Variation

The greatest change in dispersion pattern is observed by changing the arsenic emission rate.

Figure 8.1 illustrates the predicted dispersion patterns in the summer with conditions close to the present situation including the existing stack height (47.5 m), highest arsenic concentration ($30.0 \text{ mg}/\text{m}^3$), highest temperature (375°K) and highest stack flow ($60,000 \text{ m}^3/\text{hr.}$). It shows that, under existing conditions, average concentration of arsenic

contributed by the Giant Mine roaster in a 24-hour period can exceed $0.160 \mu\text{g}/\text{m}^3$ near the roaster stack, and can exceed $0.080 \mu\text{g}/\text{m}^3$ in Yellowknife.

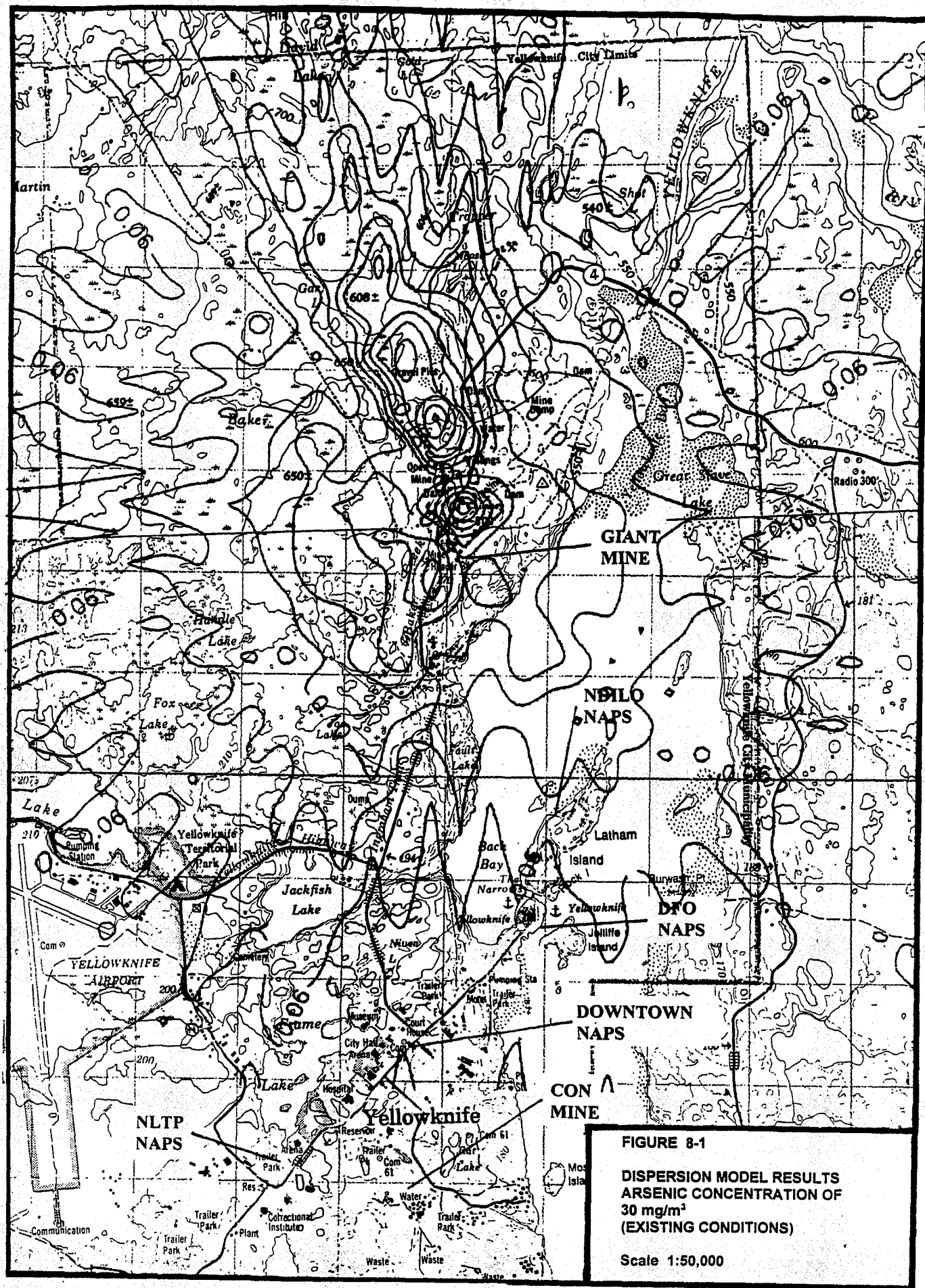
Figure 8.2 illustrates the predicted dispersion patterns with identical conditions to those shown in Figure 8.1, except that the arsenic concentration of $20.0 \text{ mg}/\text{m}^3$ represents the anticipated arsenic releases after optimizing operation of the existing air pollution control system. It shows that, even with optimization of the existing pollution control system, average concentration of arsenic contributed by the Giant Mine roaster in a 24-hour period can exceed $0.130 \mu\text{g}/\text{m}^3$ near the roaster stack, and can exceed $0.060 \mu\text{g}/\text{m}^3$ in Yellowknife. Even considering the errors inherent in the model, the small relative change indicates that simply changing the operations in the facility will not greatly improve the regional ground-level concentrations of arsenic observed at Yellowknife.

