

NATIONAL INVENTORY OF
SOURCES AND EMISSIONS
OF LEAD (1970)

by

James F. MacLaren Limited
Environmental Consultants
Willowdale, Ontario

for

Air Pollution Control Directorate
Environmental Protection Service

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ABSTRACT

Atmospheric emissions of lead from various sectors of the Canadian economy have been estimated for the year 1970. A summary of the data presented in this report is given in Table 1, along with preliminary emission factors for the United States. The total lead emissions to the atmosphere in 1970 are estimated at 21 416 tons, of which 66.7% was emitted through the consumption of lead products, 25.7% through the release of trace amounts of lead in fuels and various raw materials, 7.1% through the recovery of lead, and 0.5% through the manufacture of lead goods. Automobile exhaust is the largest single source of lead emissions, accounting for 65.8% of the total. Provincial figures are estimated in Tables 2 - 6, and point sources are identified in Figure 1.

Both controlled and uncontrolled emission factors are given when applicable. Generally the controlled factor was computed from the uncontrolled by assuming a certain efficiency for control equipment. It became apparent in sections 7.7 and 7.8 that the efficiency of removal of overall particulate does not always apply to lead particulate, since the relatively small lead particles sometimes encountered are not collected efficiently. Accordingly, some of the uncontrolled emission factors we have computed may require modification as more data become available.

In section 7, lead emissions from the iron and steel industry, ferrous foundries, and cement plants have been estimated using measurements made in the United States. These emissions may also require modification as further data for Canadian sources become available.

RÉSUMÉ

On a évalué pour 1970 les émissions atmosphériques de plomb pour différents secteurs de l'économie canadienne. Le tableau 1 donne un résumé des données présentées dans le présent rapport ainsi que des facteurs d'émissions provisoires pour les États-Unis. On a estimé les émissions totales de plomb dans l'atmosphère à 21 416 tonnes dont 66.7 p. 100 venaient de la consommation de dérivés du plomb, 25.7 p. 100 de l'échappement de traces de plomb contenues dans les combustibles et diverses matières premières, 7.1 p. 100 de la récupération du plomb et 0.5 p. 100 de l'usage d'objets en plomb. Le gaz d'échappement des voitures constitue la principale source particulière d'émissions de plomb, fournissant 65.8 p. 100 du total. On fait une estimation des émissions dans les provinces aux tableaux 2 à 6, et à la figure 1, on identifie les sources ponctuelles.

S'il y a lieu, on mentionne les facteurs d'émissions traitées et non traitées. La plupart du temps, on a calculé le facteur d'émissions traitées en se basant sur le facteur d'émissions non traitées, en supposant en certain degré d'efficacité au matériel d'épuration. Il est apparu, aux sections 7.7 et 7.8, que l'efficacité de l'élimination des particules en général ne s'applique pas toujours aux particules de plomb, puisqu'elles sont parfois relativement petites et ne sont donc pas éliminées de façon efficace. Par conséquent, certains facteurs d'émissions non traitées que nous avons calculés pourront nécessiter des changements au fur et à mesure que nous disposerons d'un plus grand nombre de données.

À la section 7, on a estimé les émissions de plomb venant des industries du fer et de l'acier, des fonderies du fer et des usines de ciment, à partir de mesures faites aux États-Unis. On aura peut-être aussi à modifier ces chiffres lorsqu'on disposera de données portant sur des sources canadiennes d'émissions.

TABLE 1 1970 LEAD EMISSIONS IN CANADA

Source	Emissions		Emission factor**			
	Tons	Percent	Present study		U.S. (96)	
			Uncontrolled	Controlled	Uncontrolled	Controlled
CONSUMPTION						
Gasoline	14 083.0	65.8	1500	(a)	-	-
Automobile	151.9	0.7	1500	(a)	-	-
Aviation	9.2	*	0.26	(a)	-	-
Handling						
Solder	0.7	*	0.26	(a)	} 3.5 (a)	-
Soldering	3.8	*	1370.0	(a)		4.1 (a)
Joint buffing	27.3	0.1	0.26	(a)	17	(a)
Printing industry	6.0	*	500	(a)	-	-
Insecticide application	0.04	*	1.5	(a)	3-20 (a)	1.3 (a)
Paint						
Consumption total	14 281.9	66.7				
INADVERTENT SOURCES						
Coal combustion	9.4	} 0.1	9.9	(b)	-	-
Power plants	0.13		0.032	(b)	-	-
Coke production	3.76		1.42	(b)	-	-
Other	105.4	0.5	12.0	(b)	-	-
Oil combustion	46.4	0.2	1.1-1.7	(b)	-	-
Wood combustion	2.17	*	41.5	(b)	630 (b)	25 (b)
Sewage sludge incineration	58.3	0.3	150	(b)	420 (b)	-
Refuse incineration	134.0	0.6	20	(d)	-	-
Waste oil incineration	37.3	0.2	-		-	-
Zinc production	2437.0	11.4	82-910	(a)	12 (a)	-
Copper, nickel production						
Iron production	1528.0	} 10.8	1.68	(c)	-	-
Sintering	705.7		3.0	(c)	-	-
Blast furnace	85.0		3.0	(c)	-	-
Electric furnace						
Steel production	8.13	} 0.7	0.18	(c)	0.18 (c)	-
Basic oxygen furnace	105.7		0.14	(c)	0.14 (c)	-
Open hearth furnace	29.0		0.18	(c)	0.18 (c)	-
Electric furnace						
Ferroalloys	42.1	} 0.3	0.9	(c)	0.9 (c)	-
Ferrosilicon	28.6		1.4	(c)	-	-
Others	23.3		0.2	(c)	0.26 (c)	-
Iron foundries						
Cement manufacture						
Wet process	111.5	0.5	0.11	(c)	} 0.13 (c)	-
Dry process			0.15	(c)		-
Inadvertent total	5500.9	25.7				

Continued....

