NATIONAL INVENTORY OF SOURCES AND EMISSIONS OF BERYLLIUM (1970)

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Report APCD 73-5
October 1973

ABSTRACT

Atmospheric emissions of beryllium in Canada have been estimated for the year 1970. A summary of the data presented in this report is given in Table 1, along with emission factors for sources in the United States. During 1970, no beryllium mining or recovery operations were carried out in Canada, nor were any planned for the near future. Manufacturing industries were found to handle imported beryllium materials with care, and therefore produced negligible emissions. Total emissions of beryllium from manufacturing operations were estimated to be less than one pound annually.

Trace amounts of beryllium in coal, coke, and oil, however, produced an estimated atmospheric emission of 7.8 tons from combustion processes. The hazards associated with this release cannot be established unequivocally at this time, since information on the beryllium compounds involved is lacking. Beryllium may be emitted in a form similar to the compound beryl, which is nontoxic; on the other hand, if beryllium follows the same pattern as do several other metals, the compound involved is beryllium oxide, which is toxic. Provincial emissions of beryllium are given in Table 2, and point sources are identified in Figure 1.

RESUME

On a évalué les émissions atmosphériques de béryllium, au Canada, pour 1970. Le tableau 1 donne un résumé des données présentées dans le présent rapport, ainsi que les facteurs d'émissions dont les sources sont aux Etats-Unis. Aucune exploitation minière ou activité de récupération concernant le béryllium n'a été effectuée au Canada, en 1970, ou n'est prévue dans un avenir rapproché. Les industries de fabrication manipulent avec soin les produits importés contenant du béryllium, de sorte que les émissions sont négligeables. On a évalué les émissions totales de la fabrication à moins d'une livre par année.

Des quantités minimes de béryllium présentes dans le charbon, le coke et le pétrole, cependant, ont produit environ 7.8 tonnes d'émissions atmosphériques, par la combustion. Pour le moment, on ne peut établir, avec certitude les dangers liés à ce rejet puisqu'on ne dispose pas des renseignements nécessaires sur les composants du béryllium. Le béryllium pourrait être rejeté sous une forme semblable au béryl, compose qui n'est pas toxique. Par contre, si le béryllium réagit de la même façon que plusieurs autres métaux, le composé rejeté serait l'oxyde de béryllium, qui est toxique. Le tableau 2 donne les émissions par province et la figure 1, leurs sources.

TABLE 1 1970 BERYLLIUM EMISSIONS IN CANADA

Source	Emissions (lb)	Emission factor[c] Present study	Emission factor[c] U.S. (19)
PRODUCTION			
Mining[a]	-	-	0.2
Beneficiation[b]	-	-	30.0
MANUFACTURING[b]			
Machining of Be metal	<1	-	0.10
Machining of Be alloys		-	0.15
Use of Be ceramics		-	1.0
INADVERTENT[a]			
Coal combustion			
Power plants	8 666.0	450	247
Coke production	133.7	1.7	
Others	3 581.0	67.0	
Coke combustion			
Iron foundries	118.8	51.0	-
Blast furnaces	257.7		
Others	11.9		
Heavy oil combustion	2 891.0	2.7	3.0
TOTAL EMISSION	15 660.1		

[a] Uncontrolled emission factors given.

[b] Controlled emission factors given.

[c] Emission factor units: production and manufacturing, pounds per ton of beryllium processed; coal combustion, pounds per 100 000 tons of coal burned; coke combustion, pounds per 100 000 tons of metal processed; and heavy oil combustion, pounds per 100 000 bbl of oil burned.

TABLE 2 PROVINCIAL EMISSIONS OF BERYLLIUM (1970)

Province	Coal combustion (lb)			Coke combustion (lb)			Oil combustion[g]	Total	Percent
	Power plants[a]	Coke production[b]	Other[c]	Iron foundries[d]	Iron production[e]	Other[f]			
Newfoundland	-	-	11.5	0.1	-	-	162	173.6	1.1
Prince Edward Island	-	-	8.0	-	-	-	33	41.0	0.3
Nova Scotia	1711	14.1	337.4	0.5	215.5	1.2	237	2 516.7	16.1
New Brunswick	664	-	107.2	0.5	-	-	191	962.7	6.1
Quebec	-	6.4	397.3	18.4	2.3	0.6	1240	1 665.0	10.6
Ontario	770	106.9	844.8	85.9	39.3	9.5	745	2 601.4	16.6
Manitoba	838	-	321.8	2.5	-	0.2	27	1 189.5	7.6
Saskatchewan	3018	1.7	291.0	0.1	-	-	13	3 323.8	21.2
Alberta	1665	-	567.5	4.9	-	-	14	2 251.4	14.4
British Columbia	-	4.6	694.5	5.9	0.6	0.4	226	932.0	6.0
Yukon and N.W.T.	-	-	-	-	-	-	3	3.0	-
TOTAL	8666	133.7	3581.0	118.8	257.7	11.9	2891	15 660.1	100.0

[a] Table 6.
[b] Table 8.
[c] Table 9.
[d] Table 10.
[e] Table 11.
[f] Table 12.
[g] Table 13.