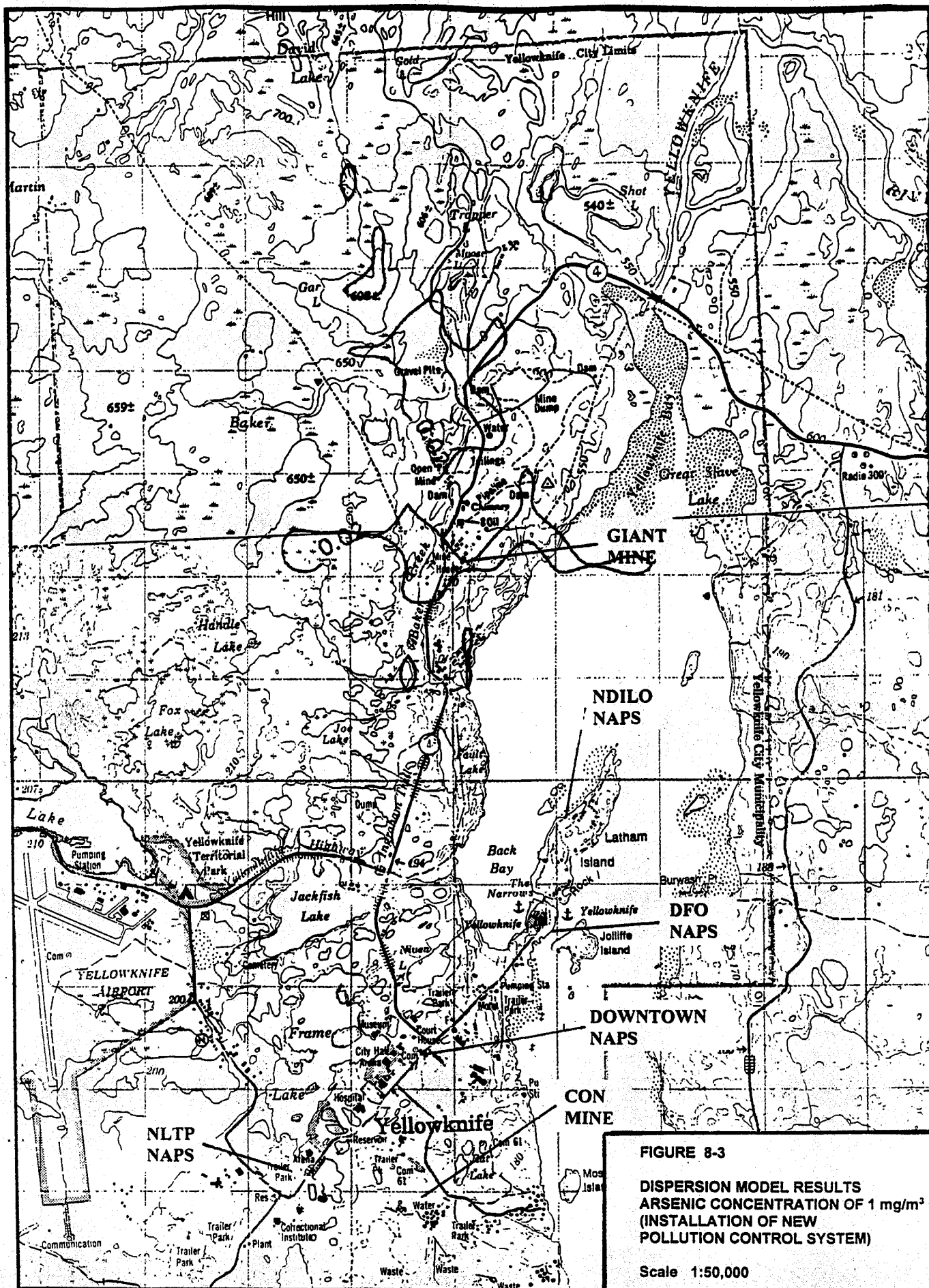
Figure 8.3 illustrates the predicted dispersion patterns with identical conditions to those shown in Figures 8.1 and 8.2, except that the arsenic concentration of $1.0 \text{ mg}/\text{m}^3$ represents the anticipated conditions with the installation of a new pollution control system to further treat the tail gas from the roaster. It shows that, at this arsenic release rate, average concentration of arsenic contributed by the Giant Mine roaster in a 24-hour period would not exceed $0.030 \mu\text{g}/\text{m}^3$.