TABLE 1 CONCLUDED

Source	Emission factor**					
	Emissions	Present study		U.S. (96)		
		Tons	Percent	Uncontrolled	Controlled	Uncontrolled
PRODUCTION						
Lead mining		1.9				
Underground	206.0		2.05 (a)	-		
Open pit	195.0		2.1 (a)	-	0.2	-
Lead milling	565.0	2.6	26.4 (a)	2.9 (a)		
Lead smelting		2.1				
Blast furnace	141.0		129.1 (a)	1.53 (a)		
Imperial furnace	316.8		-	35.8 (a)		
Lead refining						
Betts process	19.3	0.3	14.8 (a)	0.21 (a)	-	1 - 14 (a)
Softening, desilvering	43.2		-	4.15 (a)		
Secondary lead						
Blast furnace	20.5	0.2	185 (a)	1.85 (a)		
Reverberatory furnace	14.7		164 (a)	1.64 (a)	-	0.92 (a)
Melting kettles	5.3		0.26 (a)	-		
Production total	1 526.8	7.1				
MANUFACTURING						
Storage batteries						
Oxide made	2.0	}	25.1 (a)	0.2 (a)	8 (a)	1.3 (a)
Oxide bought	1.4		1.1 (a)	0.14 (a)	-	
Gasoline additives	64.5	0.3	39.7 (a)	7.25 (a)	-	0.8 - 29 (a)
Litharge	0.6	*	24.0 (a)	0.12 (a)	-	0.91 (a)
Other compounds	0.01	*	1.5 (a)	0.0075 (a)	9.5 (a)	1.3 (a)
Metal fabrication	38.0	0.2	0.26 - 11 (a)	-	1.5 - 4 (a)	-
Manufacturing total	106.5	0.5				
TOTAL LEAD EMISSIONS	21 416.1	100.0				

** Emission factor units: (a) pounds lead per ton of lead used or processed; (b) pounds lead per 1000 tons of material burned; (c) pounds lead per ton of finished material produced; (d) pounds lead per ton of material burned.

* Negligible (<0.1%).

TABLE 2 PROVINCIAL LEAD EMISSIONS (1970)

Province	Emissions (tons)				Percent of total
	Production	Manufacturing	Consumption	Inadvertent	Total
Newfoundland	44.4	0.08	202.6	21.15	268.2
Prince Edward Island	-	-	65.8	5.9	71.7
Nova Scotia	2.9	0.39	483.9	803.01	1 290.2
New Brunswick	515.6	0.30	388.4	16.2	920.5
Quebec	9.2	9.22	3 573.1	2361.76	5 953.3
Ontario	62.2	90.07	5 174.3	2118.01	7 444.6
Manitoba	3.1	1.53	674.6	66.44	745.7
Saskatchewan	-	0.27	837.1	13.79	851.2
Alberta	1.7	1.95	1 413.9	14.05	1 431.6
British Columbia	426.7	2.67	1 409.5	72.23	1 911.1
Yukon and N.W.T.	461.0	-	57.8	8.12	526.9
TOTAL	1526.8	106.5	14 282	5500.7	21 416
					100.0

TABLE 3 LEAD EMISSIONS FROM CONSUMPTION OF LEAD PRODUCTS (1970)

Province	Emissions (tons)					
	Automobile ^a gasoline	Aviation ^a gasoline	Gasoline ^b handling	Soldering ^c	Printing ^d	Insecticide ^e application
Newfoundland	197	5.2	0.13	-	0.11	0.12
Prince Edward Island	64	1.6	0.04	-	0.03	0.10
Nova Scotia	471	12.1	0.31	0.05	0.32	0.13
New Brunswick	378	9.7	0.25	0.05	0.25	0.13
Quebec	3 544	16.6	2.33	1.0	7.84	1.30
Ontario	5 125	27.3	3.33	2.7	14.19	1.81
Manitoba	655	17.4	0.43	0.1	1.17	0.48
Saskatchewan	829	6.4	0.53	0.05	0.38	0.76
Alberta	1 395	15.9	0.92	0.2	1.07	0.79
British Columbia	1 383	23.0	0.91	0.3	1.91	0.38
Yukon and N.W.T.	41	16.7	0.02	-	0.03	-
TOTAL	14 083	151.9	9.2	4.5	27.3	6.0
						14 282

^aTable 29.^bTable 29 and section 5.2.1.^cTable 27 and section 6.2.^dTable 31.^eTable 33.

TABLE 4 INADVERTENT LEAD EMISSIONS (1970)

Province	Emissions (tons)								Provincial subtotal (upper deck)
	Coal combustion ^a			Other combustion		Incineration			
	Power plant	Coke	Other	Oil ^b	Wood ^c	Sewerage ^d	Refuse ^e	Waste ^f oil	
Newfoundland	-	-	-	5.9	3.03	-	-	5.1	14.03
Prince Edward Island	-	-	-	1.2	-	-	3.9	0.8	5.9
Nova Scotia	1.6	0.01	0.36	8.7	0.50	-	2.94	4.6	18.71
New Brunswick	1.4	-	0.12	7.0	0.38	-	-	5.6	14.5
Quebec	-	0.01	0.42	45.3	6.19	-	28.29	40.4	120.61
Ontario	1.1	0.10	0.90	26.8	3.68	1.34	16.44	76.4	126.76
Manitoba	0.6	-	0.34	1.0	7.32	0.83	3.17	-	13.26
Saskatchewan	2.6	-	0.30	0.5	6.02	-	1.55	-	10.97
Alberta	2.1	-	0.60	0.6	2.54	-	1.97	-	7.81
British Columbia	-	0.01	0.72	8.3	9.80	-	-	-	18.83
Yukon and N.W.T.	-	-	-	0.1	6.92	-	-	1.1	8.12
TOTAL	9.4	0.13	3.76	105.4	46.38	2.17	58.26	134	359.5

	Emissions (tons)								
	Zinc ^g produc- tion	Copper ^h nickel produc- tion	Iron and steel industry				Cement ^m produc- tion	Provincial subtotal (lower deck)	PROVINCIAL TOTAL (upper and lower decks)
			Iron ⁱ	Steel ⁱ	Ferro- ^j alloys	Iron ^k foundries			
Newfoundland	-	-	-	0.5	-	0.02	6.6	7.12	21.15
Prince Edward Island	-	-	-	-	-	-	-	-	5.9
Nova Scotia	-	-	738.6	44.5	-	0.1	1.1	784.3	803.01
New Brunswick	-	-	-	-	-	0.1	1.6	1.7	16.2
Quebec	3.0	2079.0	85.6	5.3	35.35	3.6	29.3	2241.15	2361.76
Ontario	4.9	316.0	1474.3	86.1	35.35	16.8	57.8	1991.25	2118.01
Manitoba	5.4	42.0	-	2.0	-	0.48	3.3	53.18	66.44
Saskatchewan	-	-	-	1.2	-	0.02	1.6	2.82	13.79
Alberta	-	-	-	1.4	-	0.94	3.9	6.24	14.05
British Columbia	24.0	-	20.2	1.8	-	1.14	6.3	53.44	72.23
Yukon and N.W.T.	-	-	-	-	-	-	-	-	8.12
TOTAL	37.3	2437.0	2318.7	142.8	70.7	23.2	111.5	5141.2	5500.7

^aTables 34 and 35.