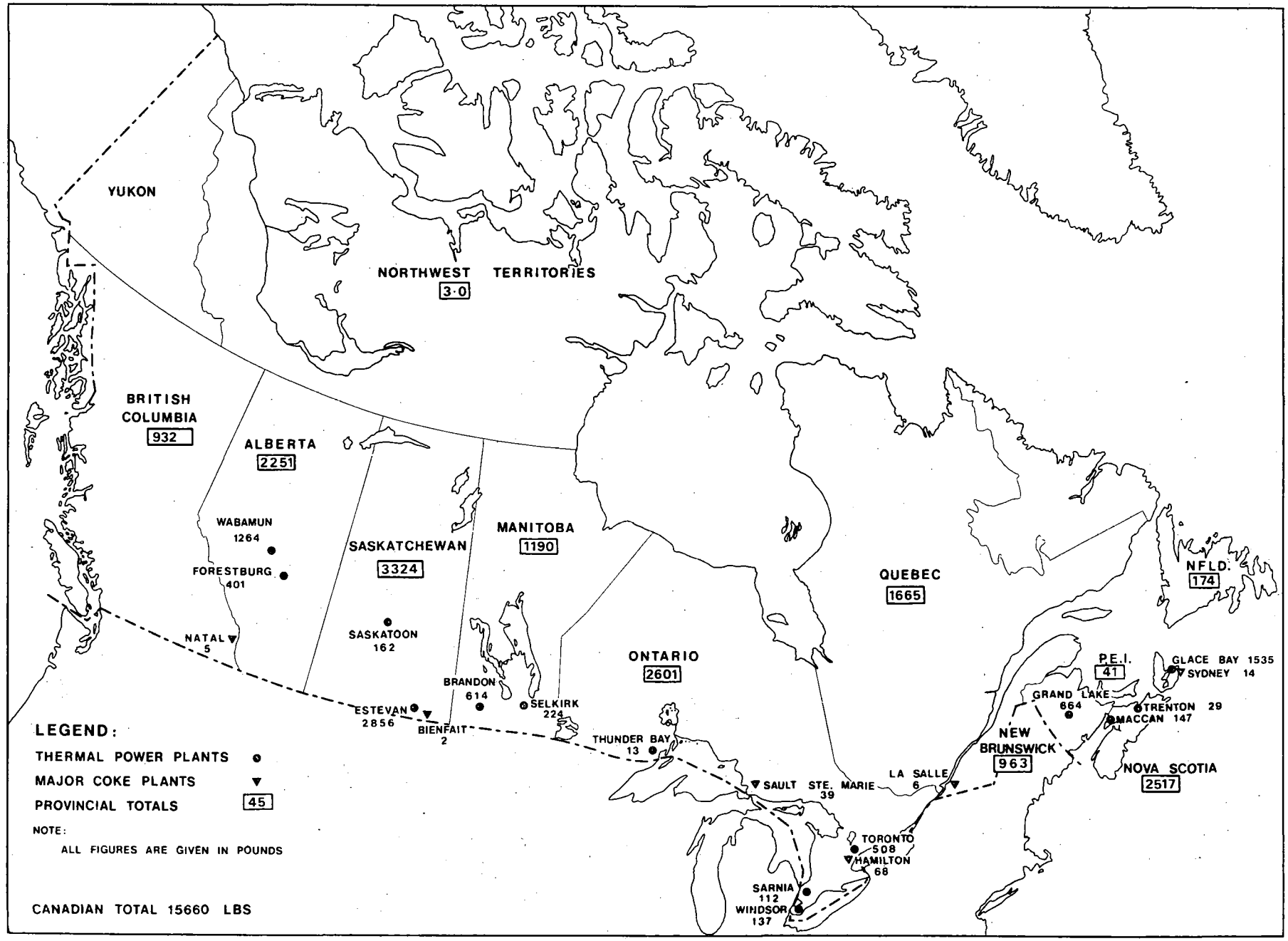

FIGURE 1: 1970 BERYLLIUM EMISSIONS IN CANADA AND POINT SOURCES

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1 INTRODUCTION

1.1 Scope

The purpose of this report is to identify and quantify sources of atmospheric emissions of beryllium (Be) and its compounds in Canada for the year 1970. Information was drawn from scientific publications, government reports, and replies received from industries surveyed by questionnaire.

1.2 Properties of Beryllium

The metal beryllium is strong, rigid, lightweight, and one of the most toxic substances used in industry (1, 2, 3). Its low specific gravity of 1.85, high melting point of 1283 ^{o}C, and high boiling point of 2970 ^{o}C make it an important constituent in metal alloys such as beryllium copper. Production of very pure beryllium is made technically difficult by the activity of the metal at high temperatures. Further, the chemical similarity of beryllium and aluminium makes the removal of aluminium impurities difficult. Some of the properties of beryllium are listed in Table 3.

TABLE 3 CHARACTERISTICS OF BERYLLIUM

Atomic weight	9.02
Atomic number	4
Density	1.85
Melting point	2345 ^{o}F
Modulus of elasticity	40% higher than steel
Electrical conductivity	40% of copper
Excellent thermal conductivity	
Very low neutron absorption cross-section	
High permeability to X-rays	
Maintains mechanical strength over a wide range of elevated temperatures	
Releases neutrons when bombarded with alpha particles	
Forms precipitation hardening alloys with other metals	
Good corrosion resistance	

Although beryllium occurs in the minerals beryl, bertandite, phenacite, chrysoberyl, and barylite, at present the only commercial source of the metal is beryl, an aluminium silicate. Typically, commercial grades of beryl contain 11-13% BeO, 17-19% Al_2O_3, and 67-70% SiO_2. Beryl ore contains mostly feldspar, quartz, and mica. Even though its occurrence is widely distributed, the quantities are seldom large enough to permit mining for beryl alone (4).

World estimates of the recoverable beryl reserves in 25 countries are 300 000 tons of beryl or 12 000 tons of beryllium metal. A Canadian deposit in the Seal Lake area of Labrador near Goose Bay was discovered about 10 years ago. This deposit is reported to have 3 million tons of barylite ore containing 0.5% beryllium oxide or 5400 tons of beryllium. No development has taken place because of the location of the find, present market demand, and technical difficulties in concentrating beryllium. Beryllium has also been found in a pegmatite deposit at Bernic Lake, Manitoba, but its recovery has not been considered economic (4).