8.5 Conclusions

Air dispersion modelling predicts that:

- under existing conditions, average concentration of arsenic contributed by the Giant Mine roaster in a 24-hour period can exceed $0.160 \mu\text{g}/\text{m}^3$ near the roaster stack, and can exceed $0.080 \mu\text{g}/\text{m}^3$ in Yellowknife;
- even with optimization of the existing pollution control system, average concentration of arsenic contributed by the Giant Mine roaster in a 24-hour period can exceed $0.130 \mu\text{g}/\text{m}^3$ near the roaster stack, and can exceed $0.060 \mu\text{g}/\text{m}^3$ in Yellowknife. Considering the errors inherent in the model, the small relative change indicates that simply changing the operations in the facility will not greatly improve the regional ground-level concentrations of arsenic observed at Yellowknife.
- by reducing the concentration of arsenic released from the stack to $1.0 \text{ mg}/\text{m}^3$, average concentration of arsenic contributed by the Giant Mine in a 24-hour period would not exceed $0.030 \mu\text{g}/\text{m}^3$, and would be less than $0.020 \mu\text{g}/\text{m}^3$ in Yellowknife.





9.0 SOCIO-ECONOMIC STUDY

9.1 Introduction

This chapter summarizes the study "Socio-economic Analysis of Three Management Options to Reduce Atmospheric Emissions of Arsenic from Gold Roasting". The three management options studied were:

- a regulated performance standard under the Canadian Environmental Protection Act (CEPA);
- a "structured voluntary agreement" (SVA) between the federal government and Royal Oak Mines; and
- a "covenant" between Royal Oak Mines, appropriate level(s) of government and representatives of the communities of Yellowknife.

A regulated performance standard under CEPA would establish a legally enforceable maximum limit for atmospheric emissions of arsenic from the gold roasting process. The latter two options are examples of the range of negotiated agreements that could be applied in this situation, and have been defined for the purpose of analysis in this study. The definitions are not intended to indicate that alternative versions are inappropriate. For the purposes of this study, these options are defined as formal negotiated agreements which include clearly stated environmental goals and recommended approaches to achieving them, quantitative targets, and explicit schedules. The SVA considered in this report would be between Royal Oak Mines and appropriate level(s) of government, whereas the signatories to the covenant would also include representatives of the communities of Yellowknife. A covenant or SVA could potentially be structured to be legally binding. These management options will be more fully discussed later in this chapter.

The study provides a socio-economic analysis of each of the three options as they relate to controlling arsenic exclusively in air emissions. In addition, however, it discusses how the two negotiated options could potentially be made more effective if they addressed a wider range of issues than atmospheric emissions of arsenic. Accordingly, the study identifies these additional issues but does not analyze them in detail.

9.2 Estimated Benefits and Costs of Reducing Atmospheric Emissions of Arsenic from Giant Mine

Current atmospheric emissions of arsenic from Giant Mine are approximately 26 to 29 kg/day at a concentration of 25 mg/m³. These emissions have affected, and will continue to affect, ambient levels of arsenic in air, water, soil and food. Due to data limitations, however, it is not possible to predict the magnitude of the impact of these emissions for any medium except air.

Chapter 7.0 of this report identified four technical control options that would reduce the atmospheric arsenic emissions from Giant Mine by 90% to 95% (i.e. leaving less than 1.0 mg/m³ of arsenic in the emissions): a scrubber, a wet electrostatic precipitator (wet ESP),

an alternative form of a wet ESP, and activated carbon. Dispersion modelling conducted by Environment Canada officials (see Chapter 8.0) predicted that the resulting emission reductions could significantly reduce the levels of atmospheric arsenic in the Yellowknife region that are contributed by Giant Mine's roaster. By reducing ambient concentrations to these levels, the proposed technical control options could reduce mortality due to lung cancer from inhalation of arsenic, saving between 0.14 and 0.86 lives over the 70 year lifespan of a population the size of Yellowknife's.

