

NATIONAL INVENTORY OF SOURCES AND EMISSIONS OF ARSENIC (1972)*

Pollution Data Analysis Division
Air Pollution Programs Branch
Air Pollution Control Directorate

Report APCD 75-5

January 1976

*This report is based on a study undertaken for the Department of the Environment by Surveyer, Nenniger and Chênevert Incorporated, Montreal, Quebec, under Contract No. OSR3-0526.

ABSTRACT

Atmospheric emissions of arsenic and its compounds have been estimated for the year 1972. The data presented in this report are summarized in Table 1 and Figures 1 and 2. Total arsenic emissions to the atmosphere in 1972 are estimated at 4073 tons. The largest contributor is the metallurgical gold processing industry which accounts for 48% of the total. Emissions from the primary iron and steel industry account for a further 26%. On a geographic basis the Province of Ontario accounts for 72% of total arsenic emissions which occur primarily from the roasting operations in the gold processing industry and from pellet and sinter operations in primary iron and steel production.

Results are first approximations of the actual quantities emitted due to paucity of data. The inventory serves to place the various emission sources in perspective and the reader is cautioned not to use emission estimates out of context of this inventory.

RÉSUMÉ

On a fait l'estimation des émissions d'arsenic et de ses composés à l'atmosphère en 1972. Le tableau 1 ainsi que les figures 1 et 2 résument les données présentées dans le présent rapport. Les émissions ont été estimées à 4 073 tonnes dont 48% sont attribuables à l'extraction industrielle de l'or tandis que 26% proviennent de l'industrie du fer et de l'acier de première fusion. Du point de vue géographique, la province de l'Ontario contribue à 72% des émissions, lesquelles proviennent principalement du grillage des minerais d'or et du bouletage et du frittage dans la production du fer et de l'acier de première fusion.

En raison du peu de données disponibles, ces chiffres constituent une première approximation. Le présent rapport est un inventaire permettant de mettre en évidence les différentes sources d'émission, et le lecteur est mis en garde contre l'utilisation hors contexte des données estimatives.

TABLE 1 ARSENIC EMISSIONS BY PROVINCE AND SECTOR, 1972 (tons)

	Province										
Sector	B. C.	Alta.	Sask.	Man.	Ont.	Que.	Nfld.	Maritimes	N. W. T. Yukon	Total Canada	% Total
INDUSTRY											
Primary copper and nickel production	-	N*	-	146	173	342	-	-	-	661	16.2
Primary lead production	17	-	-	-	-	-	-	1	-	18	0.4
Primary zinc production	N	-	-	359	N	N	-	-	-	359	8.8
Primary iron and steel production	N	N	N	N	963	61	-	17	-	1041	25.6
Metallurgical processing of gold	-	-	-	-	1766	-	-	-	168	1934	47.5
Miscellaneous sources	<1	<1	<1	<1	3	10	1	<1	<1	15	0.4
FUEL COMBUSTION/ STATIONARY SOURCES											
Power generation	<1	6	4	1	11	<1	<1	2	<1	25	0.6
Industrial and commercial	1	<1	1	2	5	3	<1	1	<1	13	0.3
Domestic	← Less than 1 ton →									<1	<0.1
TRANSPORTATION	← Less than 1 ton →									<1	<0.1
SOLID WASTE INCINERATION											
	-	-	N	<1	<1	N	-	N	-	1	<0.1
PESTICIDE APPLICATION											
	← Approximately 0.5 ton per province →									6	0.2
TOTAL	18	7	5	508	2921	416	1	21	169	4073	
% TOTAL	0.4	0.2	0.1	12.5	71.7	10.2	<0.1	0.5	4.2		100

* N - negligible

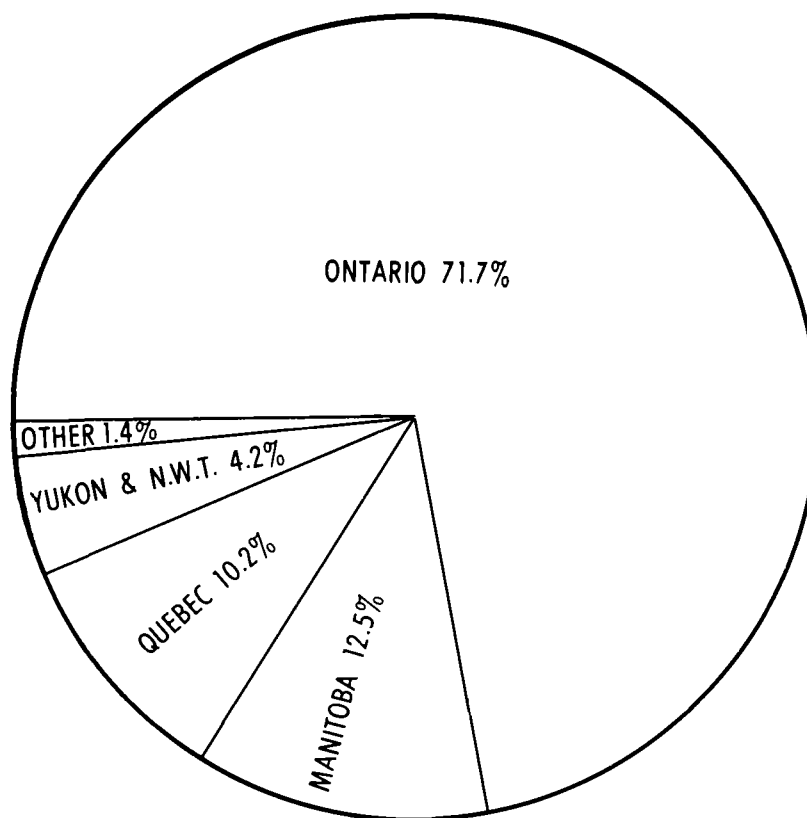


FIGURE 1 PERCENT ARSENIC EMITTED BY PROVINCE, 1972

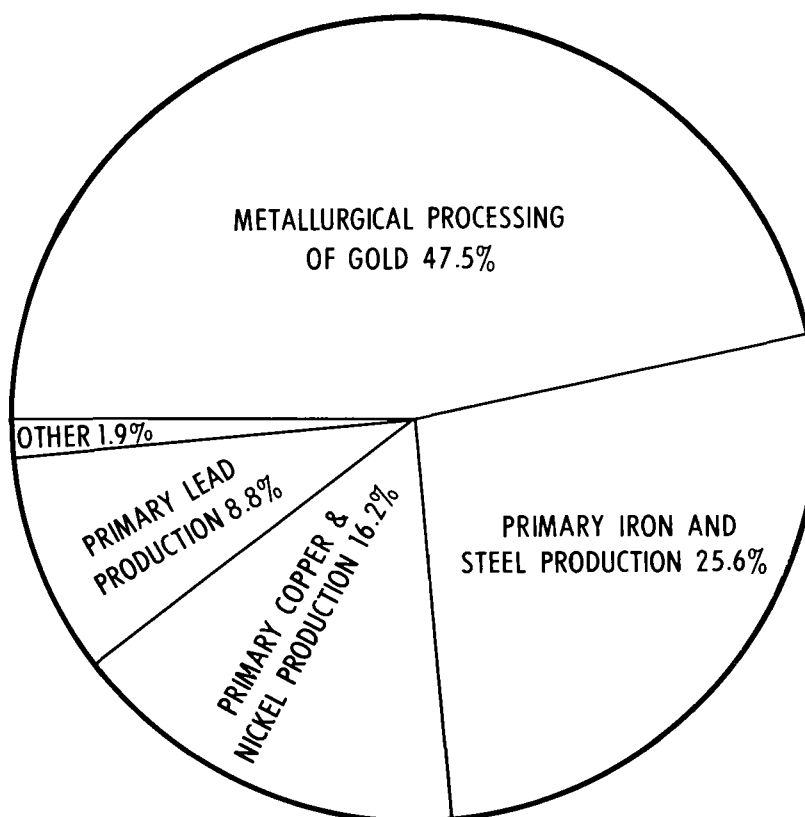


FIGURE 2 PERCENT ARSENIC EMITTED BY SOURCE, 1972

TABLE OF CONTENTS

	PAGE
ABSTRACT	i
RÉSUMÉ	ii
LIST OF TABLES	vii
LIST OF FIGURES	viii
1 INTRODUCTION	1
1.1 Scope	1
1.2 Sources and Uses of Arsenic	1
2 INDUSTRIAL EMISSIONS	2
2.1 Primary Copper and Nickel Production	2
2.2 Primary Lead Production	5
2.3 Primary Zinc Production	8
2.4 Primary Iron and Steel Production	10
2.5 Metallurgical Processing of Gold	13
2.6 Miscellaneous Industrial Sources	14
3 EMISSIONS FROM FUEL COMBUSTION - STATIONARY SOURCES	18
3.1 Power Generation	19
3.2 Industrial and Commercial	20
3.3 Domestic	21
4 EMISSIONS FROM TRANSPORTATION SOURCES	21
4.1 Motor Vehicles	21
4.2 Rail Transport	21
4.3 Shipping	21
4.4 Aviation	22
5 EMISSIONS FROM SOLID WASTE INCINERATION	22
6 EMISSIONS FROM PESTICIDE APPLICATION	22