^bTable 36.

^cTable 37.

^dTable 38.

^eTable 40.

^fTable 41.

^gTable 42.

^hTable 43.

ⁱTable 45.

^jEqually divided between Quebec and Ontario.

^kTable 46.

^mTable 47.

TABLE 5 LEAD EMISSIONS FROM LEAD PRODUCTION (1970)

Province	Emissions (tons)					Total
	Mining ^a	Milling ^b	Smelting ^c	Refining ^d	Secondary ^e	
Newfoundland	18.4	26.0	-	-	-	44.4
Prince Edward Island	-	-	-	-	-	-
Nova Scotia	1.2	1.7	-	-	-	2.9
New Brunswick	64.6	91.0	316.8	43.2	-	515.6
Quebec	2.0	2.8	-	-	4.4	9.2
Ontario	12.4	17.5	-	-	32.3	62.2
Manitoba	0.4	0.6	-	-	2.1	3.1
Saskatchewan	-	-	-	-	-	-
Alberta	-	-	-	-	1.7	1.7
British Columbia	110.5	155.9	141.0	19.3	-	426.7
Yukon Territory	68.0	95.5	-	-	-	163.5
Northwest Territories	123.5	174.0	-	-	-	297.5
TOTAL	401.0	565.0	457.8	62.5	40.5	1526.8

^aTable 13.^bSection 4.2.^cSection 4.3.^dSection 4.4.^eTable 19.

TABLE 6 LEAD EMISSIONS FROM MANUFACTURING (1970)

Province	Emissions (tons)				Total
	Storage ^a batteries	Gasoline ^b additives	Litharge ^c	Metal ^d fabrication	
Newfoundland	-	-	-	0.08	0.08
Prince Edward Island	-	-	-	-	-
Nova Scotia	0.12	-	-	0.27	0.39
New Brunswick	-	-	-	0.30	0.30
Quebec	0.48	-	-	8.74	9.22
Ontario	2.17	64.5	0.40	23.00	90.07
Manitoba	0.25	-	0.15	1.13	1.53
Saskatchewan	-	-	-	0.27	0.27
Alberta	0.32	-	-	1.63	1.95
British Columbia	0.09	-	-	2.58	2.67
Yukon and N.W.T.	-	-	-	-	-
TOTAL	3.43	64.5	0.55	38.0	106.5

^aTable 21.^bSection 5.2.1.^cSection 5.2.2 and questionnaire replies.^dTable 27.

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1 INTRODUCTION

1.1 Scope

The purpose of this report is to identify and quantify sources of atmospheric lead emissions in Canada for the year 1970. Data were drawn from government reports and scientific publications. However, many of the emission figures given in this report were computed from information supplied by Canadian industry. Essentially all major lead producers and consumers in Canada were sent questionnaires during this study.

1.2 Properties of Lead and its Compounds

Lead is a soft, bluish-grey metal with a density approximately 11 times that of water and a melting point of 621 °F (1, 2). Excellent malleability and corrosion resistance have made lead one of the most useful non-ferrous materials available; in Canada, in 1970, for example, lead consumption in tonnage used ranked fifth, following only steel, aluminium, copper, and zinc (3).

The corrosion resistance of lead results from a protective surface coating formed from the reaction of lead with the anion of the attacking solution (2). For example, a protective coating of lead sulphate is formed when lead comes in contact with sulphuric acid. The protective coating formed on lead in moist air is a surface oxide, which is later converted to a grey basic carbonate. So effective is this coating that lead water pipes used in Roman times are still in good condition today (2). Nitric acid, however, is able to corrode lead since the surface lead nitrate formed is soluble in nitric acid and thus affords no protection from further attack.

Man's use of lead has a long history. Lead pottery glazes were used in Egypt as early as 7000 BC (2) and the earliest lead metal artifact found has been dated at 3800 BC (2, 4). The use of lead in water pipes by the Romans resulted in the derivation of the English word 'plumber' from the Latin 'plumbum' (5). The availability of lead ores, and the low melting point of lead that facilitates its recovery from the ore, contributed to its early use.

Lead poisoning has also had a long history, although regulations in the United States controlling the use of lead in industry were not enacted until 1920. Lead poisoning symptoms were known to the Greeks over 2000 years ago. Also, the fall of the Roman Empire has been partly attributed to lead poisoning of the ruling class, who favored the use of expensive lead-containing cooking utensils (6, 7).

Today, lead is produced in three grades rated according to impurity levels. The purest available is corroding lead (99.94% pure), which is used mostly in the manufacture of lead compounds. Chemical lead (99.90% pure) is used in applications requiring superior creep and corrosion resistance. Common desilverized lead (99.85% pure) is used in many alloying and construction applications. Cost in 1970 varied from 14.5 to 16.5 cents a pound in Toronto and Montreal (8).

Some of the uses of lead metal are summarized in Table 7. However, as lead itself is relatively weak, its most useful application is in the production of lead alloys, which combine the corrosion resistance of lead with the superior strength and fatigue resistance of the alloy metal. Principal alloys are antimony-lead (1 - 10% antimony), used in storage batteries and cable coverings, calcium-lead (~0.07% calcium), used in industrial storage batteries; copper-lead (20 - 40% lead), also sometimes containing zinc (brasses) or tin (bronzes) with smaller amounts of lead, used extensively in bearings and bushings; silver-lead (1.5 - 5% silver), used in solders and chemical electrodes; tin-lead (38 - 98% lead), used in solders, protective coatings on copper and steel (terne metals), and, when also alloyed with antimony, in type, bearing, and casting metals (2).

About one-third of the lead consumed by modern industry in the United States is converted into lead compound form (4). Common lead compounds are described in Table 8. The most important of these are the lead oxides, used in storage batteries, ceramic glazes, metal protective paints, and glasses, and the organic compounds tetraethyl lead and tetramethyl lead, used as anti-knock additives in gasolines.