Small quantities of beryllium are widely distributed over the surface of the earth; for example, concentrations of 3-6 ppm have been measured in samples of the earth's crust, and concentrations of 0.13-0.88 ppm have been measured in soils. Significant amounts also occur in most coal and oil deposits (5).

1.3 Toxicity of Beryllium

Berylliosis, or respiratory ailments caused by inhalation and absorption of beryllium in the lungs, has been traced to the beryllium metal and most beryllium compounds except the beryl ore itself (6). Other diseases possibly related to beryllium exposure include dermatitis or beryllium granuloma, skin ulcers, the respiratory diseases of acute pneumonitis and chronic pulmonary granulomatesis, and cancer. Further, the soluble beryllium compounds (beryllium chloride, beryllium fluoride, beryllium nitrate, beryllium sulphate) are chemically toxic if ingested.

Chronic berylliosis, produced by accumulated exposure over an extended time, is difficult to trace as it has a latent period which may vary from a few months to 30 years. Once the victim is suffering from the illness he may be no longer working or living in the vicinity in which he contracted it. Chronic poisoning results partly from the fact that the human body is unable to excrete ingested beryllium.

Acute berylliosis resulting from high dosages produces inflammation of the respiratory tract from nose to lungs leading to bronchitis, trachaitis, and chemical pneumonitis. Two types of acute berylliosis have been identified. Insidious berylliosis, the most common, occurs after recurring exposure to high concentrations. Related symptoms include coughing, chest pains, weakness, fatigue, loss of appetite, and weight loss. Recovery will take six to eight weeks if the victim is removed from the area of beryllium contamination. The second form, fulminating berylliosis, occurs after brief exposure to intense beryllium levels and appears more rapidly. The high concentrations necessary for acute poisoning usually occur during the handling of beryllium compounds.

Other industrial situations which may lead to beryllium exposure are outlined as follows.

(i) Most airborne exposures occur during the mining of beryl ore and the production of beryllium metal. Although the beryl dust itself is not considered a hazard, the minerals bertrandite and phenacite are considered possible beryllium sources and may constitute a future health hazard (4).

Dusts are created during crushing, grinding, and cutting and fumes of BeO can be emitted during melting, pouring, or welding (8). Emissions of this type are nonexistant in Canada as no mining or primary refining is done.

(ii) Besides the processing and handling of the beryllium metal, danger also arises during the production of beryllium alloys. Beryllium oxide dusts and fumes can be emitted in the alloying process and during the reduction process to refine scrap alloy. Again, emissions from this source are nonexistent in Canada.

(iii) Aside from unintentional worker exposure in plants (9) there is also the additional hazard of contaminating the neighbouring community (10).

Limits based on studies of beryllium-related illnesses were set in 1949 in the United States (11). Allowable concentrations in air are:

Workroom:	2.0 $\mu g/m^3$ averaged over an 8 h day but not to exceed 25 $\mu g/m^3$ maximum
Community:	0.01 $\mu g/m^3$ averaged over one month.

Recent proposed U.S. standards while suggesting a maximum emission per plant of 10 g beryllium daily (3) have found the above levels to be safe based on experience over the past 20 years.

Ambient air levels have also been found acceptable. Air quality figures monitored at 100 U.S. locations averaged under 0.0005 μg beryllium/m^3 air. The highest reported level was 0.008 $\mu g/m^3$ for the 1964-1965 period (6).

Further, beryllium levels in water are also considered safe because of the low solubility of the metal. Although no Canadian measurements of beryllium in water have been published, experience in the United States suggests that it is unlikely that the 0.1 $\mu g/m^3$ level considered

acceptable (11) for both drinking and recreational uses of water will be exceeded.

Trace amounts of beryllium can be analysed with sufficient accuracy by colorimetric, fluorimetric, and spectrographic techniques. Measurement methods and problems are discussed in References 5 and 6.

2 NATURAL BERYLLIUM BACKGROUND

The beryllium content of the earth's crust is estimated to be 0.006% (5, 6). From an annual weathering of 10^{10} tons of rock (12), the release of 6×10^5 tons of beryllium is suggested on a world-wide basis. For Canada, which accounts for 6% of the earth's land surface, the natural release is estimated at 3.6×10^4 tons.

Part of that released by weathering will enter the atmosphere. However, the chemical forms of beryllium involved, its residence time in the atmosphere, and corresponding natural background levels are unknown. The air monitoring average of 0.0002 $\mu g/m^3$ for 933 samples analysed by Cholak (5) may be considered as an upper limit on the natural concentration in the atmosphere, since human sources were probably involved. Rural concentrations of 0.0001 $\mu g/m^3$ are reported by Durocher (6). Considerable variations in background levels across Canada are expected to occur, with levels higher near beryl ore deposits, for example.

3 FLOW OF BERYLLIUM THROUGH THE CANADIAN ECONOMY IN 1970

All beryllium and beryllium compounds used in Canada are imported, principally from the United States. Because of small usage by individual companies and lack of detailed Statistics Canada information, flow patterns have been difficult to establish. Estimates based on information from United States' sources (13-16), Canadian distributers (17, 18),

and questionnaire returns are given in Figure 2. A total consumption of 2.2 tons of beryllium in various alloys, compounds, and ceramics is suggested, with principal consumers being the aerospace, metal casting, electrical, and nuclear industries.

4 PRODUCTION OF BERYLLIUM

At the present time, no beryllium is produced in Canada. However, should production begin in the future, a short description of mining and beneficiation techniques and resulting atmospheric emissions is included in this report.