REFERENCES	25
BIBLIOGRAPHY	27
APPENDIX	
SURVEY OF QUESTIONNAIRE RETURNS AND QUALITY INDEX	31

LIST OF TABLES

TABLE		PAGE
1	ARSENIC EMISSIONS BY PROVINCE AND SECTOR, 1972	iii
2	PARTICLE SIZE DISTRIBUTION FOR PARTICULATE EMISSIONS FROM PRIMARY COPPER AND NICKEL SMELTERS	5
3	ARSENIC EMISSIONS FROM PRIMARY LEAD PRODUCTION, 1972	7
4	PARTICLE SIZE DISTRIBUTION FOR PARTICULATE EMISSIONS FROM PRIMARY ZINC SMELTERS	10
5	ARSENIC EMISSIONS FROM PRIMARY IRON AND STEEL PRODUCTION, 1972	12
6	PARTICLE SIZE DISTRIBUTION FOR PARTICULATE EMISSIONS FROM ELECTRIC ARC STEELMAKING FURNACES	13
7	ARSENIC EMISSIONS FROM MISCELLANEOUS INDUSTRIAL SOURCES, 1972	18
8	ARSENIC EMISSION FACTORS FOR FUELS	19
9	ARSENIC EMISSIONS FROM POWER GENERATION, 1972	20
10	ARSENIC EMISSIONS FROM INDUSTRIAL AND COMMERCIAL FUEL USE, 1972	20
11	ARSENIC EMISSIONS FROM PESTICIDE APPLICATION BASED ON 10% DRIFT LOSS, 1972	23

LIST OF FIGURES

FIGURE		PAGE
1	PERCENT ARSENIC EMITTED BY PROVINCE, 1972	iv
2	PERCENT ARSENIC EMITTED BY SOURCE, 1972	iv
3	PRIMARY COPPER AND NICKEL PLANT FLOW DIAGRAM	4
4	PRIMARY ZINC PLANT FLOW DIAGRAM	9
5	METALLURGICAL PROCESSING OF GOLD FLOW DIAGRAM	15

1 INTRODUCTION

1.1 Scope

The purpose of this report is to identify and quantify sources of atmospheric emissions of arsenic in Canada for the year 1972. The information contained in this report was obtained from a literature survey, a computer search conducted at the National Science Library as well as from previous inventory studies. The major information source, however, was a specifically designed questionnaire sent to approximately 1050 plants in Canada, which received an overall response of 51%. Details on response rate and quality of returns are given in the Appendix. As far as possible emission estimates are based on source testing data applicable to Canadian conditions. Emission sources showing seasonal variation are indicated in the text.

1.2 Sources and Uses of Arsenic

In 1972 no arsenic or arsenic trioxide was produced in Canada for the domestic or export markets. Prior to 1972 Canadian output fluctuated with varying product demand (1). There were no data available on imports for 1972.

Refined arsenic trioxide is the most common compound of arsenic. It is a white, toxic powder refined from greyish-white crude arsenic trioxide. It is an unavoidable by-product of smelting and roasting operations, principally copper and lead smelting and roasting of gold, silver and cobalt ores (1).

Prior to 1961 Deloro Smelting and Refining Company Limited in Deloro, Ontario, accounted for all Canadian production of arsenic trioxide as a by-product of cobalt-silver ores and concentrates processing. In January 1961, this smelter and refinery closed due to a decline in the selling price of cobalt oxides and salts and the inability of the company to obtain sufficient good quality smelter feed (1). Production was resumed in Ontario in 1962 by a company which later became known as Kam-Kotia Mines Limited. The plant treated complex silver-oxide ores and concentrates produced in the Cobalt-Gowganda area of northern Ontario primarily for their silver content. This plant ceased operations in February 1972, producing only a small quantity of refined silver that year (1).

Cominco Limited in Trail, British Columbia, has produced high-purity arsenic for use in semiconductors but no production was reported for 1972.

Arsenic trioxide is produced during the roasting of gold concentrates at Giant Yellowknife Mines Limited in the Northwest Territories but is collected in baghouses and carefully disposed of in special underground workings (1).

Arsenic trioxide is used in the production of other arsenic compounds (both metallic and organic), arsenic metal and arsenic alloys.

Arsenic's major use is as a pesticide in agriculture in the form of calcium arsenate, arsenic acid, lead arsenate and sodium arsenite. Calcium and lead arsenate are the more important end-products;

however, in recent years, other organic and inorganic poisons have become popular as substitutes for the arsenates. These include dichlorodiphenyltrichloroethane (DDT), benzene hexachloride (BHC) toxaphene, and organic phosphate compounds (1).

Sodium arsenite was widely used to defoliate potato plants prior to harvesting and to control weeds but was phased out in 1971.

Arsenic compounds are also used in wood preserving, hide tanning, and in the manufacture of paint pigments. Arsenic trioxide and some of its derivatives are used in cattle and sheep dips, crabgrass control and aquatic weed control (1).

A significant use of white arsenic, not based on its toxic properties, is in glassmaking where it assists in decolorization and firing of glass products. By 1972, however, most glass manufacturers had discontinued the use of arsenic trioxide for this purpose.

Metallic arsenic is used primarily as an alloying agent because of its hardening properties. Additions of small amounts of arsenic, up to 3%, harden lead and minimize softening of lead-base bearing alloys used in internal combustion engines where elevated temperatures are encountered. Small amounts of arsenic may also be added to lead-base battery grids and cable sheathing to increase hardness. Minor amounts of arsenic may be added to copper, to increase corrosion and erosion resistance, raise the annealing temperature and possibly serve as a deoxidizer. When 0.02%-0.05% arsenic is added to brass it minimizes dezincification, and reduces season cracking (1).

A familiar metallurgical application of arsenic is in manufacturing lead shot. The addition of 0.5%-2.0% arsenic changes the surface tension of lead and improves the sphericity of the shot.

Over the past several years there has been a limited demand for very high-purity arsenic metal (99.999 %) as a semiconductor in the electrical and electronics industries. High-purity arsenic forms semiconductor compounds when alloyed with aluminium, gallium and indium. Gallium arsenide has been used to make tunnel diodes, varactor diodes, light emitting diodes (LED's), transistors, solar cells, experimental lasers and Gunn-effect devices. Indium arsenide has been used to produce Hall-effect and infrared devices (1).

2 INDUSTRIAL EMISSIONS

2.1 Primary Copper and Nickel Production

There were six primary copper smelters in Canada in 1972, three of which also produced primary nickel. One other company produced the remainder of the primary nickel and also a small amount of copper sulphide as a by-product. A small amount of copper matte was also produced as a by-product from primary lead producers. A total of 801 690 tons of recoverable copper and 258 087 tons of nickel were produced in Canada in 1972 (2, 3).

2.1.1 Process Description. The type of process and process stages required depend primarily on the characteristics and chemical composition of the ores. The most common method of producing primary copper and nickel consists of the following basic process steps:

Roasting. Concentrates are roasted to drive off most of the sulphur in preparation for subsequent smelting and converting reactions.

Smelting. In this stage the charge is melted, usually in a reverberatory furnace, where it separates into a matte and a slag.

Converting. The mattes are converted, through a series of chemical reactions, to the crude metals.

Anode Furnace and Electrolytic Refining. The crude copper or nickel is then cast into anodes to be refined by electrolysis.

Cathode Melting. Electrolytic copper is melted under reducing atmosphere in a shaft-type furnace to cast into billets, slabs, etc. for marketing.

Figure 3 is a typical flow diagram for the pyrometallurgical process. Nickel is also produced by the hydrometallurgical process which is practiced at one plant in Canada.

2.1.2 Emissions. The main atmospheric emission points from the production of primary copper and nickel are the roasters, furnaces, and converters. Emissions from operations such as ore handling and anode furnace are negligible in comparison. Arsenic is emitted primarily in the form of gaseous arsenic trioxide.

Because of process variations from one company to the other, emission factors for various process stages could not be compared. Very few smelters had source test data on arsenic although many have carried out stack tests for particulate emissions. Where information was insufficient arsenic emissions were based on the ratio of arsenic emitted to arsenic input from other smelters.

A similar survey in the United States (4) gives an uncontrolled emission factor for copper smelters of 4.9 lb arsenic/ton of copper. This factor is based on material balances and unspecified data reported in the literature. From data reported in questionnaires for the present survey, it was estimated that the emission factor for Canadian plants is 1.2 lb arsenic/ton of copper products. This figure takes into account the fact that the control equipment used at most plants is solely for particulate emissions. The arsenic, emitted as gaseous arsenic oxide is therefore essentially uncontrolled because of the relatively high operating temperatures of the control equipment. Information was not sufficient to enable basis of the Canadian emission factor on actual copper metal produced.

Total emissions of arsenic to the atmosphere from primary copper and nickel production in 1972 are estimated at 661 tons.

2.1.3 Particle Size Distribution. Table 2 summarizes information received on particle size distribution for particulate emissions from primary copper and nickel smelters.