In order to compare the control costs with the health benefit achieved by such controls, a technique can be used whereby the health benefit can be translated into monetary terms. The methodology used here is the same as that adopted by the Canadian Council of Ministers of the Environment (CCME) Task Force on Cleaner Vehicles and Fuels. This method is based upon an economic assessment of the monetary value that people place on the value of risk reduction of risk of death. Through the use of various socio-economic tools, a determination has been made of the monetary amount that the population in general is willing to pay to reduce their risk of death from various risk sources/causes.

It should be noted that the calculated benefits based upon estimated cancer deaths carry with them all the uncertainties that are inherent in the estimation of the cancer risk. As indicated in section 5.1, this may extend over orders of magnitude. Similarly, the resulting net value of the benefit is subject to the assumptions and methodology adopted in the economic analysis, which may themselves have uncertainties associated with them. It is important to understand that the monetary value for the health benefit analysis is based upon an economic assessment of "willingness to pay to reduce the risk of premature death", and does not represent, nor is it intended to represent, the "value of a human life".

Using the CCME methodology, the present net value of the health benefit associated with reducing mortality due to lung cancer in Yellowknife ranges from \$50,000 to \$2 million (see Table 9-1). These estimates follow the standard Environment Canada practice of relying on a 7.5% discount rate with sensitivity analysis of 5% and 10%.

Due to data limitations, these estimated benefits do not account for the health-related benefits of reduced ingestion or of reduced sub-mortality effects, nor do they account for potential environmental benefits. Scientific evidence suggests that ingestion of arsenic at the ambient levels in which it is found in soil, water and food in the Yellowknife region could have adverse health effects. However, there is insufficient information to estimate the impact of reduced airborne emissions on these effects. Scientific evidence also suggests that the current ambient levels of arsenic in the region of the Giant Mine stack are probably adversely affecting small mammals, terrestrial plants and invertebrates. Again, however, there is insufficient information to predict the impact of reduced air emissions on these effects.

The costs to Royal Oak Mines of reducing emissions by means of one of the four technical control options identified previously could range from \$1.2 to \$2.2 million in capital investment and between \$168,000 and \$206,000 in annual operating costs, plus about \$180,000 per year in monitoring costs. The present net value of these costs is from \$3.5 to \$5.2 million, depending on the discount rate. The estimated annualized costs to the company range from \$550,000 to \$707,000 using a discount rate of 7.5%.

This range of annualized costs is less than 2% of the average annual operating costs of Giant Mine, and approximately 9% of the net cash flow from the Giant Mine to its owner, Royal Oak Mines.

9.3 Management Options

The Task Force examined the full range of management options which could be used to address atmospheric emissions of arsenic from gold roasting. It was concluded that a regulated performance standard, a structured voluntary agreement (SVA) and a "covenant" were potentially the most cost-effective, efficient and feasible options to consider. The following socio-economic analysis of these three management options applies four criteria:

- impacts on emissions;
- impacts on industry;
- impacts on government; and
- indirect economic impacts.

Since each of the three management options analyzed offers considerable flexibility in terms of how environmental performance objectives will be achieved, they are roughly comparable with respect to likely impacts on emissions and in terms of the costs they will impose on the company.

The costs to government of a regulation should be similar to the costs of an SVA or a covenant. The cost of additional analysis of scientific and economic considerations to support the development of these three options will likely be equivalent, as will associated process and public information costs. The main difference between a regulation and an agreement will likely be negotiation and enforcement costs.

TABLE 9-1
COMPARISON OF COSTS AND BENEFITS

COSTS

CONTROL OPTION	5.0%		7.5%		10.0%	
	NPV ¹	AC ²	NPV	AC	NPV	AC
Wet Scrubbing	\$4.1	\$0.53	\$3.8	\$0.55	\$3.5	\$0.57
Wet Electrostatic Precipitation	\$4.7	\$0.61	\$4.4	\$0.65	\$4.2	\$0.68
Wet Electrostatic Precipitation plus Carbon Adsorption	\$5.2	\$0.67	\$4.9	\$0.71	\$4.6	\$0.75

BENEFITS

COST PER FATAL CANCER CASE ³		AVOIDED CANCER MORTALITY	NET PRESENT VALUE (Millions of Dollars)		
			5.0%	7.5%	10.0%
Low (\$ 2.5)		0.14	\$ 0.10	\$ 0.07	\$ 0.05
		0.86	\$ 0.59	\$ 0.41	\$ 0.31
Central (\$ 4.2)		0.14	\$ 0.16	\$ 0.11	\$ 0.08
		0.86	\$ 1.00	\$ 0.68	\$ 0.52
High (\$ 8.3)		0.14	\$ 0.32	\$ 0.22	\$ 0.17
		0.86	\$ 1.97	\$ 1.35	\$ 1.02

1. Net Present Values (NPV) for costs are in "millions of dollars", and include incremental annual costs for operation and monitoring, calculated over 10 years at the discount rates of 5.0%, 7.5%, and 10%.
2. Annualized Costs (AC) are in "millions of dollars" calculated over 10 years.
3. The value of Dollars per Fatal Cancer Case are from Lang et al, 1995, and given in "millions of dollars".