4.1 Mining

Drilling, blasting, and separation of beryl crystals are the principal mining operations. Hand-cobbing of ore containing beryl crystals is used to select crystals 1 in. or more in diameter for further processing. Since, on the average, 100 tons of hand-sorted rock is required to produce 0.5-1 ton of beryl crystals, this procedure is expensive and slow (4).

Emissions from mining operations are principally in the form of harmless beryl dust, although, as was mentioned in section 1.3, other toxic forms of beryllium may be involved. Davis (19) has estimated an emission of 0.2 lb beryllium/ton beryllium handled.

4.2 Recovery of Beryllium and Beryllium Alloys

Beneficiation of beryl ore involves crushing and heating followed by the recovery of beryllium hydroxide through treatment with caustic soda (Copaux-Kawecki process) or sulphuric acid (Sawyer-Kjellgren process) (4, 6, 19).

To produce beryllium metal, beryllium fluoride is prepared chemically from beryllium hydroxide. The beryllium fluoride is then treated with magnesium in a reduction furnace to produce a slag from which beryllium metal may be recovered by a water leaching process. Approximately 63% efficiency

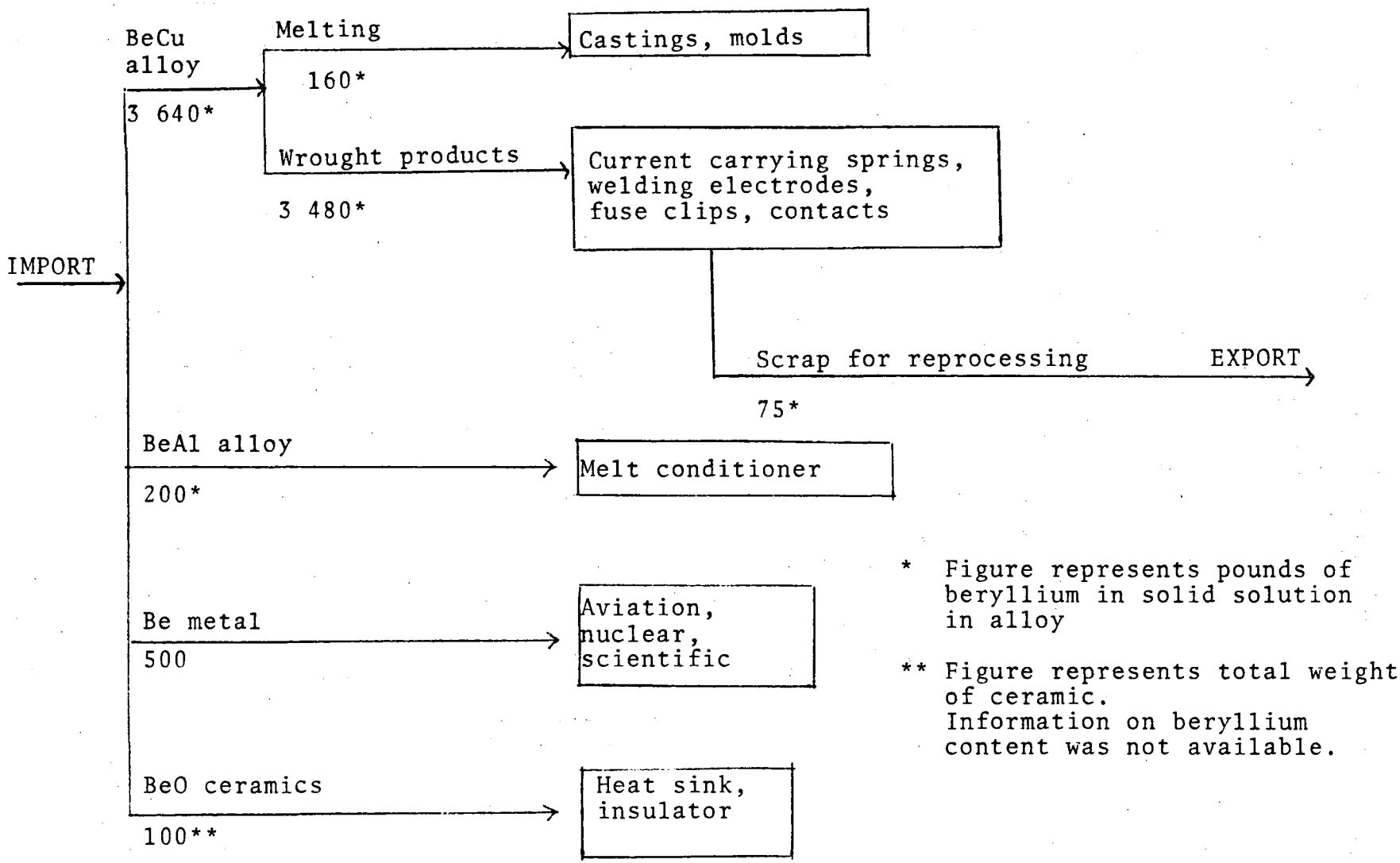

FIGURE 2 CANADIAN BERYLLIUM TRADE AND CONSUMPTION IN 1970 (1b)

in the recovery of metal from beryl ore has been obtained. In 1968, approximately 200 tons of beryllium were refined throughout the world (4).

To produce beryllium alloys, beryllium oxide is prepared by calcining beryllium hydroxide. A charge of carbon powder, copper, and beryllium oxide forms a beryllium-copper master alloy, containing 4% beryllium, in an electric arc furnace. Beryllium-copper alloys 2% or lower in beryllium content are produced by diluting the master alloy with copper in an induction furnace.

Similar techniques are employed to produce master alloys of aluminium, magnesium, and nickel. Beryllium ceramics are also made from beryllium oxide (4, 19).

Davis has estimated an emission factor of 30 lb/ton of beryllium processed for the various beneficiation steps (19).