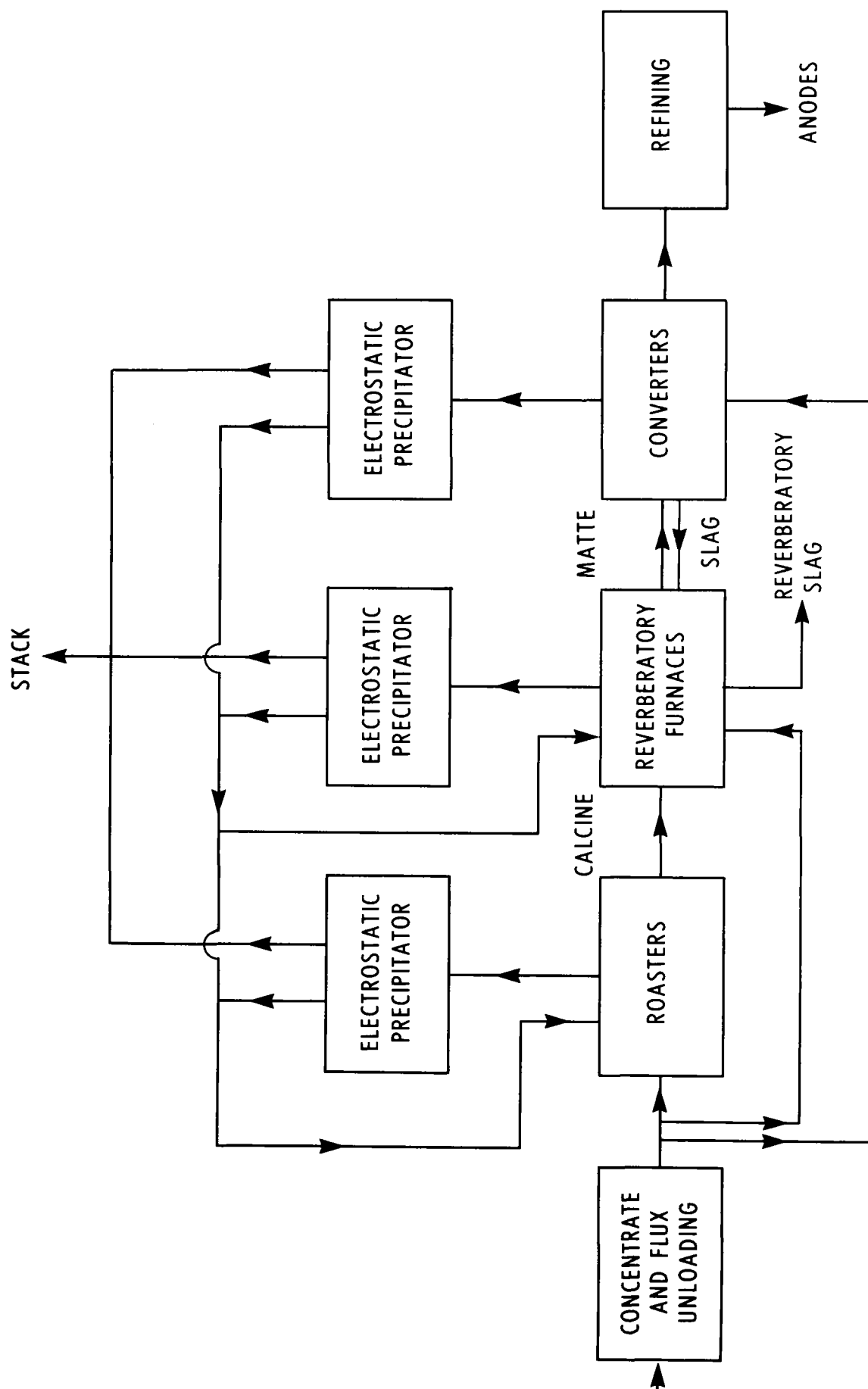


FIGURE 3 PRIMARY COPPER AND NICKEL PLANT FLOW DIAGRAM

TABLE 2 PARTICLE SIZE DISTRIBUTION FOR PARTICULATE EMISSIONS FROM
PRIMARY COPPER AND NICKEL SMELTERS

Source	Particle size (microns)	Weight of particulates (%)
Sinter plant	> 74	10
	37 - 74	18
	0.4 - 37	38
	< 0.4	34
Smelter plant A	> 74	19
	37 - 74	26
	0.4 - 37	30
	< 0.4	25
Smelter plant B	> 45	5
	21 - 44	10
	11 - 20	20
	< 10	65
Smelter plant C	44 - 100	5
	10 - 44	20
	< 10	75
Smelter plant D	4.8 - 11.7	19
	2.1 - 4.8	27
	0.5 - 2.1	14
	< 0.5	40

2.2 Primary Lead Production

There were two primary lead producers in Canada in 1972, producing a total of 204 452 tons of lead. Small amounts of copper matte, totalling 3677 tons, were a by-product of the lead refining operations.

2.2.1 Process Description. Lead is extracted from ore by first partially oxidizing the concentrate in a sintering plant. The partially roasted ore is then smelted in a blast furnace where the lead sulphide is oxidized by air to lead oxide, lead sulphate and sulphur dioxide. The lead oxide and lead sulphate then

react with carbon and carbon monoxide producing lead metal, carbon dioxide, and sulphur dioxide. The lead is further refined by either electrolysis or chemical precipitation from the molten metal.

2.2.2 Emissions. The main points of arsenic emission from primary lead production are:

Sinter Plant. One plant has an acid plant which results in low arsenic emissions in the form of arsenic trioxide, while the other plant has scrubbers. Total emissions of arsenic to the atmosphere from this source in 1972 are 878 lb or 0.44 ton.

Blast Furnace. The average controlled emission factor for the blast furnaces is 0.02 lb arsenic/ton of lead produced. Emissions are in the form of arsenic trioxide. Both companies control their emissions with a baghouse. Total arsenic emissions to the atmosphere from this source in 1972 are 3586 lb or 1.79 ton.

Anode Furnace. Arsenic is emitted from anode furnace operations in the form of arsenic trioxide. Total emissions of arsenic to the atmosphere from this source in 1972 are 70 lb or 0.04 ton.

Miscellaneous. Arsenic emissions from activities such as ore preparation, drying and handling are small relative to other emissions. Depending on the activity, the arsenic is emitted either as arsenic sulphate or arsenic trioxide. Total emissions of arsenic to the atmosphere from this source in 1972 are estimated at 190 lb or 0.10 ton.

Slag Fuming. At one plant the slag and the baghouse dust from the blast furnace operation are fumed to recover zinc. The zinc oxide fume is sent to the zinc oxide fume leaching plant. Emissions from the fuming operation are controlled with a baghouse. Arsenic emissions from the slag fuming operation were reported at 352 lb or 0.18 ton in 1972.

Lead Refining. Both electrolytic and chemical precipitation processes are used in Canada. From the questionnaires it was concluded that the chemical process has no significant emissions, while the electrolytic process emissions for 1972 are:

Source	Arsenic emissions (lb)
Bullion melting	1 908
Cathode melting	100
Slimes fuming	6 092
Antimonial reduction	22 440
Total	30 540 (15.27 tons)

Zinc Oxide Fume Leaching Plant. Zinc oxide fume from the slag fuming is leached and purified and the zinc is sent for refining by electrolysis (section 2.3). The leach residue is returned to the lead smelter and the purification residue is sent to the cadmium plant in the zinc refinery. The main source of emissions from this process is the solution cooling vent stack. Small emissions also occur from the fume-unloading and acid-thickening vent stack.

Arsenic emissions from the acid thickeners and solution cooling are in the form of arsenic sulphate droplets. Arsenic from fume handling in the form of arsenic trioxide is controlled with a baghouse. No controls were indicated for acid thickeners and solution cooling. Total emissions of arsenic to the atmosphere in 1972 from the zinc oxide fume leaching plant are 118 lb or 0.06 ton.

Total Emissions. The total estimated arsenic emissions to the atmosphere in 1972 from primary lead production are listed in Table 3.

TABLE 3 ARSENIC EMISSIONS FROM PRIMARY LEAD PRODUCTION, 1972

Process stage	Arsenic emissions (lb)
Sinter plant	878
Blast furnace	3 586
Anode furnace	70
Slag fuming	352
Bullion melting	1 908
Cathode melting	100
Slimes fuming	6 092
Antimonial reduction	22 440
Miscellaneous	190
Zinc oxide leaching	118
TOTAL	35 734 (17.87 tons)

One producer reported test data as a basis for arsenic emissions. This was used to estimate emissions, where applicable, from the other lead producer. Some emission estimates were also based on information from equipment suppliers. The uncontrolled emission factor for primary lead was calculated to be 2.61 lb arsenic/ton of lead produced. A previous study by the U.S. Environmental Protection Agency reported an uncontrolled arsenic emission factor from the primary lead process of 0.8 lb/ton of lead (4). This factor was based on material balances and unspecified data reported in the literature.

2.2.3 Particle Size Distribution. Neither company provided particle size distribution data and no such information was found in the literature.