The negotiation costs for an SVA or a covenant would probably be higher than for a regulation, particularly if multiple jurisdictions were involved. On the other hand, since one of the main benefits of such agreements is assumed to be increased industry "ownership" of the objectives, the enforcement costs would likely be lower. Assuming that these two differences roughly cancel each other, the overall costs of an SVA or a covenant should be approximately equal to those of a regulation.

The indirect effects of the three options would probably be similar. Assuming that Giant Mine does not shut down in response to these measures, the indirect effects should be minimal. Locally, the increased expenditures associated with upgrading the control technology could add a short term "pulse" of economic activity in the community. Over the long term, implementation of the measures could increase employment slightly. If Giant Mine does shut down, the indirect effects to the local economy would be significant in the short term since Giant Mine is the fifth largest employer in the region. However, Yellowknife's relatively robust economy, which is bolstered by a number of forthcoming prospects, should facilitate a fairly rapid recovery. The regional and national impacts of either scenario are likely to be negligible.

Regulated Performance Standard

A regulated performance standard or Regulation would specify a maximum limit for atmospheric arsenic emissions from gold roasters, typically in terms of an emission rate (e.g. volume or mass of emissions per hour or day), a loading (e.g. in kilograms per year), or an emission concentration.

A regulated performance standard would offer three main advantages over the two negotiated options. First, it would provide certainty. Second, it would enhance government control over the final outcome. Third, the performance standard set forth in the regulation could potentially be applied to the development of additional regulatory and non-regulatory initiatives for arsenic.

The primary consideration with respect to a regulated performance standard, in light of the scientific data gaps, is demonstrating that the overall benefits of a proposed regulation outweigh the costs.

A second consideration with respect to this approach is that most parties - including Giant Mine officials, local environmental organizations, the aboriginal community and the local government - view airborne arsenic as less important than other environmental issues relevant to Giant Mine.

Structured Voluntary Agreement (SVA)

For the purposes of this report, a structured voluntary agreement is defined as a formal negotiated agreement between industry and government which includes environmental goals and recommended approaches to achieving them, quantitative targets and explicit schedules. It could be made legally binding and subject to the law related to contracts and to any relevant legislative provisions related to Environment Canada contracts.

Although the precise content of the SVA would depend on the negotiations, in this context an SVA could take one of two general forms: a negotiated agreement between Royal Oak Mines and the federal government, focused on atmospheric emissions of arsenic only; or an agreement among Royal Oak Mines, the GNWT and the federal government, addressing a more complete set of Giant Mine's environmental issues. There are few prospects for the first model, since Royal Oak Mines is unlikely to be willing to negotiate with respect to atmospheric emissions of arsenic alone. Royal Oak Mines and other parties might, however, be interested in an SVA that addressed a wider range of environmental issues. The main reasons for such interest relate to the opportunities that negotiations might provide to: i) avoid the creation of inconsistent regulatory requirements from different government agencies; ii) set priorities among the environmental issues related to Giant Mine and the community; and iii) create some long-term certainty with respect to the environmental regime facing Giant Mine.

Two questions with respect to the parties' willingness to negotiate such an agreement are:

- Would these incentives be sufficient to induce Royal Oak Mines to include atmospheric emissions of arsenic in the negotiations?
- What are the prospects of inter-jurisdictional co-operation between levels of government with respect to such an approach?

The preliminary interviews conducted for the study suggest that the answer to both questions is positive. Although they did not indicate precisely which issues they would be willing to negotiate, Giant Mine officials suggested that they would be interested in negotiating a comprehensive package of the environmental issues they face. And while the GNWT is pursuing the promulgation of the SO₂ regulation, it would be interested in exploring whether negotiations could help resolve other concerns such as the liability for the contaminated site upon closure of the Giant Mine.

An SVA would also have to address at least two additional questions in order to be effective in these circumstances. First, it would have to address concerns on the part of various parties about the need for effective enforcement powers. More analysis is required in order to determine whether the communities would be satisfied with a non-regulated approach. Second, it would be important to ensure that community representatives trust the federal and territorial governments to negotiate on their behalf.

Covenant

Both negotiated agreement options (i.e. the SVA and the covenant) offer the potential to address other aspects of the Giant Mine's environmental performance rather than being restricted to atmospheric emissions of arsenic. The key issue with respect to these options is whether the relevant parties would willingly consent to enter into such an agreement.