5 MANUFACTURE OF BERYLLIUM PRODUCTS IN CANADA

5.1 Beryllium Metal

The high cost and exotic properties of beryllium metal limit its use to very specialized areas in the nuclear and aerospace industries and research institutions of Canada. For these uses, beryllium in powder or strip sheet form is imported from one of two producers in the United States (13, 14).

In the nuclear field, beryllium diaphragms are manufactured to seal the ends of the zirconium fuel rods for the CANDU reactor. Small amounts of beryllium powder, only a few pounds per year, are also used to produce radium-beryllium or americium-beryllium neutron sources. These neutron sources are employed in research applications.

In the aerospace field, beryllium is used to manufacture components for inertial guidance systems.

Emission control in these industries is obtained by enclosing the areas of fabrication and handling, and by continuously exhausting the air from these areas through 'absolute' type filtration (99.9% removal efficiency). Any items not in use are identified and wrapped in plastic. Care in handling beryllium is emphasized in scientific laboratories, where beryllium powder is clearly marked and stored in double containers. Studies in the United States have found that ambient concentrations under such control systems are well within acceptable levels (3).

Davis (19) cites an emission factor of 0.10 lb beryllium dust/ton beryllium used by industry. Although this figure may apply to the larger and more diversified industry of the United States, emissions from the specialized and well-controlled Canadian consumers mentioned above are believed to be lower.

5.2 Beryllium-Copper Alloys

The principal use of beryllium is in the production of beryllium-copper alloy. Because beryllium is able to harden copper by precipitation, these alloys have remarkable strength, wear and fatigue resistance, and electrical conductivity (6).

Alloys are not manufactured in Canada, but are available from the United States as master base alloys (4% Be) or in diluted forms. The alloys are primarily imported in the diluted forms with only small amounts of master alloy being used in the making of molds.

In the electronics industry, alloys containing 0.5-2% beryllium are used to make wire, springs, fuse clips, connectors, contacts, and welding electrodes. In 1970, 5-10 companies in Canada were estimated to use approximately 3480 lb beryllium in alloy form for these applications. Alloy is purchased in sheets, which are wet stamped or drawn to form the desired finished product. This process has negligible emissions, and the scrap left from the stamping is returned to

the United States for reprocessing.

Beryllium-copper alloys are also used in the casting of molds by approximately five Canadian companies. These molds on the average require about 100 lb of 2.2% beryllium alloy. Emissions occur during melting and casting of the mold, and during grinding and finishing of the final product. Surveys have shown that fume hoods over kettles are exhausted to the atmosphere and dust from machining the mold is allowed to fall to the floor where it is swept into the garbage and disposed of through municipal refuse collection.

The low concentration of beryllium in the alloy is not a reliable index of the degree of hazard attending the machining of the alloy. Reported cases of beryllium poisoning have occurred from the machining and grinding of 2.75% beryllium-copper alloy when no control procedures were used (16). In Table 4 air measurements recorded during the handling of beryllium-copper alloys in the United States are given. These measurements show that those operations that create fine inhalable dust or fume are of most concern. Milling and lathe turning, which produce large chips, are less critical, for example, than are grinding and jointing. The use of coolants will control the amount of emissions during machining of beryllium-copper alloys. The most highly concentrated emissions are found to occur during the first machine cut. These emissions may be controlled by the application of a preparatory coat of heavy oil before the work is started. Davis (19) estimates an emission factor of 0.15 lb/ton beryllium machined. Once again, however, Canadian emissions are believed to be lower than corresponding U.S. ones.

TABLE 4 BERYLLIUM CONCENTRATIONS IN AIR WITHOUT EMISSION CONTROLS (6)

Operation	Concentration ($\mu g/m^3$)
Melting, pouring	0.39 - 0.78
Drossing, casting	3.55 - 31.3
Dry surface grinding	87 - 144

5.3 Beryllium-Aluminium Alloys

Beryllium-aluminium alloys manufactured in the United States are shipped to Canada in ingot form. Beryllium, in quantities of 0.004-0.25%, acts as a melt conditioner, stabilizing the magnesium content of aluminium alloys and forming an oxidation-resistant protective film on the melt. Alloys are made in the United States using 5% beryllium-aluminium ingots.

In 1970, two Canadian distributers handled 4000 lb of beryllium-aluminium alloys. These alloys were used predominantly in castings for such items as cookware. The beryllium content makes polishing of these products easier (20). Emissions would occur during melting and machining the alloy. Controls consist of fume hoods and exhaust over the melting areas, although the beryllium hazard is relatively small because of the low concentration used in the alloy.

5.4 Beryllia Ceramics

Beryllia ceramics, which are manufactured from beryllium oxide, have a high melting point, high thermal conductivity, and very low electrical conductivity. These properties have found application in electronic heat sinks, insulators, electrical porcelains, and microwave windows (4, 19). Canadian companies in these fields indicated that the limited use and the physical form of beryllia ceramics would lead to negligible atmospheric emissions during manufacture and use.

5.5 Manufacturing Emissions

Detailed emissions and emission factors for beryllium in Canada have not been given since rough calculations indicate a total atmospheric loss of under 1 lb in 1970. Controls are apparently stringent, and the precious nature of the material results in conservation of as much waste as possible for reselling to United States suppliers. Strict health regulations necessitate the use of expensive control equipment such as 'absolute' filtration systems. Because of the limited uses of beryllium materials, and because of the expensive controls required, it is often more economic to import finished beryllium goods from the United States than to manufacture them in Canada.

6 INADVERTENT BERYLLIUM EMISSIONS

In this section, the emission of beryllium from sources not related to actual beryllium uses will be examined. These sources were found to contribute the only significant beryllium emissions in Canada in 1970.