2.3 Primary Zinc Production

During 1972 a total of 555 200 tons of primary zinc and 1538 tons of cadmium were produced in Canada from four plants.

2.3.1 Process Description. All the primary zinc in Canada is produced by an electrolytic process consisting of:

Roasting. The zinc sulphide ore is roasted to zinc oxide. The roasted ore is termed calcine and contains up to 3% sulphur.

Leaching. The calcine is leached with sulphuric acid to produce a neutral solution of zinc and other metal sulphates. The insoluble portion is separated from the soluble portion and contains about 20% zinc as ferrite, when the conventional electrolytic process is used.*

Purification. Cadmium and other metals are precipitated from the solution and the purified solution is cooled in forced draft cooling towers before going to the electrolysis plant. Arsenic trioxide and zinc dust are usually added to precipitate impurities. Approximately 2 lb of arsenic trioxide are used per ton of zinc produced (5).

Electrolysis. Zinc is plated from the solution. The temperature of the electrolyte is controlled by forced draft cooling towers.

Melting and Casting. The zinc cathodes are melted and cast into ingots.

Zinc Dust Plant. Zinc dust required for the purification step is made by melting some of the zinc followed by air atomization of the liquid metal.

Cadmium Plant. Cadmium is a by-product of zinc production. It is precipitated from solution during the purification stage then melted and cast into ingots.

Figure 4 is a typical flow diagram for a zinc plant.

2.3.2 Emissions. Concentrations of arsenic in the ores as reported in the questionnaires range from 0.005%-0.02%. Most of this is driven off as gaseous arsenious oxide during the roasting operation. All but one company have acid plants for the production of sulphuric acid from roaster gases. Before entering the acid plant, the gases are thoroughly cleaned by cyclones, electrostatic precipitators and acid

* Two plants in Canada use the Jarosite Process, which gives higher zinc recovery than the conventional method. In the Jarosite Process the insoluble portion contains up to 3% zinc as ferrite.

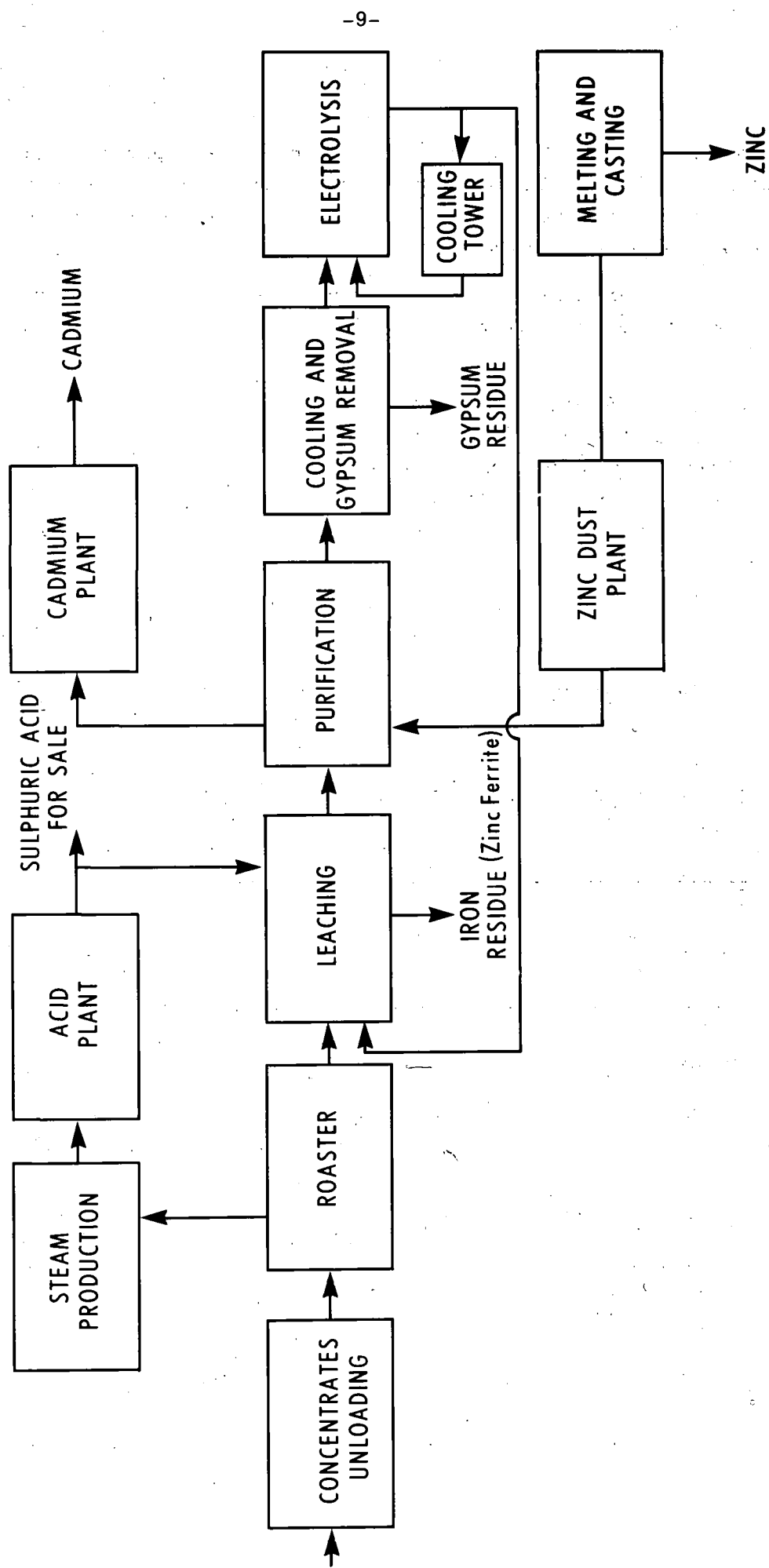


FIGURE 4 PRIMARY ZINC PLANT FLOW DIAGRAM

scrubbers. Virtually all arsenic is removed before the gas enters the acid plant. The company without an acid plant has an electrostatic precipitator which is ineffective for removal of gaseous arsenious oxide. Small amounts of arsine gas are formed during the purification stage and trace amounts of arsenic are present in dust generated by ore handling and storage.

Most companies reported source test data which were used to estimate arsenic emissions; however, some of the information was based on information from equipment suppliers and on mass balance calculations.

A similar survey in the United States (4) reports an average uncontrolled emission factor of 1.3 lb arsenic/ton of zinc produced based on material balances and unspecified data reported in the literature. It is not stated what type of process is used or whether there is an acid plant to treat roaster gases. The uncontrolled emission factor calculated in this survey for a primary zinc process without an acid plant is 10.5 lb arsenic/ton of zinc. Arsenic emissions from the primary zinc processes which have acid plants are negligible.

Total emissions of arsenic from primary zinc production in 1972 are estimated at 359 tons.

2.3.3 Particle Size Distribution. The only information received on particle size distribution is summarized in Table 4.

TABLE 4 PARTICLE SIZE DISTRIBUTION FOR PARTICULATE EMISSIONS FROM PRIMARY ZINC SMELTERS

Source	Particle size (microns)	Weight of particulates (%)
Zinc Dross	>5	27
	<5	73

2.4 Primary Iron and Steel Production

Forty-five plants in Canada were engaged in the production of primary iron and steel in 1972. Primary iron production capacity was about 12 million tons, and steel furnace plant capacity was about 16 million tons (6).

2.4.1 Process Description. The manufacture of iron and steel comprises some or all of the following steps:

Iron Ore Pretreatment. In certain cases iron ore is pretreated prior to the blast furnace operation. This process usually involves ore concentration followed by either sintering or pelletizing.

Iron Production. This takes place in the blast furnace. In this process, the iron-bearing materials (iron ore, sinter, pellets, mill scale, iron or steel scrap, etc.), fuel (coke), and flux (limestone and/or dolomite) are charged to the top of the furnace.

Heated air (blast) and, in some instances, fuel (gas, oil or powdered coal) are blown in at the bottom. The blast air burns part of the fuel to produce heat for the chemical reactions involved and for melting the iron, while the balance of the fuel and part of the gas from combustion remove the oxygen combined with the metal.

A typical blast furnace charge in Canada, per ton of product is:

Ore, Sinter, Pellets	1.6 tons
Coke	0.5 ton
Air	2.0 tons
Limestone/Dolomite	0.1 ton

The product from the blast furnace is known as either hot metal (molten) or pig iron (solid).

The pig iron may be remelted with scrap in cupolas for the production of cast iron.

Steel Production. Blast furnace product and steel scrap are charged to the steel furnace, where further refining takes place. Careful control of contaminants such as silica, phosphorus, sulphur and carbon is necessary to impart the desired characteristics to the product steel. Chemical and mechanical properties may be changed by alloying with other metals, such as nickel, chromium and manganese.

The major steel furnaces used in Canada in 1972 were the basic oxygen, the basic open hearth and the electric arc, listed in decreasing order of overall production capacity. Open hearth furnaces are becoming obsolete and should eventually be replaced by basic oxygen furnaces. The availability of cheap hydroelectric power in certain areas may sometimes favour the use of electric furnaces.