For the purposes of this study, a covenant is defined as a negotiated agreement between Royal Oak Mines, appropriate level(s) of government, and representatives of the communities in the Yellowknife area. It would include clearly stated environmental goals and recommended approaches to achieve them, quantitative targets and explicit schedules. It could be structured to be legally binding or not. If it is intended to be legally binding, it would take the form of a contract and would be enforceable under civil law by the parties to the agreement, but not by third parties.

The preliminary interviews conducted for the study suggest that although some of the parties might be interested in negotiating a covenant, many have reservations about such an approach. The local environmental organizations and the Yellowknives Dene First Nation have expressed an interest in addressing a wider range of issues with respect to the past and present operations of Giant Mine, issues which would not be included in a regulation dealing with atmospheric releases of arsenic from gold roasters. A covenant might provide the opportunity for negotiation of such issues, and also for opening lines of communication and restoring trust.

On the other hand, there appear to be few incentives for Royal Oak Mines to enter into such an agreement. A covenant could potentially benefit the company by addressing atmospheric arsenic emissions and other environmental issues relevant to the Mine's operation, in an integrated manner. The main incentive, however, would likely come from the credible threat of federal government intervention to limit arsenic in emissions from gold roasting, if an agreement was not entered into.

Additional questions posed by a number of parties are: Which parties should participate in such an agreement? Who speaks for the community? And, if the list of participants grows in order to accommodate the diversity of interests, would the negotiations be manageable? These questions would have to be resolved before this option could be implemented.

9.4 Conclusions

The costs of alternate technologies to completely eliminate airborne releases of arsenic greatly exceed the calculated health benefits. Officials of Royal Oak Mines Inc. have stated publicly several times that a requirement to spend the capital costs estimated in this report for alternate processing technologies would probably result in the closure of Giant Mine.

The costs to reduce arsenic releases to 1 kg/day exceed the benefits to human health calculated from the limited evidence available, as defined by the specific cost/benefit analysis adopted for this assessment and recognizing that there are inherent limitations to any such analysis. There is not enough information to accurately quantify benefits to the environment. If environmental benefits could be quantified and added to the calculated health benefits, the benefits might exceed the costs. In any case, the additional costs would probably not place undue financial pressure on Giant Mine.

Estimated costs to industry and government, and estimated benefits to health, are relatively similar for either of the three management options studied. The decision as to which management option to recommend should be based on:

- the number of environmental issues to be addressed;
- the likelihood of success in negotiating agreements; and
- the feedback from public consultation.

10.0 CONCLUSIONS

Based upon the assembled information, the Task Force determined that releases of liquid effluent containing arsenic in the Northwest Territories, including issues related to the underground storage of arsenic trioxide at Giant Mine, could be adequately controlled through the water licensing processes of the NWT Water Board and the Nunavut Water Board.

Arsenic releases to the air in the Northwest Territories are not subject to regulatory control, and are not being examined by any other federal or territorial regulatory initiatives. Because of this, the Task Force has determined that, in the Northwest Territories, atmospheric releases of arsenic from gold roasting warrant the highest priority for federal action.

The gold roaster at Giant Mine in Yellowknife is the only anthropogenic source of arsenic releases to the air in the NWT. Because the intent of CEPA is to control activities on a nation-wide or industry-wide basis, this examination of options for the reduction of arsenic releases considered releases from all gold roasters in Canada. Besides the gold roaster at Giant Mine, there is only one other gold roaster in Canada. It is located at Golden Bear Mine in British Columbia, and has been out of operation since 1994.

Voluntary control measures instituted at Giant Mine reduced arsenic releases from their gold roaster to the atmosphere from approximately 7300 kg/day in the early 1950's to approximately 30 kg/day by 1978. Atmospheric arsenic releases from Giant Mine have remained at this level since 1978. Also since 1978, the concentration of arsenic being released to the atmosphere has averaged 25 mg/m³.

The amount of arsenic released to the air varies due to a number of factors. Taking into account these variations, the existing air pollution control system at Giant Mine could be expected to consistently achieve an arsenic concentration of 30 mg/m³.

Arsenic levels measured in the ambient air in Yellowknife have improved substantially since 1975, and are now similar to the levels measured near arsenic point sources in other parts of Canada. The annual mean ambient concentrations of airborne arsenic measured in downtown Yellowknife over the period from 1978 to 1995 ranged from 0.006 to 0.023 µg/m³, averaging 0.013 µg/m³. From 1989 to 1995, the annual mean arsenic concentrations of airborne arsenic averaged 0.009 µg/m³. This compares with a mean annual concentration of 0.001 µg/m³ measured in cities across the rest of Canada, and a range of between 0.0086 and 0.22 µg/m³ measured near industrial arsenic point sources in Canada.