6.1 Coal Combustion

Studies have shown that varying concentrations of beryllium occur in most coal deposits. Analysis of American coals finds an average of 3 ppm beryllium and a range of 0.1-31.0 ppm (5, 6). Appalachian coals which comprise most of the American imports have an average beryllium content of 2.5 ppm (6) and an average ash content of 6.11% (19). Very little work has been done on Canadian coals. Calgary Power Limited indicates that the coal they use, which is mostly from Alberta, has a beryllium concentration of 0.04-5.0 ppm (21). Ontario Hydro studies of trace elements in fly ash have detected beryllium (22). For the purpose of this report, an overall concentration of 3.35 ppm beryllium in the coal consumed was established. This weighted average was calculated using 2.5 ppm for the imported Appalachian coals,

5.0 ppm for the Alberta coals, and 3.0 ppm for the remaining Canadian coals. The 3.0 ppm concentration is an average beryllium concentration established from American coal studies. The lack of data on Canadian coals from provinces other than Alberta made a more accurate approach impossible.

It must be pointed out that the form of beryllium in coal and in the combustion products of coal has not been defined. The toxic hazard would be eliminated entirely, for example, if the compound formed was similar to beryl (7). More probably, however, the toxic compound beryllium oxide is involved (1). Regardless, it has been established that trace amounts of beryllium in coal are retained in the ash (5). Accordingly, only that fraction of the ash passing through particulate control equipment leads to an atmospheric emission of beryllium.

Reported coal consumption in 1970 was 34 148 854 tons of which 4 391 575 tons were exported, leaving 29 757 279 tons for direct internal use. Of this, 18 863 779 tons were imported from the United States (23, 24). The use of coal in each province is subdivided into consumption by thermal power plants, coke producers, and others in Table 5. On a national basis, electric utilities account for approximately 51% of consumption, and coke producers approximately 32% of consumption, with other users accounting for the remaining 17% (23, 24). Beryllium emissions from each of these three sources are estimated in the following sections.

6.1.1 Thermal Power Plants. Emissions of beryllium have been computed by using the ash content of the coal in conjunction with the assumed 3.35 ppm beryllium concentrations in coal to establish the beryllium content of ash. Power company particulate emission figures thereby led to beryllium emission estimates. In the few cases where no power company emissions were available, U.S. Environmental Protection Agency emission factors (25) for coal combustion were applied, making

TABLE 5 COAL CONSUMPTION IN 1970 BY PROVINCE (tons) (23, 24)

Province	Thermal power	Coke*	Other	Total
Newfoundland	-	-	17 100	17 100
P.E.I.	-	-	12 000	12 000
Nova Scotia	609 362	830 000	503 638	1 943 000
New Brunswick	125 000	-	160 000	285 000
Quebec	-	378 000	593 000	971 000
Ontario	8 486 426	6 320 000	1 260 900	16 067 326
Manitoba	555 000	110 000	480 268	1 145 268
Saskatchewan	2 170 683	-	434 300	2 604 983
Alberta	3 253 000	-	847 000	4 100 000
British Columbia	-	270 000	1 036 500	1 306 500
TOTAL	15 199 471	7 908 000	5 344 706	28 452 177

* Reported coal consumption by major coke producers, which account for approximately 98% of total coke production in Canada.

allowances for the appropriate control equipment. On an uncontrolled basis, the U.S. factor, which corresponds to a loss of 80% of the ash content of the coal, is 1600A pounds of particulate per ton of coal burned, where A is the weight fraction of ash in the coal. The uncontrolled beryllium emission therefore becomes

$$1600A \times \frac{3.35 \times 10^{-6} \text{ (Be in coal)}}{A \text{ (ash in coal)}}$$

$$= 536 \text{ lb beryllium/100 000 tons coal consumed}$$

All five coal-fired thermal power plants in Ontario use electrostatic precipitators for fly ash control. The average removal efficiency of these control devices is 97.5%.

Since 1970, the R. L. Hearn plant in Toronto has been converted to burn natural gas with a minimum of coal. Emissions of coal-fired products have been accordingly reduced to one-eighth of their value in 1970 at this plant (3410 tons to 430 tons of fly ash) (26).

In Nova Scotia, only the Trenton plant has control equipment. Electrostatic precipitators of 98.5% efficiency are used. No other major controls are planned for the immediate future at Trenton or at the other two plants in the province (27).

Saskatchewan's four power plants that burn coal use mechanical precipitators on the coal-burning units to control ash carry-over. Estimated efficiency of these units in 1970 was 70%. Since then, maintenance work has increased removal efficiency to about 75% (28).

In Alberta the plants at Wabamun and Sundance collect the fly ash by mechanical 'cyclone' dust collectors with a reported 85% efficiency. To meet new Alberta Government regulations, electrostatic precipitators with 99.5% efficiency are planned (29).

Manitoba has two coal-fired thermal power plants, which use cyclone separators on flue gas emissions. An average ash removal efficiency of 70% has been found with these units (30).

In New Brunswick, the one thermal station using coal located at Grand Lake has no control equipment (31).

Thermal power plants in Newfoundland, Prince Edward Island, Quebec, and British Columbia do not burn coal.

Based on the information outlined above, 1970 beryllium emissions from coal combustion in thermal power plants are estimated in Table 6. The indicated total is 4.33 tons of beryllium for an average controlled emission factor of 57.0 lb beryllium/100 000 tons of coal burned.

Without the various emission controls present on some plants, beryllium emissions would be 34.9 tons from thermal power plants. The uncontrolled emission factor, weighted by coal consumption, becomes 450 lb/100 000 tons of coal burned, which is lower than the factor calculated earlier using U.S. particulate emission data.