Steel Finishing. This includes a large number of operations, depending on the final product. The required product shape may be achieved by casting, or in rolling mills, bar mills or railing mills. Other processes such as scarfing, pickling and galvanizing are employed to achieve the desired surface properties.

2.4.2 Emissions. The main source of arsenic emissions in primary iron and steel production is from iron ore pretreatment plants processing ores with relatively high arsenic content. Only some iron ores used in Canada contain appreciable amounts of arsenic and these are found primarily in Northern Ontario. Minor arsenic emissions also occur from blast furnace and steel furnace operations.

Steel finishing operations are carried out at relatively low temperatures where the volatility of arsenic is comparatively small.

Emissions arise from the volatilization of arsenic contained in iron ore during sintering and pelletizing. For those pretreatment operations processing iron ores of relatively high arsenic content (about 0.05%), the uncontrolled emission factor was calculated to be 0.35 lb arsenic/ton of pellet or sinter. For pretreatment operations processing iron ores of low arsenic content, emissions are assumed to be negligible. Emissions also arise from blast furnace operation due to volatilization of arsenic contained in the iron ore and coke used. An uncontrolled emission factor from this source is estimated to be 0.07 lb arsenic/ton pig iron produced.

Emissions arise principally from volatilization of arsenic oxides during the refining process (7). Arsenic is assumed to be emitted only from steel furnaces which process pig iron, because no information was found on the presence of arsenic in steel scrap.

The uncontrolled emission factor from this source is estimated to be 0.02 lb arsenic/ton product.

Total estimated arsenic emissions from primary iron and steel production in 1972 are listed in Table 5.

TABLE 5 ARSENIC EMISSIONS FROM PRIMARY IRON AND STEEL
 PRODUCTION, 1972

Process stage	Arsenic emissions (tons)
Iron ore pretreatment	959
Blast furnaces (iron)	74
Steel furnaces (steel production)	8
TOTAL	1041

Few of the companies surveyed reported estimates for arsenic emissions. About half reported measurements of total particulate emissions.

No previous studies were found which indicated emission factors for arsenic or the percentage of arsenic present in total particulates for primary iron and steel production. Estimates were based mainly on material balances from information received in the questionnaires.

Arsenic emissions for this industrial category were not reported in any previous study. One study indicated steel mills only as a possible source (4).

2.4.3 Particle Size Distribution. Some companies reported measured particle size data, as summarized in Table 6.

TABLE 6 PARTICLE SIZE DISTRIBUTION FOR PARTICULATE EMISSIONS FROM ELECTRIC ARC STEELMAKING FURNACES

Source	Particle size (microns)	Weight of particulates (%)
Electric furnace	< 5	20 - 50
	5 - 10	30 - 50
	10 - 20	10 - 25
	> 20	5 - 10
Electric furnace with oxygen lance	0.2 - 5	95

2.5 Metallurgical Processing of Gold

There were 16 major gold producers in Canada in 1972 producing approximately 2 074 000 troy ounces of gold (71.1 tons) (8). Gold was also recovered by placer mining in the Yukon and from copper, lead, and zinc ores. All producers sold their gold bullion to the Royal Canadian Mint in Ottawa for further refining. No significant emissions can be attributed to this additional refining.

2.5.1 Process Description. Gold ore processing is based on the outstanding characteristic properties of this element, such as its high density, low chemical affinity, ability to easily form amalgams with mercury, and solubility in alkaline cyanide solutions.

Processing may include some or all of the following steps:

- Milling or Crushing
- Flotation (concentration)
- Roasting
- Cyanidation (and precipitation)
- Amalgamation
- Refining

Gold ores contain this precious metal mainly as free metal, and all processing steps are intended to separate the impurities accompanying it.

Placer operations recover free gold from gold-bearing gravel or sand which is crushed to break up frozen or caked material. When the gold content is too low, this is followed by amalgamation with mercury and filtration. The mercury is then removed by distillation.

For ores from other origins, especially those which contain, in addition to quartz, such impurities as mispickel, pyrrhotite, stibnite, sylvanite, krennerite, calaverite, arseno-pyrites and pyrites, the separation after ore crushing is incomplete, and flotation is used to concentrate the gold fraction by reducing the gangue. The product is then processed by cyanidation.

Cyanidation is based on the property of gold to easily form a gold-cyanide-potassium complex, which allows the dissolution of gold into a liquor. Gold is reprecipitated from the liquor by the addition of zinc metal dust. This is followed by amalgamation and refining. Elements such as arsenic, tellurium, sulphur and antimony interfere with the cyanidation process. In order to remove these elements prior to cyanidation a roasting step may be necessary.

A general process flow diagram is given in Figure 5.

2.5.2 Emissions. Only 4 of the 16 plants producing gold by cyanidation in 1972 had roaster operations. This was found to be the only significant source of arsenic emissions (in the form of arsenic trioxide) from metallurgical gold processing.

A similar study in the United States (4) mentions that arsenic emissions from roaster operations are high but no emission factor is given.

An average uncontrolled emission factor for the roaster operation is calculated to be 15 lb arsenic/ton of ore processed. This varies with the arsenic content of the ore and the processing used.

All of the companies which provided emission information based their estimates on source testing.

Total emissions of arsenic from metallurgical gold processing for 1972 are estimated at 1934 tons.

2.5.3 Particle Size Distribution. No data were reported or found in the literature on particle size for gold processing emissions.

2.6 Miscellaneous Industrial Sources

During the survey there were many operations identified which either processed arsenic or arsenic compounds or had arsenic introduced as an impurity in the raw materials; however, they were found to emit only relatively small amounts of arsenic. This section summarizes these operations.

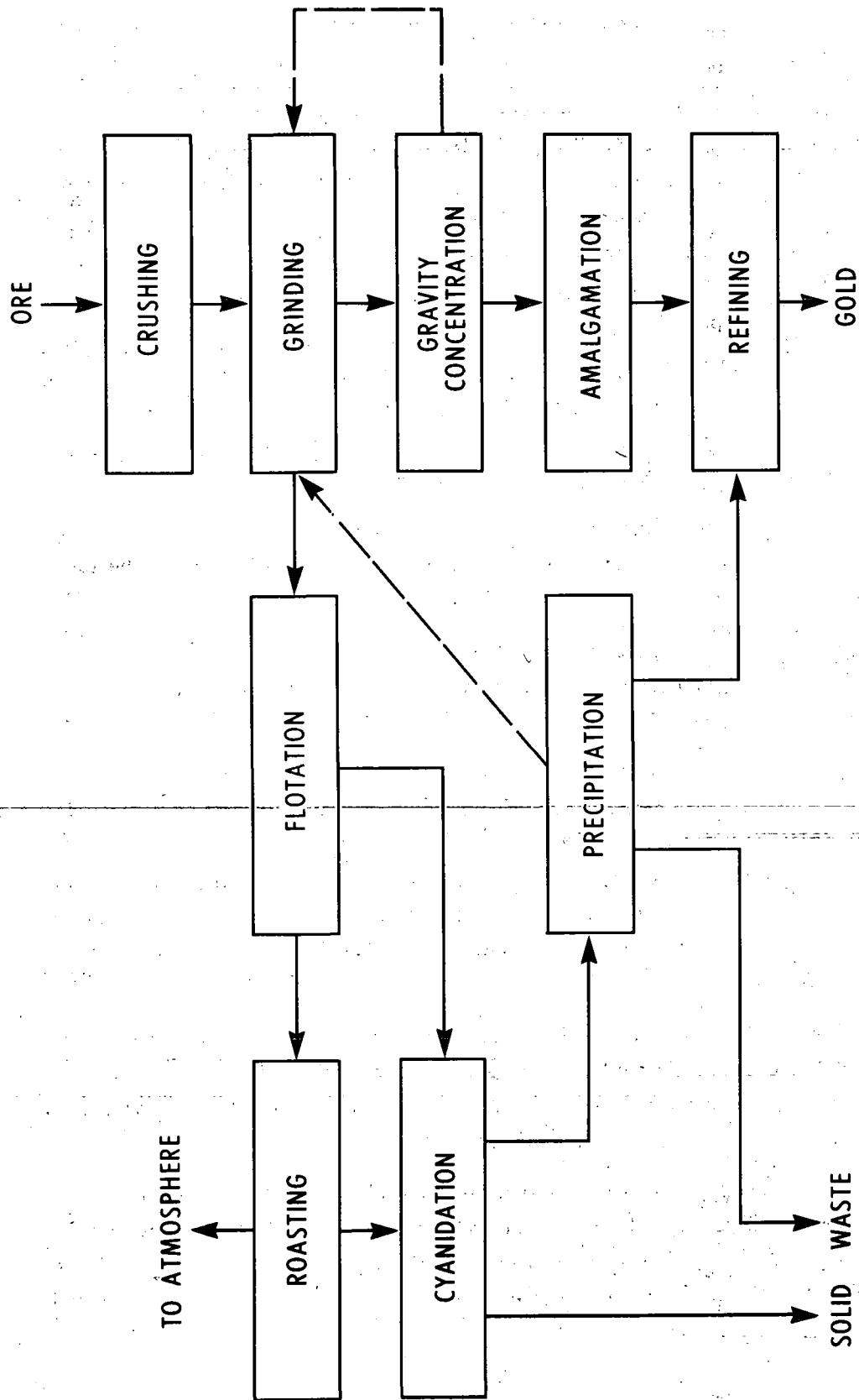


FIGURE 5 METALLURGICAL PROCESSING OF GOLD FLOW DIAGRAM

2.6.1 Arsenic Trioxide Production. There was only one producer of arsenic trioxide in Canada prior to 1972. In February 1972, operations ceased (9). Only small amounts of silver were produced in January 1972, and the quantity was not reported (9). It is assumed that emissions of arsenic during this one-month period were negligible.