TABLE 7 USES OF LEAD METAL (1-8)

Characteristics	Use
Corrosion resistance	Construction, water pipes, chemical equipment, electrical cable sheathing, storage batteries
Soft, malleable	Ammunition, packaging - collapsible tubes
Low melting point	Printing type, solder, casting metals
High density	Ballast, counterweights, γ-ray shielding, acoustic insulation
Frictional properties	Bearings, machinable alloys

TABLE 8 SOME LEAD COMPOUNDS (1-8)

Compound	Formula	Use
Tetraethyl lead	$\text{Pb}(\text{C}_2\text{H}_5)_4$	Gasoline anti-knock additives, organic mercury pesticide manufacture, polyurethane foam manufacture
Tetramethyl lead	$\text{Pb}(\text{CH}_3)_4$	
Litharge	PbO	Ceramics, insecticides, oil refining, rubber compounding, varnish manufacture
Black or grey oxide	60 - 80% PbO 20 - 40% Pb metal	Storage batteries
Red lead	Pb_3O_4	Metal protective paints, glasses, ceramics
White lead	$2\text{PbCO}_3 \cdot \text{Pb}(\text{OH})_2$	Paints, ceramics, enamel coatings
Lead chromates	$\text{PbO} \cdot \text{PbCrO}_4$ PbCrO_4	Yellow, green, red pigments in paints and inks
Lead arsenate	PbAsO_4	Insecticides
Blue basic lead sulphate	$\text{PbO} \cdot \text{PbSO}_4$	Metal protective paints
Silicate frit	PbSiO_3	Ceramics, glasses, enamel coatings
Lead bisilicate	65% PbO 35% SiO_2	

1.3 Toxicity of Lead and its Compounds

Lead and its compounds can be absorbed into the body through the respiratory and gastrointestinal tracts; the compounds tetraethyl lead, tetramethyl lead, lead acetate, and lead oleate can also be absorbed through the skin (1). Once ingested, lead is a cumulative poison with no known beneficial effects on plant or animal life (9). Organic lead compounds are usually more toxic than are inorganic compounds (10).

Exposure to lead is currently measured by the level of lead in the blood. In the case of repeated low doses, inorganic lead is concentrated in the skeleton. Any subsequent disease which tends to mobilize calcium in the body can then release the stored lead to produce poisoning symptoms (1).

Symptoms include fatigue, insomnia, constipation, abdominal colic, anemia, peripheral paralysis (neuritis), and the appearance of a blue-grey line on the gums. In severe cases, lead encephalopathy results. This involves brain damage manifesting itself in muscular tremors, mental confusion, alternating periods of excitement and depression, hallucinations, delirium, and eventually coma and death. Kidney disease (nephritis), gout, arteriosclerosis, and birth abnormalities have also been related to lead ingestion (1, 2, 11).

Organic lead compounds tend to accumulate in the brain rather than in the skeleton. Symptoms of encephalopathy arise when a threshold of 2 - 3 $\mu\text{g/g}$ of brain tissue is surpassed.

From industrial experience, the threshold limit value for an 8 h exposure to lead in air has been set at 200 $\mu\text{g/m}^3$ (6). Occupational lead poisoning is now relatively rare, at least in the acute sense (1, 12). It has been cautioned, however, that mild lead intoxication may still be fairly widespread (2).

Of major concern is the possible airborne lead hazard faced by the general population (13), who may absorb lead from automobile exhausts, coal combustion products, and industrial emissions (10). A possible hazard has been demonstrated by numerous correlations of ambient lead

measurements with such factors as traffic, age of dwelling, type of neighbourhood, presence of pets, etc. (14, 15, 16). A related problem is the ingestion of lead in paint chips and urban dirt by children. Up to 8% of ghetto children in the United States are estimated to suffer lead poisoning effects from swallowing a few dime-sized paint chips daily (6, 17). The body burden of lead as measured in 150 accidental deaths in the United States is shown in Table 9.

TABLE 9 LEAD IN HUMAN TISSUE (18)

Tissue ^a	Concentration (ppm)
Muscle	0.06
Fat	0.05
Skeleton	11.0
Brain	0.1
Kidneys	1.1
Hair	50.0
Blood	
Accident victims	0.25
Remote rural	0.12
Average rural	0.16
Average urban	0.21
TOTAL	1.7

^aAll measurements, except the last three values for blood, were performed on 150 accidental death victims in the United States.

Ontario has established an acceptable impingement level of exposure to lead in ambient air of 20 $\mu\text{g}/\text{m}^3$ for a period of 30 min. Although this level is believed sufficient to provide a safety margin wide enough to prevent the absorption of enough lead to produce lead poisoning symptoms mentioned previously, there is some controversy regarding sub-clinical lead effects (10, 18). In the United States, the Environmental Protection Agency has indicated that the evidence of lead interference

with certain blood enzymes at blood concentrations below those required for overt poisoning symptoms warrants an ambient air standard of $2 \mu\text{g}/\text{m}^3$ (11). Studies in the USSR have also suggested that a lower acceptable standard should be set. Russian limits are therefore about 100 times lower than are United States' limits (17).

The bulk of ingested lead at present is absorbed through the diet. Lead concentrations in food and drink, as listed in Table 10, result in an average American daily intake of approximately 300 μg . This intake has apparently not changed significantly over the last 30 years. The acceptable water standard of 50 μg lead/litre is seldom exceeded (11).

TABLE 10 LEAD CONTENT IN DIET (11, 12)

Item	Average concentration (μg Pb/g)
Condiments	1.2
Seafood	0.5
Meat, eggs	0.2
Grains	0.4
Vegetables	0.2
Milk	<0.1
Waters ($\mu\text{g}/\text{litre}$)	1.10

Respiratory lead intake, on the other hand, may have increased during the last few decades (6, 15). Present ambient air levels are typically $2 - 5 \mu\text{g}/\text{m}^3$ of air in cities (11), although some yearly averages of as high as $8 \mu\text{g}/\text{m}^3$ have been recorded (6). Of some concern is the suggestion that up to 10% of this lead may be in the more toxic organic form (15). Daily lead intake through breathing could vary from about 1 - 60 μg depending on occupation and place of residence (11).

Another form of lead poisoning of concern in wildlife conservation results from the use of lead pellets in ammunition (9). Lead shot accumulates around blinds and feeding spots in marshes where birds are hunted, and are subsequently mistaken for seeds or gravel and swallowed

by waterfowl. With sufficient lead dosage, wing paralysis makes flight impossible, impairment of the action of the gizzard makes food utilization difficult, and plumage deterioration forces the birds to shun water and hide in available cover. Death comes either through lead poisoning or through capture by predators.