Although the health risk to the population of Yellowknife from exposure to current levels of airborne arsenic would be considered low relative to the risks encountered in day-to-day life, they are considered to be high in comparison with the risks generally associated with other environmental contaminants.

Alternative processing technologies which could replace roasting are commercially available and would completely eliminate atmospheric emissions of arsenic. Installation of one of these processes would require significant capital expenditures, and operating costs at least as expensive as those associated with roasting. These processes would also require significant development to ensure that acceptable gold recovery from the concentrates at a specific mine could be achieved.

Roasting technology for treating refractory gold concentrates has been practised for over 50 years. Proven, commercially-available treatment technology could reduce atmospheric arsenic releases from Giant Mine from the present 30 kg/day to approximately 1 kg/day, by reducing arsenic concentration in the tail gas from 30 mg/m³ to less than 1.0 mg/m³. Operating costs are modest and would include the marginal costs associated with operating the existing tailings disposal facilities.

It may be possible to slightly reduce arsenic releases from the roaster at Giant Mine using the existing pollution control system. This would involve using different filter bags and changing some operating procedures. Increased costs would be low, but arsenic reductions would probably be small.

Air dispersion modelling predicts that:

- under existing conditions, average concentration of arsenic contributed by the Giant Mine roaster in a 24-hour period can exceed 0.160 µg/m³ near the roaster stack, and can exceed 0.080 µg/m³ in Yellowknife;
- even with optimization of the existing pollution control system, average concentration of arsenic contributed by the Giant Mine roaster in a 24-hour period can exceed 0.130 µg/m³ near the roaster stack, and can exceed 0.060 µg/m³ in Yellowknife. Considering the errors inherent in the model, the small relative change indicates that simply changing the operations in the facility will not greatly improve the regional ground-level concentrations of arsenic observed at Yellowknife.
- by reducing the concentration of arsenic released from the stack to 1.0 mg/m³, average concentration of arsenic contributed by the Giant Mine in a 24-hour period would not exceed 0.030 µg/m³, and would be less than 0.020 µg/m³ in Yellowknife.

The costs of alternate technologies to completely eliminate airborne releases of arsenic greatly exceed the calculated health benefits. Officials of Royal Oak Mines Inc. have stated publicly several times that a requirement to spend the capital costs estimated in this report for alternate processing technologies would probably result in the closure of Giant Mine.

The costs to reduce arsenic releases to 1 kg/day exceed the benefits to human health calculated from the limited evidence available, as defined by the specific cost/benefit analysis adopted for this assessment and recognizing that there are inherent limitations to any such analysis. There is not enough information to accurately quantify benefits to the environment. If environmental benefits could be quantified and added to the calculated health benefits, the benefits might exceed the costs. In any case, the

additional costs would probably not place undue financial pressure on Giant Mine. Estimated costs to industry and government, and estimated benefits to health, are relatively similar for either of the three management options studied. The decision as to which management option to recommend should be based on:

- the number of environmental issues to be addressed;
- the likelihood of success in negotiating agreements; and
- the feedback from public consultation.

11.0 OPTIONS FOR FUTURE ACTION

This chapter describes a number of options for future actions, which will form the basis of discussion at public consultation sessions. There are other options which may be considered. The purpose of the public consultation is to recommend to Environment Canada and Health Canada future actions regarding arsenic releases to the environment in the NWT.

Option 1 Maintain the Status Quo

Arsenic releases to the air and water in the NWT should continue to be controlled as at present.

Points for Consideration

- No increased costs to industry and government.
- Allows resources to be focused on the most important environmental issues.
- Doesn't address current health risks from existing arsenic release levels.
- Fails to minimize exposure as recommended in the PSL Assessment Report.
- Fails to respond to Recommendation 107.

Option 2 Conduct Further Studies

The Government of Canada should conduct further studies on the environmental effects of the existing releases of arsenic to the air in the Yellowknife area to address the lack of data regarding environmental impacts. The studies should have a fixed time for completion and, if the studies determine that there are measurable environmental effects, action should be taken to reduce arsenic releases.

Points for Consideration

- Could provide additional information about the environmental and health risks to the residents of Yellowknife.
- No increased costs to industry.
- Will cause further delay if studies recommend action to reduce releases.
- Increased costs to government.
- The types of studies which would be required to provide any significant improvement in the health risk assessment over the current estimates would be very expensive and take considerable time to complete.
- Result of the studies would very likely be inconclusive.