TABLE 6 THERMAL POWER PLANT EMISSIONS OF BERYLLIUM (1970)

Province	Emissions (lb)
Nova Scotia	1711
New Brunswick	664
Ontario	770
Manitoba	838
Saskatchewan	3018
Alberta	1665
CANADA TOTAL	8666

6.1.2 Coke Production. Coke is produced by heating suitably cleaned and sized coal in an atmosphere of low oxygen content, driving off volatile matter and leaving a porous carbonaceous product. Coal is charged to the oven through ports in the top and then heated. Once sufficiently heated, the glowing coke is pushed from the oven by a ram and quenched with water (32).

In 1970 8 092 379 tons of coal were used to produce 5 668 219 tons of coke (1.42 tons coal/ton coke (24)). About 80% of the coke produced from coal in Canada is used in blast furnaces for pig iron production. The major coke plants accounting for coke made from coal and the beryllium emissions produced are shown in Table 7. The large Ontario producers obtain their coking coal from mines in West Virginia; 60% of the coal for coke production in Nova Scotia was from Nova Scotian mines and the remainder was imported from the United States. British Columbia uses local domestic coals.

TABLE 7 THERMAL POWER PLANT UNCONTROLLED EMISSIONS OF BERYLLIUM (1970)

Province	Coal used (tons)	Uncontrolled emission factor (lb/100 000 tons coal)	Uncontrolled emissions (lb)
Nova Scotia	609 362	589	3 592
New Brunswick	125 000	530	664
Ontario	8 486 426	480	42 000
Manitoba	555 000	505	2 800
Saskatchewan	2 170 683	440	9 618
Alberta	3 253 000	341	11 100
WEIGHTED AVERAGE		450	
TOTAL			69 774

Emissions occur during charging of coal into ovens, oven leakage during heating, pushing coke out of ovens, and quenching the hot coke. The following chart gives the percentage of total emissions for various processes in by-product coking, that is, coke operations that recover both coke and the volatized products (25).

Unloading	11.3%
Charging	43.0%
Coking cycle	2.8%
Discharging	17.1%
Quenching	25.8%

Research is being conducted to provide a method of controlling by-product coke oven emissions but at present no control is available.

Of the coke produced, 80%, or 4.6 million tons, is used in charging blast furnaces for pig iron production, 5% is exported, and the rest is used for fuel and making gas and associated coal tar products (24).

Davis (19) reports that analyses of particulates from the production of iron have shown the presence of beryllium. Coke is the likely source of the beryllium emission, although no definitive studies have yet been made.

The fate of the trace beryllium in coal during coking has not been established. Since beryllium stays in the ash during coal combustion, it seems reasonable that it would be similarly retained in the coke and in the particulates emitted during coke production. Using the average 3.35 ppm beryllium content of coal that was computed earlier, the indicated average beryllium content of coke becomes

$$3.35 \text{ ppm (Be in coal)} \times \frac{1.42 \text{ ton coal}}{1 \text{ ton coke}}$$

$$= 4.76 \text{ ppm}$$

To compute beryllium emissions during coke production, the U.S. Environmental Protection Agency coking emission factor of 3.5 lb particulate/ton of coal charged has been used (25). These particulates are assumed to carry 4.76 ppm beryllium into the atmosphere. The beryllium emission factor becomes 1.7 lb beryllium/100 000 tons of coal charged or 1.7 x 1.42 = 2.4 lb beryllium/100 000 tons coke produced. Emissions are summarized using these average emission factors in Table 8.

TABLE 8 BERYLLIUM EMISSIONS IN COKE PRODUCTION (1970)

Province	Plant	Coke (tons)	Emissions (lb)
Nova Scotia	Sydney	586 000	14.1
Quebec	Ville La Salle	266 000	6.4
Ontario	Sault Ste. Marie	1 619 000	38.9
	Hamilton	1 874 000	45.0
	Hamilton	960 000	23.0
Saskatchewan	Bienfait	70 000	1.7
British Columbia	Natal	190 000	4.6
CANADA TOTAL			133.7

6.1.3 Other Uses. Beryllium emissions from the combustion of coal by other users are estimated in Table 9. Lacking definite information, the U.S. Environmental Protection Agency emission factor of 20 lb fly ash/ton coal burned (25) has been used. It is assumed that no control equipment is used. The beryllium emission factor is accordingly taken to be

$$20 \ \frac{\text{lb fly ash}}{\text{ton coal}} \times 3.35 \times 10^{-6} \ \frac{\text{lb beryllium}}{\text{lb coal}} \Big/ \frac{200}{2000} \ \frac{\text{lb ash}}{\text{lb coal}}$$

$$= 67 \text{ lb beryllium/100 000 tons coal burned}$$

TABLE 9 BERYLLIUM EMISSIONS FROM OTHER CONSUMERS OF COAL (1970)

Province	Emissions (lb)
Newfoundland	11.5
Prince Edward Island	8.0
Nova Scotia	337.4
New Brunswick	107.2
Quebec	397.3
Ontario	844.8
Manitoba	321.8
Saskatchewan	291.0
Alberta	567.5
British Columbia	694.5
TOTAL	3581.0

6.2 Coke Consumption

In section 6.1.2 coke was estimated to contain 4.76 ppm beryllium on average. Particulates emitted during combustion of this coke will therefore carry trace amounts of beryllium into the atmosphere. The beryllium content of the particulates emitted is expected to lie somewhere between the 4.76 ppm beryllium in coke and 55.8 ppm beryllium in coal ash (for coals containing 6% ash).