A single shotgun shell contains about 1.25 oz lead in 240 pellets, enough to poison about 40 birds, and some marshes are estimated to accumulate eight to ten tons of lead annually.

Although iron shot with plastic sleeves has been suggested as a viable alternative to lead shot, no action has been taken by regulatory agencies to force this change. In any event, lead already lying on marsh bottoms will continue to poison waterfowl even if the change to iron pellets is made.

2 NATURAL LEAD BACKGROUND

Several lead compounds occur naturally in the earth's crust. Lead carbonate, for example, is found in the mineral cerussite, lead sulphate in anglesite, lead chromate in crocoisite, and lead phosphate in morphite (1, 4). The most abundant lead ore, and of most commercial importance in Canada, contains galena, a silvery coloured mineral. The ore contains 6 - 8% lead as lead sulphide. Frequently, galena is associated with sphalerite, the principal zinc ore. Accordingly, the metals lead and zinc are often recovered together, along with smaller amounts of copper and silver (19).

Natural weathering processes will release lead into the environment during erosion of the rock containing lead minerals. Because the average lead content of the earth's crust has been estimated at 16 ppm (20) and natural processes weather an estimated 10^{10} tons of rock from the earth's surface annually (21), a lead release of 160 000 tons a year is suggested. As Canada comprises about 6% of the earth's land area, a yearly release of 9 600 tons is estimated. This figure can only be regarded at best as an order of magnitude, not only because of the figures on which it is based, but also because of variations in lead concentration across the earth's surface, which were not taken into account

in making this estimate. These variations will also result in unequal releases of lead across Canada.

Lead released through weathering circulates through the environment, entering air, water, soils, plants, and animals. Extensive measurements of the lead content of various items have been published (6, 11, 20, 22). Some of these figures are presented in Table 11; others have already been given in Tables 9 and 10.

TABLE 11 BACKGROUND LEAD LEVELS

	Concentration
SOILS (ppm) (20)	
Virgin	0.038 - 108
Canadian arable	0.5 - 1 000
Mining areas	20 - 10 000
WATERS (mg/l) (20)	
Sea	0.00008 - 0.008
Ground	0.001 - 0.06
Surface	0.001 - 0.055
AIR ($\mu\text{g}/\text{m}^3$)	
Rural (10)	0.002 - 0.15
Urban (23)	1.0 - 11.8
Detroit	1.0 - 13.0
New York	0.4 - 18.4
Los Angeles	
Mid-Pacific (24)	0.001

It is difficult, however, to separate human and natural sources of lead emissions (16). Figure 2 shows the increase in lead content of Greenland snow with time. It is evident that human activities had already altered the lead background before 'background' lead measurements could be made. Nevertheless, a natural lead level of $0.0005 \mu\text{g}/\text{m}^3$ of air has been estimated. Measurements made in the atmosphere over the mid-Pacific are reasonably close to this estimate (24) (Table 11).

A significant emission source, distinct from the production and use of lead itself, is the release of trace amounts of lead that are contained in fuels. The sharp increase in lead levels shown in Figure 2

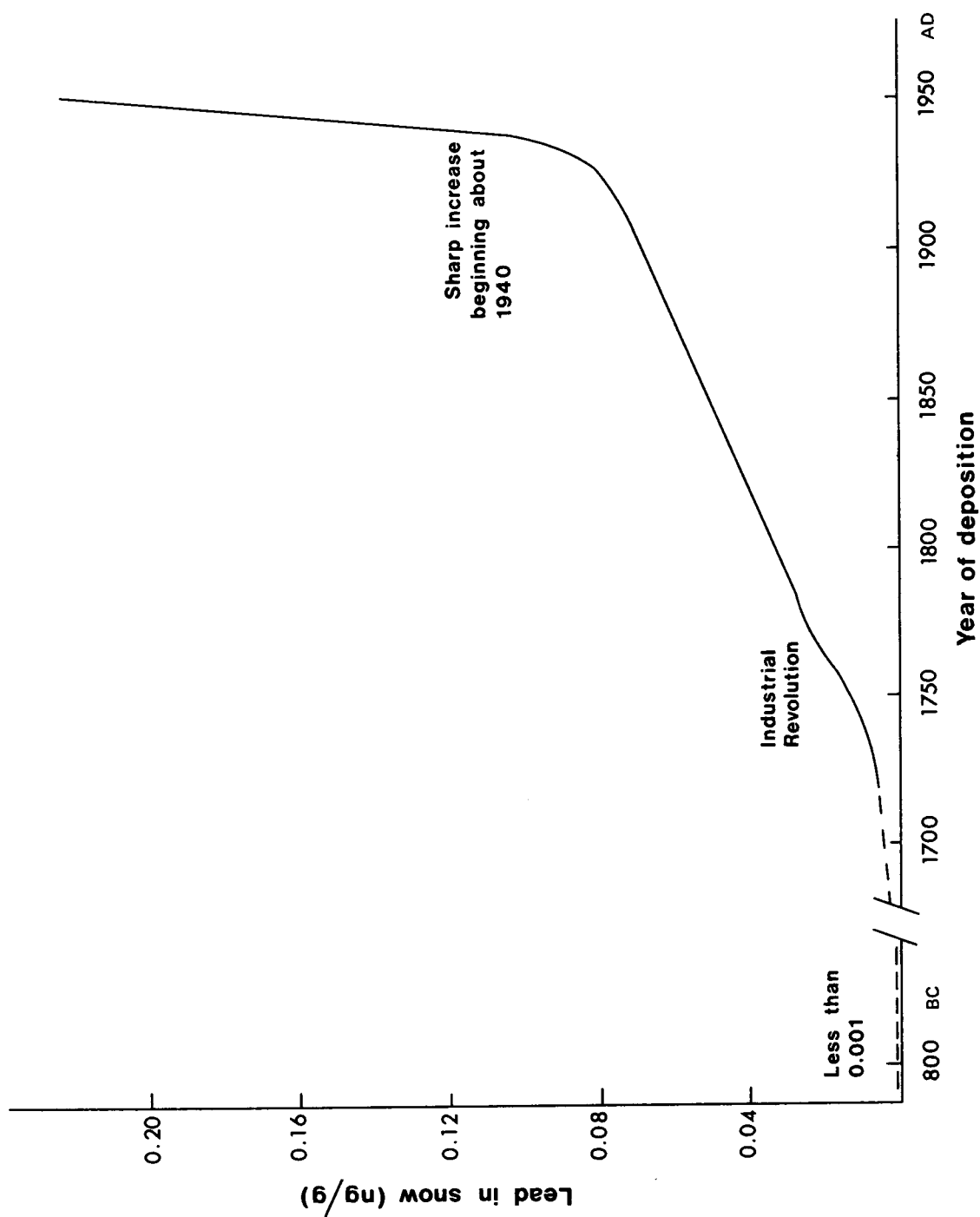


FIGURE 2 : LEAD CONTENT OF GREENLAND SNOW (6)

near the time of the industrial revolution probably resulted largely from the increased use of fuels. The lead contents of some common fuels are listed in Table 12.