2.6.2 Glass Manufacture. Nearly all glass produced commercially in Canada during 1972 was one of five basic types: soda-lime, lead, fused silica, borosilicate and 96% silica. Of these, the modern soda-lime glass accounted for most of the Canadian production because of its suitability for melting and shaping into window glass, plate glass, containers, inexpensive tableware, electric light bulbs, and many other inexpensive, mass-produced articles.

Arsenic compounds were once used extensively as decolorizers and aids to the glass manufacturing process but today they have been largely replaced by other compounds. Only two companies report using arsenic and this is for specialty glass products. Because of these replacements and improvements in processing techniques (10) arsenic emissions from this source are small. Emissions to the atmosphere from glass manufacturing in 1972 are estimated at about 2.5 tons.

2.6.3 Ferrous Foundries. The total production in Canada from ferrous foundries in 1972 was estimated at 737 567 tons of iron and steel castings. None of the companies replying to the survey reported any arsenic emissions.

A published paper on emissions from grey iron cupolas in Ontario does not report any arsenic in the emissions (11, 12). A conversation with one of the authors confirmed that only the elements indicated in the article were detected (13). Analyses were done by X-ray diffraction.

A similar survey in the United States (4) provides some information on arsenic content of particulates. According to the report spectroscopic analyses of dust samples reveal the presence of arsenic, but the quantity reported (0.07% of particulates) is based only on a private communication. These data are not felt to be adequate and the Canadian papers (11, 12) are used as a basis. Also, as discussed in section 2.4, all arsenic present in iron ores is assumed to be driven off during the pretreatment, blast furnace and steel furnace operations. It is therefore assumed that there were no arsenic emissions from ferrous foundries.

2.6.4 Phosphate Rock Processing and End Uses. The largest consumers of phosphate rock in 1972 were manufacturers of phosphate fertilizers. Phosphate rock was also used in the manufacture of elemental phosphorus, the main component in the production of phosphoric acid for producing foods, drugs, and detergents.

The only significant points of arsenic emission from phosphate rock processing are the electric furnaces used to reduce phosphate ore to elemental phosphorus (14). Only small amounts are emitted by phosphate fertilizer plants from the crushing and grinding operations. Based on a limited amount of data supplied in the questionnaires, the total amount of arsenic emitted to the atmosphere in 1972 from phosphate rock processing is estimated at 2 tons.

2.6.5 Metallurgical Coke Manufacture. There were seven coke manufacturing companies in Canada in 1972 with a total coke production of about 5.2 million tons (15). It is assumed that most of the arsenic contained in coal is volatilized during coking and removed in scrubbing/cooling towers; therefore, arsenic emissions to the atmosphere could only occur during coal handling operations. Since these are low-temperature processes, the content of the particulate emissions would be similar to that of coal. It has been reported (16) that about 1.5 lb particulate are emitted to the atmosphere per ton of coke produced and the arsenic content of coal is about 5 ppm (4).

Total emissions from coke manufacturing in 1972 are therefore assumed to be negligible.

2.6.6 Nonferrous Alloy Manufacture. One company reported importing 61 tons of arsenic in 1972 for the manufacture of arsenical lead. Another company reported reprocessing arsenical lead. Their total arsenic emissions are estimated at less than 1 ton for 1972.

None of the other nonferrous alloy manufacturers, including brass and bronze foundries, reported any arsenic emissions or used arsenic in their processes.

2.6.7 Pesticide Manufacture. No pesticides containing arsenic were manufactured in Canada in 1972.

2.6.8 Mining Operations. Regardless of the type of mine (underground or open-pit), all mining operations are basically the same. The main process steps involved are ore removal, ore handling, crushing, grinding and concentration.

Some emissions occur during blasting, drilling, and ore transportation but the arsenic concentration of any dust emitted is usually low. The highest concentrations of arsenic occur in gold ores and average 0.60% arsenic by weight for the companies reporting. Copper and lead ores also contain relatively high arsenic concentrations. Minor emissions also occur from ore crushing and drying. Based on the above, it is estimated that arsenic dust generated from mining activities in 1972 amounts to about 1 ton.

2.6.9 Petroleum Refining. Data received in this study provide no evidence to indicate that arsenic is discharged to the atmosphere during the refining process; however, arsenic is found in crude oil, and it is believed that most of the arsenic remains behind in the heavy oils and asphalts (4). When the heavy oil is subsequently burned as a fuel it is likely that the arsenic is discharged with the combustion products. This source is dealt with in Sections 3 and 4 of this report.

2.6.10 Copper Refining. Two companies were refining copper in Canada in 1972. Anode and blister copper from the primary copper industry are refined by electrolysis. Blister copper must first be cast into anodes prior to electrolysis. Arsenic is emitted as arsenious oxide from the anode furnace and as arsine gas formed during the electrolysis, electrolyte purification and slime treatment processes.

TABLE 7 ARSENIC EMISSIONS FROM MISCELLANEOUS INDUSTRIAL SOURCES, 1972

Source	Arsenic emissions (tons)
Arsenic trioxide production	N*
Glass manufacture	2.5
Ferrous foundries	0
Phosphate rock processing and end uses	2
Metallurgical coke manufacture	N
Nonferrous alloys	<1
Pesticide manufacture	0
Mining operations	1
Petroleum refining	0
Copper refining	9.7
TOTAL	15 (approx.)

*N-negligible

Total arsenic emissions in 1972 from this source are estimated at 9.7 tons.

3 EMISSIONS FROM FUEL COMBUSTION - STATIONARY SOURCES

3.1 General

Stationary sources can be divided into the following categories:

- Power generation
- Industrial and commercial
- Domestic

The five principal types of fuels used are gaseous (natural gas, propane, etc.) diesel oils, light oils, heavy oils and coal. Of these five fuels only heavy oils and coal contain arsenic (4, 14).

The emission factors used for these fuels are based on two reports by the United States Environmental Protection Agency (4, 14) and are listed in Table 8.

TABLE 8 ARSENIC EMISSION FACTORS FOR FUELS

Fuel	Arsenic emission factor (uncontrolled)
Heavy oil	0.0013 lb arsenic/1000 Imp. Gal.
Coal	0.008 lb arsenic/ton 0.003 lb arsenic/ton (controlled)

The controlled emission factor for coal is based on fly ash samples taken after passage through control equipment (4, 14). The degree of emission control for arsenic removal was not stated in either report (4, 14) but it is assumed that part of the arsenic remained in the bottom ash and part in the fly ash collected by the control equipment. This emission factor is used for stationary sources having dry collection devices.

The uncontrolled emission factor is assumed to be 75% of the original quantity of arsenic in the coal, the other 25% remaining in the bottom ash. Based on an average arsenic content of United States coals of 5.44 ppm (4, 14) the uncontrolled emission factor is estimated at 0.008 lb arsenic/ton of coal. This factor is used for stationary sources having no emission control equipment.

For wet collectors, an efficiency of 85% of the uncontrolled factor is assumed.

3.2 Power Generation

In 1972, generation of electricity from coal-operated facilities accounted for 62% of total Canadian thermal generation; petroleum fuels were responsible for 1.0%, natural gas for 15.7% and nuclear fuels for 12.3% (17).

Estimates of arsenic emissions from power generating stations are listed in Table 9.

Approximately 60% of these emissions occur during the winter (18), depending on climate and the extent to which electricity is used for heating.

TABLE 9 ARSENIC EMISSIONS FROM POWER GENERATION, 1972

Source	Arsenic emissions (lb)
Heavy oil facilities	467
Coal facilities	50 256
TOTAL	50 723 (25.4 tons)

3.3 Industrial and Commercial

Approximately 90 million barrels of heavy oils and 2.7 million tons of coal were consumed for industrial and commercial purposes in Canada during 1972. The figure of 2.7 million tons of coal does not include coal used for coke manufacturing (section 2.6).

Estimates of arsenic emissions resulting from the combustion of industrial and commercial fuels during 1972 are listed in Table 10.

TABLE 10 ARSENIC EMISSIONS FROM INDUSTRIAL AND COMMERCIAL FUEL USE, 1972

Source	Arsenic emissions (lb)
Heavy oil combustion	4 077
Coal combustion	21 640
TOTAL	25 717 (12.9 tons)

Heavy oil is used throughout the year for process heating. In the winter, however, it is also used for plant heating causing a seasonal increase in arsenic emissions. The degree of emission control is assumed to be insignificant.