The only data available on beryllium emissions from coke combustion suggested that particulates from iron foundry cupolas contain 0.003% or 30 ppm beryllium (19). Using the U.S. Environmental Protection Agency uncontrolled emission factor for iron foundries (25) 17 lb particulate/ton metal processed, or 51 lb beryllium/100 000 tons metal processed may be emitted. Assuming the 80% efficiency of control estimated by Environment Canada for the iron foundries (40), the controlled factor

TABLE 10 BERYLLIUM EMISSIONS FROM IRON FOUNDRIES (1970)

Province	Plants	Value of shipments (38) (1000 dollars)	Percent	Emissions (lb)
Newfoundland	1	299[a]	0.1	0.1
Nova Scotia	3	897[a]	0.4	0.5
New Brunswick	3	897[a]	0.4	0.5
Quebec	35	32 436	15.5	18.4
Ontario	59	151 272	72.4	85.9
Manitoba	5	4 378	2.1	2.5
Saskatchewan	1	299[a]	0.1	0.1
Alberta	6	8 456	4.1	4.9
British Columbia	13	10 190	4.9	5.9
TOTAL		209 124	100.0	118.8

[a]Statistics Canada did not supply these figures. Estimates have been made by dividing the $2 392 000 unaccounted for in the total according to the number of plants.

becomes 10.2 lb beryllium/100 000 tons metal processed.

In 1970, iron foundries processed 1.16 million tons of pig iron (37). The indicated release of beryllium is 118.8 lb. Provincial estimates are given in Table 10.

The beryllium emissions from the iron and steel industry have been calculated using a control efficiency of 99%, except for Nova Scotia, where control efficiency of 50% was used (41). These calculations used the uncontrolled emission factor of 51 lb beryllium/100 000 tons metal processed.

In 1970, 9.086 million tons of pig iron were produced in Canada (37). The estimated release of beryllium is 257.7 lb. Provincial figures are given in Table 11.

TABLE 11 BERYLLIUM EMISSIONS FROM IRON PRODUCTION (1970)

Location	Furnace capacity (39) (1000 tons/year)	Percent of total	Emissions (lb)
Sydney, N.S.	875	83.6	215.5
Sorel, Que.	465	0.9	2.3
Hamilton, Ont.	1 650	3.1	8.1
	3 800	7.2	18.6
Sault Ste. Marie, Ont.	2 335	4.4	11.4
Port Colborne, Ont.	240	0.5	1.2
Kimberley, B. C.	110	0.3	0.6
TOTAL	9 475	100.0	257.7

Beryllium emissions from other coke consumers are difficult to establish.

However, as the iron and steel industry consumed approximately 80% of the coke produced in Canada in 1970 (24), and the iron foundries consumed most of the remaining coke, beryllium emissions from the other coke users may be estimated at about 10% of the beryllium emissions from iron foundries, or about 11.9 lb beryllium. Provincial estimates, according to the consumption data of Table 5, are presented in Table 12.

6.3 Oil Combustion

Data regarding the beryllium content of oil is sparse (19). Preliminary measurements indicate a concentration of under 0.1 ppm, and suggest that beryllium is retained in the heavy fuels. A large Canadian oil company supplied very preliminary estimates which led to a concentration of 0.05 ppm, a figure of reasonable agreement with that given by Davis (19). Accordingly, the concentration of 0.08 ppm beryllium reported by Davis has been used in this report.

TABLE 12 BERYLLIUM EMISSIONS FROM OTHER COKE USERS (1970)

Province	Coke consumed in coke production (23, 24) (1000 tons)	Percent	Emissions (lb)
Nova Scotia	830	10.5	1.2
Quebec	378	4.8	0.6
Ontario	6320	79.9	9.5
Manitoba	110	1.4	0.2
British Columbia	270	3.4	0.4
TOTAL	7908	100.0	11.9

Emissions have been computed by assuming that the entire beryllium content of oil is emitted during combustion. On this basis, amounts of beryllium emitted are summarized in Tables 13 and 14. The indicated emission factor is 0.27 lb beryllium/10 000 bbl of fuel oil burned. No information on the chemical form of the emission is available.

6.4 Sewage Sludge Incineration

In trace element analyses of sewage sludges in the United States and Great Britain, beryllium has been detected. Amounts in input sludge, incinerator ash, and incinerator stack emissions vary, and, in some cases, no beryllium was found (34, 35). Studies at a Toronto incinerator have not included trace beryllium analyses (36).

Because of the small amounts of sludge incinerated in Canada, and the apparently very low or nonexistent beryllium content, emissions from this source are considered negligible.

TABLE 13 BERYLLIUM EMISSIONS FROM HEAVY FUEL OILS (1970)[a] (33)

Province	Oil (1000 bbl)	Emissions (lb)
Newfoundland	5 988	162
P.E.I.	1 228[b]	33
Nova Scotia	8 837[b]	237
New Brunswick	7 138[b]	191
Quebec	45 744	1240
Ontario	27 473	745
Manitoba	986	27
Saskatchewan	475	13
Alberta	511	14
British Columbia	8 352	226
Yukon and N.W.T.	114	3
CANADA TOTAL	106 846	2891

[a] Assuming 0.08 ppm in heavy fuel oil and 339 lb/bbl.

[b] Statistics Canada only reports a total Maritime figure. Estimates have been made according to population.

TABLE 14 BERYLLIUM IN OIL BY DISPOSITION (1970)[a] (33)

Disposition	Oil (1000 bbl)	Emissions (lb)
Forest products and paper industry	20 873	565
Mining, smelting, quarrying, petroleum exploration	12 355	335
Marine	10 685	288
Residential, apartment, farm	6 156	167
Governments	2 960	80
Construction industry	1 398	38
Railways	1 268	34
Other commercial and industrial	46 284	1253
Unclassified	4 865	131
TOTAL	106 844	2891

[a] Assuming 0.08 ppm in heavy fuel oil and 339 lb/bbl.

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