TABLE 12 LEAD CONTENT OF FUELS

Fuel	Concentration (ppm)
Coal	
Pennsylvania, Rhode Island (25)	30 - 265
Alberta (26)	7.0 - 9.2
Ash from Virginia coals (27)	71.0
Residual fuel oil (28, 29)	5 - 6
Crude oil	0.01
Gasoline ^a	833
Wood ash (15) - Douglas fir	
Trunk	350 - 1 400
Needles	110 - 1 200

^aFrom questionnaires returned by Canadian oil companies, the average lead content of gasoline has been computed to be 2.8 g/gal or 833 ppm.

3 FLOW OF LEAD THROUGH THE CANADIAN ECONOMY IN 1970

In 1970, Canada was the noncommunist world's third largest lead producer, following the United States and Australia (8). As indicated in Table 13, principal sources of the 389 185 tons of lead mined in Canada were the Northwest Territories, British Columbia, the Yukon Territory, and New Brunswick.

Milling of recovered ores, which contained up to 8% lead, produced concentrates of 30 - 70% lead. Concentrates were either exported or shipped to Trail, British Columbia, or Belledune, New Brunswick, for smelting (30).

Exports accounted for the bulk of lead production. Approximately 165 912 tons of lead were exported in ore or concentrate form, and an additional 165 189 tons were exported as lead metal, materials, and scrap.

TABLE 13 CANADIAN LEAD PRODUCTION^a IN 1970 (30)

Province	Production	
	Tons	Percent
Northwest Territories	119 603	30.8
British Columbia	107 419	27.6
Yukon Territory	65 835	16.9
New Brunswick	62 675	16.1
Newfoundland	17 730	4.6
Ontario	11 960	3.1
Quebec	2 159	0.5
Nova Scotia	1 299	0.3
Manitoba	505	0.1
TOTAL	389 185	100.0

^aLead content of base bullion produced from domestic primary materials (concentrates, slags, residues, etc.) plus estimates of recoverable lead in domestic ores and concentrates exported.

Accordingly, 43% of lead production was exported unsmelted, and an additional 39% of production was exported as primary lead metal. Several countries, including the United States, Britain, and Japan, paid a total of 80.5 million dollars for these materials (30).

Consumption of lead by Canadian industry in 1970 was 93 437 tons. Approximately 55 684 tons, or 60% of consumption, consisted of domestic primary lead, 4 459 tons or 5% of consumption was included in imports, and the remaining 33 294 tons or 35% of consumption consisted of secondary lead, lead recovered from scrap. Estimates of the disposition of lead among various industries in Canada are presented in Figure 3. Further information on the disposition of primary and secondary lead is given in Table 14.