3.4 Domestic

Generally, light oils are used for domestic heating; however, a small quantity of heavy oils, containing arsenic, are used mainly in apartment complexes. This quantity totalled 3 million barrels in 1972 with emissions occurring mainly in the winter months (October - April).

Arsenic emissions from domestic sources in 1972 are estimated at 139 lb or 0.07 ton.

4 EMISSIONS FROM TRANSPORTATION SOURCES

Transportation is considered under four headings:

- Motor Vehicles
- Rail Transport
- Shipping
- Aviation

4.1 Motor Vehicles

Motor vehicles use either gasoline or diesel oil as a fuel, neither of which contain arsenic (section 3).

4.2 Rail Transport

Rolling stock use diesel oil or gasoline, neither of which contain arsenic (section 3). Although the railway companies purchase heavy oils and coal, these are employed for heating and power generation and the emissions are dealt with in the appropriate sections of this report.

4.3 Shipping

Shipping uses arsenic-containing bunker oil as a fuel (section 3), but it is estimated that only 20% of this oil is burned within Canadian territory. The remainder is burned on the high seas and is not included in this inventory. Approximately 11 million barrels of bunker oil were purchased in Canada in 1972 (19). Emissions are estimated using an uncontrolled emission factor of 0.0013 lb arsenic/1000 Imperial Gallons (section 3). Emissions are substantially reduced during winter months when some inland waterways are closed.

Arsenic emissions from shipping operations in Canada for 1972 are estimated at 101 lb or 0.05 ton.

4.4 Aviation

Aircraft are fuelled with either aviation gasoline or kerosene, neither of which contain significant quantities of arsenic.

5 EMISSIONS FROM SOLID WASTE INCINERATION

The only data available on arsenic emissions from solid waste incineration deals with sewage sludge incineration (14). The uncontrolled emission factor for sewage sludge incineration is 0.02 lb arsenic/ton of sewage sludge (14).

In Canada in 1970, 133 900 tons of sewage sludge were incinerated. It is assumed that approximately the same quantity was incinerated in 1972. Based on the above assumptions, it is estimated that about 2040 lb or 1.02 tons of arsenic were discharged to the atmosphere during 1972 from sewage sludge incinerators.

6 EMISSIONS FROM PESTICIDE APPLICATION

Approximately 340 000 lb of pesticides containing arsenic were sold in Canada in 1972 (21).

When considering atmospheric emissions from the use of pesticides it is very important to delineate the parameters that determine the percentage 'drift' (drift being the amount of pesticide leaving the target area). Factors affecting drift are the droplet size of the liquid, wind speed, temperature, foliage density, humidity, and operator skill.

Pesticide application is dependent upon chemical make-up and the desired effect. Aerial application is used for treatment of large areas such as forests. Fruit tree spraying is usually from the operator upward whereas spraying of vegetable crops is from the operator downward. Fogging is used in cases that can take advantage of drifting.

Losses during aerial application range from 10%-50% depending on the factors mentioned above. In fruit tree spraying the air emissions may be 50% early in the season when the leaves are small. As leaf cover increases loss from drift decreases rapidly (22). Other types of application have an average loss of about 10% (23).

Since pesticides containing arsenic are usually organic or inorganic salts, there would be no loss by volatilization (23).

Approximately 164 770 lb of lead arsenate and 173 726 lb of calcium arsenate were sold in Canada in 1972 and both were normally applied as a spray. These accounted for virtually all the pesticides containing arsenic sold in Canada in 1972. Lead arsenate was used almost exclusively to control apple magots in the Maritimes. Calcium arsenate was used to control earthworms at airports and

golf courses. Table 11 summarizes emissions from pesticide application during 1972 based on a 10% drift loss.

TABLE 11 ARSENIC EMISSIONS FROM PESTICIDE APPLICATION BASED ON 10%
DRIFT LOSS, 1972

Pesticide	% Arsenic	Amount sold in Canada (lb)	Weight of arsenic (lb)	Arsenic emissions (lb) (tons)	
Lead arsenate	22.3	164 770	36 744	3 674	1.837
Calcium arsenate	50	173 726	86 863	8 686	4.343
TOTAL		338 496	123 607	12 360	6.180

Information on arsenic emissions from cotton plantations in the United States is available (4) but is not applicable to this study.

Pesticides are applied mainly during June and July, however, lead arsenate was also extensively used during August as part of an integrated control procedure for apple magots.

REFERENCES

1. George, J.G., *Arsenic Trioxide - 1969*, Mineral Review No. 5, Department of Energy, Mines and Resources, Ottawa (1970).
2. Cajka, C.J., *Nickel - 1972*, Mineral Review No. 32, Department of Energy, Mines and Resources, Ottawa (Aug. 1973).
3. Shank, Robert J., *Copper - 1972*, Mineral Review No. 16, Department of Energy, Mines and Resources, Ottawa (Aug. 1973).
4. U.S. Environmental Protection Agency, *National Inventory of Sources and Emissions: Arsenic - 1968*, Office of Air and Water Programs, Office of Air Quality Planning and Standards, Publication No. APTD-1507, (1971).
5. Surveyer, Nenniger & Chênevert Inc., Mining and Metallurgy Division (Personal Communication).
6. Statistics Canada, *Primary Iron & Steel 1972 and 1973*, Publication No. 41-001, (1973).
7. Hutchinson, E., *Chemistry: The Elements and Their Reactions*, W.B. Sanders Co., Philadelphia (1960).
8. Hogan, J.J., *Gold 1972*, Mineral Review No. 18, Department of Energy, Mines and Resources, Ottawa (1973).
9. George, J.G., *Silver - 1972*, Mineral Review No. 44, Department of Energy, Mines and Resources, Ottawa (1973).
10. Banks, G., Canadian Pittsburg Industries (Personal Communication).
11. Warda, R.D., Buhr, R.K., "A Detailed Study of Cupola Emissions", *AFS Transactions*, 81, p. 32-37 (1973).
12. Warda, R.D., Buhr, R.K., "A Method of Sampling Cupola Emissions", *A.F.S. Transactions*, 81, p. 24-31 (1973).
13. Gish, C.D. and Christensen, "Cadmium, Nickel, Lead, and Zinc in Earthworms from Roadside Soil", *Environmental Science and Technology* (Nov. 1973).
14. U.S. Environmental Protection Agency, *Emission Factors for Trace Substances*, Publication No. PB-280-894 (Dec. 1973).
15. Statistics Canada, *Coal and Coke Statistics Catalogue*, Publication No. 45-002, (Dec. 1972).

16. Choquette, P.J., *Air Pollution Emissions and Control Technology, Metallurgical Coke Manufacturing Industry*, Environment Canada, Report EPS 3-AP-74-6 (Nov. 1974).
17. Statistics Canada, *Electrical Power Statistics Vol. II*, Annual Statistics, Publication No. 57-202.
18. Environment Canada, Air Pollution Control Directorate, Combustion Sources Division (Unpublished Information).
19. Statistics Canada, *Annual Refined Petroleum Products - consumption of petroleum products 1972*, Publication No. 45-208, (1972).
20. Environment Canada, *National Inventory of Sources and Emissions of Lead (1970)*, Air Pollution Control Directorate, APCD 73-7 (Nov. 1973).
21. Statistics Canada, *Sales of Pest Control Products by Canadian Registrants*, Publication No. 46-212 (1972).
22. Chiba, M., Fisher, R.W., Hernes, D.C., "Pesticide Pollution in relation to Orchard Spray Application". *Proceedings of International Symposium on Identification and Measurement of Environmental Pollutants*. National Research Council, pp. 250-254 (1971).
23. Saha, J.G., Department of Agriculture, Chemistry and Biology Research Institute Canada (Personal Communication).

BIBLIOGRAPHY

Bashforth, G. Reginald, *The Manufacture of Iron and Steel - Vol. 2 Steel Production*, 2nd ed., Chapman & Hall Ltd., London (1959).

B.C. (The) Paint Manufacturers Association, *Summary of a Brief to the British Columbia Pollution Control Inquiry - Chemical & Petroleum Industries*, (March 15, 1972).

Brandt, D.J.O., *The Manufacture of Iron and Steel*, British Iron and Steel Federation, The English Universities Press Ltd, London, Third Impression (1964).

Bray, John L., *Non-Ferrous Production Metallurgy*, 2nd ed., John Wiley and Sons Ltd., New York, Sixth Printing (1959).

Canada Department of Agriculture, *Pesticides Listed by Active Ingredient Registered for Use in Canada, for 1972*, Catalogue No. A41-17/1972.

Canadian Machinery and Metalworking, *Metalworking Catalogue and Buying Directory 1974*, Maclean Hunter Publication (1974).

Christmas, L.P. and McMullen, M.K., *Coking Coal in Canada*, Department of Energy, Mines and Resources, Mineral Bulletin MR 135 (March 1973).

Department of Energy, Mines and Resources, *Canadian Minerals Yearbook 1968*, Mineral Resources Branch, Ottawa (1968).

Department of Industry, Trade and Commerce, *Brass and Bronze Foundries and Ingot Makers*, Resources Industries and Construction Branch, Ottawa (1974).