Option 3 Control Arsenic Releases

3A Regulated Performance Standard for Air Releases

Environment Canada should draft a regulated performance standard (Regulation) controlling the release of arsenic to the air from gold roasters. When promulgated, this Regulation would specify a limit on the concentration of arsenic in airborne releases from gold roasters, set a time frame for complying with the specified limit, and require appropriate testing and reporting of emissions from roaster stacks.

Points for Consideration

- Atmospheric arsenic releases could be reduced in a reasonable time.
- Adherence to precautionary principles.
- Responsive to national and local concerns.
- Provides certainty to public and industry on the requirements.
- Readily enforceable.
- Provides public accountability.
- Increased costs to industry and government.

3B Negotiated Agreements

3B(i) Structured Voluntary Agreement (SVA) on Air Releases

The Government of Canada should initiate negotiation of a "Structured Voluntary Agreement" with Royal Oak Mines to reduce atmospheric releases of arsenic to a specified level. All quantitative reduction targets and the schedule for achieving them would be clearly stated in the agreement. The signatories to the SVA would be the Government of Canada and Royal Oak Mines.

Points for Consideration

- Atmospheric arsenic releases could be reduced in a reasonable time.
- Adherence to precautionary principles.
- Responsive to national and local concerns.
- Provides certainty to public and industry on the requirements.
- Negotiations would not involve public or Government of the NWT.
- Enforceability is a concern.
- Increased costs to industry and government.

3B(ii) Multi-faceted Structured Voluntary Agreement

The Government of Canada should initiate negotiation of a "Structured Voluntary Agreement" with Royal Oak Mines to address several environmental issues facing the Mine. Possible issues that could be considered include the underground storage of arsenic trioxide, atmospheric releases of arsenic and sulphur dioxide, releases of liquid effluent, and site remediation. The SVA would include clear quantitative reduction targets and schedules for achieving them. The federal government cannot waive or alter existing regulatory requirements with respect to these issues, however, it could take them into account when negotiating the terms of the agreement. The parties to the agreement would be the Government of Canada and Royal Oak Mines. The Government of the Northwest Territories may also need to be a signatory to the agreement given the jurisdictional nature of some of the issues. In the event of an unsatisfactory outcome either of the negotiation process or of performance under the agreement, the federal government could intervene to pursue an alternative course of action.

Points for Consideration

- Increased flexibility for Royal Oak Mines in addressing several environmental issues at Giant Mine.
- Provides "one-window" approach for several environmental issues at Giant Mine.
- Could provide greater sense of "public ownership" in the control of environmental issues.
- Negotiations could be cumbersome and time consuming, depending on the number of participants and issues to be included.
- Complexity of the negotiations could delay action on atmospheric releases of arsenic.
- If an agreement includes water issues, the NWT Water Board and DIAND will need be involved because of their responsibility for the NWT Waters Act.
- If an agreement includes water issues, there may be pressure to negotiate agreements with all mines in the NWT, which would be a duplication of the work of the NWT and Nunavut Water Boards.

3B(iii) Covenant

The Government of Canada should initiate negotiation of a Covenant to address several environmental issues facing the Mine. The Covenant would include clear quantitative reduction targets and schedules for achieving them. Possible issues that could be considered include the underground storage of arsenic trioxide, atmospheric releases of arsenic and sulphur dioxide, releases of liquid effluent, and site remediation. The federal government cannot waive or alter existing regulatory requirements with respect to these issues, however, it could take them into account when negotiating the terms of the agreement. The Parties to the agreement would be the Government of Canada, Royal Oak Mines, and the affected communities (e.g. municipal government, aboriginal organizations, environmental organizations). The Government of the Northwest Territories may also need to be a signatory to the agreement given the jurisdictional nature of some of the issues. In the event of an unsatisfactory outcome either of the negotiation process or of performance under the agreement, the federal government could intervene to pursue an alternative course of action.

Points for Consideration

- Increased flexibility for Royal Oak Mines in addressing several environmental issues at Giant Mine.
- Provides "one-window" approach for several environmental issues at Giant Mine.
- Could provide greater sense of "public ownership" in the control of environmental issues.
- Negotiations could be cumbersome and time consuming, depending on the number of participants and issues to be included.
- Complexity of the negotiations could delay action on atmospheric releases of arsenic.
- If an agreement includes water issues, the NWT Water Board and DIAND will need be involved because of their responsibility for the NWT Waters Act.
- If an agreement includes water issues, there may be pressure to negotiate agreements with all mines in the NWT, which would be a duplication of the work of the NWT and Nunavut Water Boards.

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