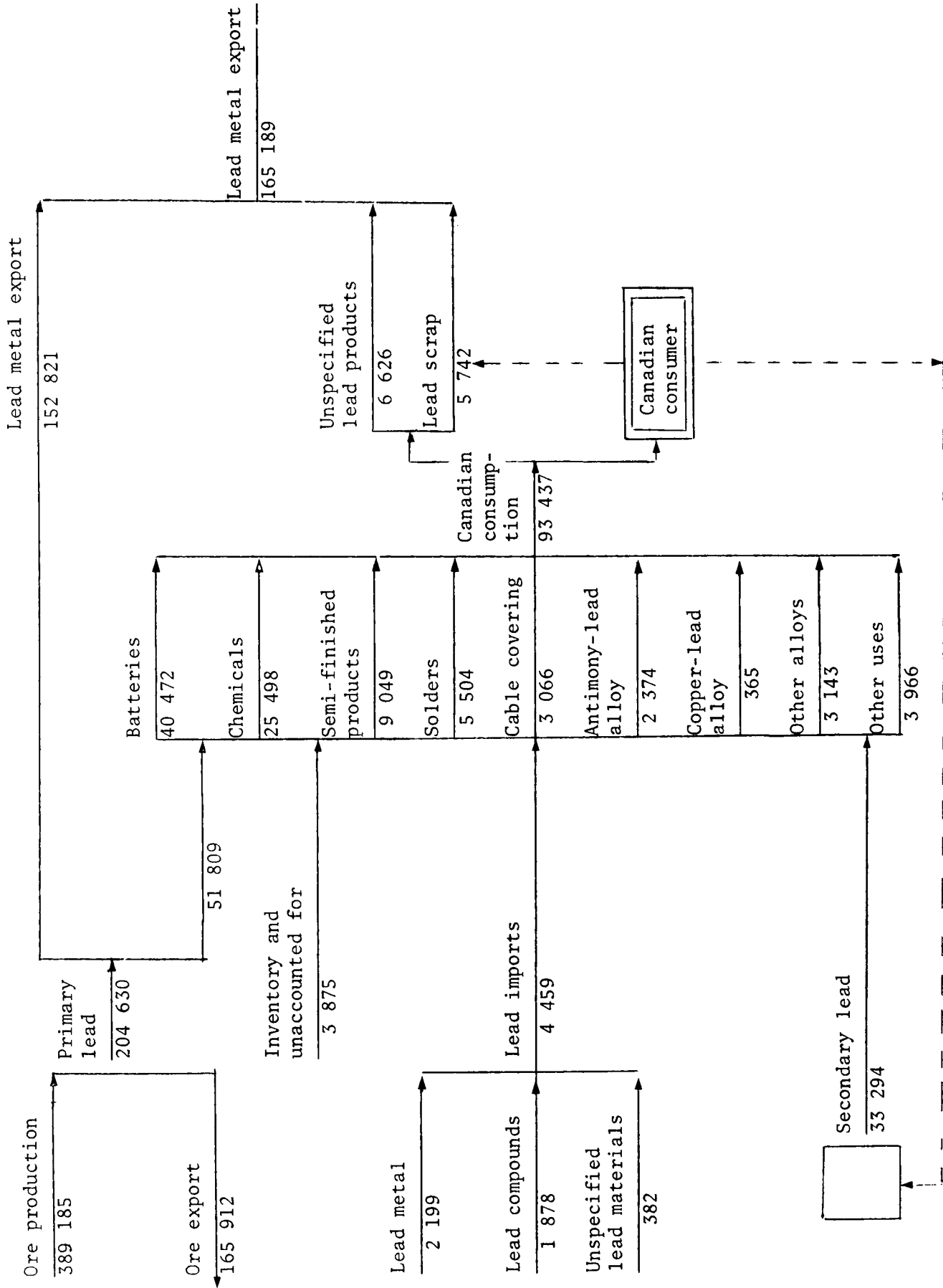


FIGURE 3 FLOW OF LEAD IN CANADA IN 1970 (tons) (30).

TABLE 14 LEAD CONSUMPTION BY CANADIAN INDUSTRY (1970) (30)

Industry	Lead consumption (tons)			Percent of consumption
	Primary	Secondary	Total	
Battery manufacture	20 273	20 199	40 472	43.2
Lead compound manufacture	22 112	3 386 ^b	25 498	27.3
Semifinished products ^a	8 570	479	9 049	9.7
Solders	2 527	2 977	5 504	5.9
Alloys (babbitts, type etc.)	268	2 875	3 143	3.4
Cable sheathing	2 296	770 ^b	3 066	3.3
Antimony-lead	1 412	962 ^b	2 374	2.5
Copper alloys	318	47 ^b	365	0.4
Other uses	2 367	1 599	3 966	4.3
TOTAL	60 143	33 294	93 437	100.0

^aIncludes pipe, sheets, traps, bends, foil, caulking blocks, ammunition, tubes, etc.

^bSecondary lead use by these industries was available only for 1967. Use in 1970 has been estimated by applying the percentages of primary versus secondary lead calculated from 1967 data. A total of 5 165 tons of secondary lead was involved in these estimates.

4 EMISSIONS FROM LEAD PRODUCTION

4.1 Lead Mining

Recoverable lead production in 1970 increased to 389 185 tons, maintaining Canada's position as the third largest lead producer in the free world (8). The 29 mines listed in Table 15 processed ores with lead content varying from 0.06 to 7.6%, with an average content of 2.4%. Lead minerals were always associated with minerals of such other metals as zinc, copper, silver, and gold. The lead production total of 387 188 tons indicated in Table 15 therefore differs from the 389 185 tons given in Figure 3 because of traces of lead regained from the slags and residues produced during recovery of these other metals.

Generally, lead ore deposits are located far below the surface. Accordingly, 25 of the 29 lead mines use underground mining techniques (31). The four open pit operations, however, are relatively large and account for approximately 48% of total production.

A typical open pit operation involves drilling and blasting to loosen the ore, followed by machine loading of the ore onto trucks for transportation to the mill. Underground mines operate similarly, with large volumes of ventilating air supplied to protect the health of the miners. Rock wetting and dust collectors on drills are frequently employed for dust suppression. In underground mines, however, preliminary crushing into rocks of approximately 6-in. diameter is usually carried out underground to facilitate transportation of ore to the surface. Dust control devices such as cyclones and bag filters are used on the crusher.

During the study, questionnaire replies were received from the 14 mines identified by the lower case letter b in Table 15. These mines accounted for 93% of total production. Mining emission data could not be supplied by these companies. Five companies did, however, supply their mine ventilation rates. Lead carried out with ventilation air can therefore be estimated using these volumes and the assumption that the lead content of the air equals half the occupational threshold limit value of $200 \mu\text{g}/\text{m}^3$. On this basis emission factors of 0.02 - 0.03 lb/ton of lead mined have been calculated. No emission controls were reported on mine ventilation exhaust. A mine ventilation loss of 0.025 lb lead/ton of lead mined has

TABLE 15 CANADIAN LEAD PRODUCERS IN 1970 (8, 30)

Location	Lead in ore (%)	1970 lead production ^a	Percent of total
NORTHWEST TERRITORIES			
Pine Point ^b (op) ^c	3.0	101 780	26.2
YUKON TERRITORY			
Faro ^b (op) ^c	4.4	63 476	16.4
Mayo District ^b	4.1	3 473	0.9
Carcross	1.2	197	0.1
BRITISH COLUMBIA			
Kimberley ^b	-	98 664	25.4
Riondel ^b	-	10 446	2.7
Myra Falls	0.8	2 387	0.6
Salmo	1.2	2 275	0.6
Remac			
Plant 1	4.8	1 337	0.3
Plant 2	1.1	647	0.2
Golden	3.5	1 097	0.3
Slocan District ^b	7.6	942	0.2
Beaverdell	0.9	297	0.1
Keremeos	-	12	-
MANITOBA			
Snow Lake	0.3	515	0.1
ONTARIO			
Timmins (op) ^c	-	9 349	2.4
Manitouwadge			
Plant 1 ^b	-	1 742	0.5
Plant 2	0.2	538	0.1
Plant 3	0.1	8	-
QUEBEC			
Val d'Or ^b	0.4	774	0.2
Stratford Centre			
Plant 1	0.9	738	0.2
Plant 2 ^b	0.5	279	0.1
Plant 3	-	started late 1970	-
NEW BRUNSWICK			
Bathurst ^b			
Plant 1 ^b	2.9	26 612	6.9
Plant 2 ^b (op) ^c	2.1	14 450	3.7
Plant 3 ^b	2.6	7 348	1.9
Newcastle ^b	2.3	12 324	3.2
NOVA SCOTIA			
Walton ^b	6.3	1 478	0.4
NEWFOUNDLAND			
Buchans ^b	7.0	24 103	6.2
TOTAL (29 mines)		387 288	100.0

^aEstimated lead in domestic ores and concentrates produced.

^bQuestionnaire reply received.

^cAbbreviation: op, open pit mine.

therefore been used in this report for underground mines. The loss in open pit operations is believed to be higher than it is in underground mines since environmental control is generally less strict. Accordingly, the figure of 0.025 lb/ton has been doubled to 0.05 lb/ton for open pit mining.