Department of Industry, Trade and Commerce, *Die Casting in Canada, Manual and Directory*, 4th ed., Information Canada, Ottawa (1972).

Department of Industry, Trade and Commerce, *Iron and Steel Foundries*, 3rd ed., Information Canada, Ottawa (1971).

Department of Industry, Trade and Commerce, *Iron and Steel from Canada*, Information Canada, Ottawa (1972).

Department of Industry, Trade and Commerce, *Protect your Investment with Canadian Galvanizing. Manual and Directory of Galvanizing in Canada*, Ottawa.

Gauvin, M., *Lead - 1972*, Mineral Review No. 23, Department of Energy, Mines and Resources, Ottawa (Aug. 1973).

Jens, W. and Rehm, F.R., "Municipal Incineration and Air Pollution Control", *Proceedings of the 1966 National Incinerator Conference* (1966).

Knox, Arthur C., "Air Pollution from Combustion Equipment and Fuels", *Combustion*, 44 (3): p.11-12 (Nov. 1972).

Koepke, W.E., *Fertilizers and Fertilizer Minerals in Canada*, Department of Energy, Mines and Resources, Mineral Bulletin MR 115, Ottawa (1971).

Liddell, Donald M., *Handbook of Non-Ferrous Metallurgy: Recovery of the Metals*, 2nd ed. McGraw - Hill Inc., New York (1945).

Lugg, W.G., *Petroleum - 1972*, Mineral Review - No. 33, Department of Energy, Mines and Resources, Ottawa (June 1973).

Lund, Herbert F. (ed), *Industrial Pollution Control Handbook*, McGraw - Hill, New York (1971).

Manitoba Hydro, *A Brief Description of Emissions to the Atmosphere at Brandon Generating Station*, (Nov. 29, 1972).

Mineral Resources Branch, *Coal Mines in Canada January 1973*, Operators List 4, Department of Energy, Mines and Resources, Ottawa (1973).

Mineral Resources Branch, *Metal and Industrial Mineral Mines and Processing Plants in Canada 1972* Operators List 1, Department of Energy, Mines and Resources, Ottawa (1972).

Mineral Resources Branch, *Metallurgical Works in Canada, Primary Iron and Steel, January 1973*, Operators List 2, Department of Energy, Mines and Resources, Ottawa (1973).

Minerals Resources Branch, *Metallurgical Works in Canada, Non-Ferrous and Precious Metals, January 1973* Operators List 3, Department of Energy, Mines and Resources, Ottawa (1973).

Ruddle, R.W., *Losses in Melting Copper-Base Alloys*, Modern Castings 67-95, p. 91-98 (1968).

Statistics Canada, *Annual, The Motor Vehicle, Part III, Registrations 1972*, Publication No. 64-202 (1972).

"Cross Canada Solid Waste Survey", *Water and Pollution Control*, p. 21 (Jan. 1972).

Miniato, O., Technical Supervisor, Manufacturing Department, Shell Canada Ltd. (Personal Communication).

Lee, G.K., Department Energy, Mines and Resources, Canadian Combustion Research Laboratory (Personal Communication).

Dutton, M., Engineering Section, Canadian Pacific Railways (Personal Communication).

Spencer, E.Y., *Guide to the chemicals used in crop protection*, Publication No. 1093, Research Branch, Dept. of Agriculture, Ottawa, 6th edition, (1973).

National Incinerator Conference (1966).

Baum & Parker, *Solid Waste Disposal Vol I*, Ann Arbor Science Publishers Inc.

Gough, W.K., Toronto P.W.D. (personal communication).

Service de Protection de l'Environnement du Québec, *La Gestion des Déchets Solides*, Gouvernement du Québec (Décembre 1972).

Statistics Canada, *Canadian Statistical Review*, Jan.-June 1973 and July-Dec. 1973, Quarterly estimates of population for Canada & Provinces, Publication No. 91-001 (1973).

Statistics Canada, *Coal Mines Calendar Year 1972*, Publication No. 26-206 (1972).

Statistics Canada, *Energy Statistics, Vol. 8 No. 11*, February 1973, Publication No. 57-002 6503-521 (1973).

Statistics Canada, Service Bulletin, *Energy Statistics, Vol. 8 No. 33*, June 1973, Publication No. 54-002 5-3301-521 (1973).

Steiner, J., "Inco's Superstack Emission", *Emissions from Smelter Operations and Their Effect on The Environment* Seminar (Feb. 21, 1974).

Stern, Arthur C., *Air Pollution Vol. III*, Academic Press, New York, Second Edition (1968).

U.S. Environmental Protection Agency, *Guide for Compiling a Comprehensive Emission Inventory (revised)*, Office of Air and Water Programs, Office of Air Quality Planning and Standards, Publication No. APTD-1135.

U.S. Environmental Protection Agency, *Nationwide Air Pollutant Emission Trends 1940-1970*, Publication No. AP-115.

Walker, A.B. & Schmitz, F.W., "Characteristics of Furnace Emissions from Large Mechanically-Stoked Municipal Incinerators", *Proceedings of the 1966 National Incinerator Conference* p. 64-73 (1966).

Brown, P.S., Canadina Paint Manufacturers (Personal Communication).

Statistics Canada, *Annual Household Facilities and Equipment*, Publication No. 64-202 (April 1973).

Statistics Canada, *Rubber Products Industries*, Publication No. 33-206 (1971).

Statistics Canada, *Steel Ingots and Pig Iron*, Publication No. 41-002 (Dec. 1972).

Buhr, R.K., Energy, Mines and Resources (Personal Communication).

Thompson, Hazen, Environmental Protection Service, Ottawa (Personal Communication).

Johnson, R., Energy, Mines and Resources (Personal Communication).

United States Steel, *The Making, Shaping and Treating of Steel*, 9th Edition, Pittsburg, Pa. (1970).

Lynch, T., Canadian Industries Limited (Personal Communication).

Report of the Commission Appointed to Inquire Into and Report Upon the Pollution of Air, Soil and Water in the Townships of Dunn Moulton and Sherbrooke (Haldamand County) Queens Printer, (1968).

Northern Miner, Canadian Mines Handbook.

Foster, E.O., *The Collection and Recovery of Gold from Roaster Exit Gases at Giant Yellowknife Ltd.*, The Canadian Mining and Metallurgical Bulletin, (June, 1963).

Montreal Star, "Arsine Gas Poisoning", (Jan. 13, 1975)

Sullivan, R.J., *Air Pollution Aspects of Arsenic and Its Compounds*, Litton Systems, Inc., Bethesda, Maryland (1969).

APPENDIX - SURVEY OF QUESTIONNAIRE RETURNS AND QUALITY INDEX

Sector	Number of questionnaires		Rate of response (%)	Quality index of questionnaires returned*					Average quality index
	Sent	Returned		1	2	3	4	5	
Primary copper & nickel & assoc.	13	12	92	-	-	-	4	8	4.7
Primary iron & steel	45	28	62	2	2	5	7	12	3.9
Primary aluminum	6	6	100	-	-	-	-	6	5.0
Primary lead & zinc	6	6	100	-	-	-	-	6	5.0
Copper, brass & bronze foundries	84	27	32	2	4	7	8	6	3.4
Die casting	91	51	56	4	18	14	10	5	2.9
Iron & steel foundries	194	88	45	10	16	25	24	13	3.2
Metallurgical coke	7	3	43	-	-	1	-	2	4.7
Phosphate fertilizers & elemental phosphorus	31	28	90	-	1	13	2	12	3.9
Galvanizing	46	26	57	2	3	10	10	1	3.2
Plating	83	25	30	7	9	3	6	-	2.3
Ferroalloys & assoc.	13	4	31	-	-	-	1	3	4.8
Pesticides	58	26	45	9	10	-	4	3	2.3
Ceramics and glass	105	44	42	1	8	6	18	11	3.7
Nonferrous alloys	20	11	55	1	2	-	5	3	3.6
Battery mfg.	5	2	40	-	-	-	1	1	4.5
Rubber mfg.	24	20	83	-	2	5	7	6	3.9
Zinc oxide mfg.	2	1	50	-	-	-	-	1	5.0
Mining	39	21	54	2	2	4	5	8	3.7
Porcelain & enamels	30	17	57	4	4	4	3	2	2.7
Clay products mfg.	57	21	37	7	4	3	4	3	2.6
Petroleum refining	47	35	74	4	5	11	-	15	3.5
Vinyl stabilizers & plasticizers	13	8	62	-	-	2	3	3	4.1
Welding rods mfg.	12	10	83	2	2	-	2	4	3.4
Miscellaneous	16	13	81	-	-	4	3	6	4.2
TOTAL:	1047	533	51	57	92	117	127	140	3.4

* Quality index of questionnaires returned was based on the following rating:

1. No emissions reported, no back-up given
2. No pertinent information.
3. Poor reply, data insufficient
4. Medium reply, emissions can be calculated
5. Good reply, emissions data given and documented

LIBRARY
CANADA CENTRE FOR INLAND WATERS
867 LAKESHORE ROAD
BURLINGTON, ONTARIO, CANADA
L7R 4A6