Additional dust emissions will be produced during surface loading and hauling operations. The magnitude of these emissions has been calculated using the emission factor of 2.0 lb/ton of uncontrolled rock handling reported by the Environmental Protection Agency in the United States (32). Evidently, hauling operations lead to larger emissions than does the mining operation itself. Based on the foregoing analysis, lead emissions from mining are summarized as follows.

Source	Emission factor		1970 emissions (tons)
	lb/ton lead	lb/ton ore	
Open pit mines (4)	2.05	0.0013-0.16	195
Underground mines (25)	2.025		206
TOTAL (29 mines)			401

The emission data given above assume no emission controls on the mine exhaust or on the hauling operation. The range shown for the lead loss per ton of ore mined covers lead levels of 0.1 - 8.0% in the ore. Although detailed information is not available, atmospheric emissions will be in the form of rock dust, containing 0.1 - 8% lead as lead sulphide.

4.2 Lead Milling

Few lead ores are rich enough in lead or low enough in impurities to be smelted directly. Consequently, the first step in recovering lead metal is the separation of lead minerals from other valued ore constituents and waste material. Because most lead-bearing ores in Canada are complex sulphides, milling involves crushing and grinding followed by flotation to separate the finely divided minerals from the gangue. Usually, the lead concentrate is recovered separately, although when the minerals are interlocked, a bulk sulphide concentrate may be prepared, reground, and then

sent to selective flotation processes. The various concentrates are dewatered, dried, and shipped to the smelter.

The milling process is unable to completely separate the various minerals. Table 16 shows the amount of lead contained in various concentrates, as reported in questionnaire returns. These figures vary with the type of ore being processed. Lead emissions produced from the smelting of base metals other than lead itself is discussed in section 7 of this report.

TABLE 16 LEAD CONTENT OF ORES AND CONCENTRATES

Location	Lead content (% by weight)					
	Ore	Tailings	Concentrates			
			Lead	Zinc	Copper	Bulk
Manitouwadge, Ont.	0.14	0.01	45.68	0.02	0.89	-
Mayo District, Yukon	5.17	0.15	64.15	-	-	-
Bathurst, N.B.	2.12	-	37.46	1.34	11.81	12.15
Bathurst, N.B.	2.93	-	35.40	1.51	8.68	-
Sandon, B.C.	6.39	-	65.0	-	-	-

Atmospheric emissions from milling consist of dust produced principally during conveying and crushing the ore, drying and transporting the concentrates, and disposing of the tailings. Generally, grinding and flotation are wet operations producing negligible atmospheric emissions. Similarly, emissions from handling of tailings is very small since the tailings are transported to the disposal area in a water slurry. Dust suppression equipment such as cyclones, scrubbers, and baghouses are used in the mills both to protect the workers and to permit maximum recovery of valuable minerals.

Although questionnaire replies were received from 14 producers identified in Table 15, milling emissions were estimated by only three companies. Figures supplied for emissions from crushing operations resulted in emission factors of: 0.029 lb lead/ ton of lead processed, with a stated control efficiency of 98% (scrubber); 0.37 lb/ton, with a control efficiency of 80% (cyclone); and 0.39 lb/ton, with a control efficiency of 80% (cyclone).

On an uncontrolled basis these emission factors become 1.45, 1.72, and 1.94 lb/ton, respectively. These figures are in reasonable agreement with EPA estimates of 1.5 lb/ton for secondary rock crushing operations plus 0.5 lb/ton for primary crushing operations (32). Uncontrolled crushing losses have been estimated at 1.89 lb lead/ton of lead processed by taking an average of the three factors given above, weighted by lead production figures.

No figures on losses from concentrate drying operations were available. Data discussed in section 4.3 on drying operations at a smelter were therefore used. The indicated emission factor is 0.49 lb lead/ton of lead contained in the dried concentrate when a scrubber of 98% efficiency is used for control. The uncontrolled factor accordingly becomes 24.5 lb/ton, a figure which falls within the range of data reported in the United States. For phosphate rock processing, the Environmental Protection Agency (EPA) gives an uncontrolled drying factor of 15 lb/ton, whereas for brick and ceramic clay manufacturing, a 70 lb/ton figure is estimated (32).

Miscellaneous handling losses are estimated by applying the uncontrolled emission factor of 2 lb/ton reported by EPA (32).

Atmospheric emissions of lead from lead milling operations have been estimated by using the uncontrolled emission factors given previously, making allowance for average control efficiencies. Seven companies, accounting for about 77% of lead production, gave control efficiencies for their milling operations. One company used a baghouse (99% efficiency), two scrubbers (98% efficiency), and four used cyclones (80% efficiency). The average control efficiency weighted by lead production was 89%. In the absence of data on drying and miscellaneous handling emissions, the same control equipment is assumed, and the 89% average is again applied. Milling emissions are accordingly summarized as follows.

Source	Emission factor (lb/ton)	1970 emissions (tons)
Crushing	0.2	38.9
Concentrate drying	2.5	487.2
Transporting, handling	0.2	38.9
TOTAL	2.9	565.0

On an uncontrolled basis, the milling emission factor becomes 26.4 lb lead/ton of lead processed. Information in questionnaire returns suggests that emissions are in the form of lead sulphide particles, up to about 7 μm in diameter when baghouses and scrubbers are used (-200 mesh) and about 44 μm in diameter when cyclones are used.

4.3 Lead Smelting

In 1970, two smelters in Canada recovered 204 630 tons of lead metal from concentrates. The smelter at Trail, British Columbia, which uses blast furnace methods, accounted for about 90% of lead production. The remaining 10% was recovered at Belledune, New Brunswick, where the Imperial smelting process was employed in 1970 (8, 30). This process recovered lead and zinc simultaneously from a mixed concentrate (33). Since 1971, separate concentrates have been used.

Discussion of blast furnace smelting may be found in References 34 and 35. Fluxing agents are mixed through the zinc concentrate, which is then dried and sintered. Sintering involves burning the concentrate under forced draught to expel the sulphide as sulphur oxides and to produce a metal oxide sinter suitable for treating in the furnace. This sinter material and a controlled amount of coke form the blast furnace charge. As air is forced through the furnace, the coke burns to carbon monoxide and carbon dioxide, and the lead oxide is reduced to lead metal.

Blast furnace products consist of molten lead bullion, containing various impurities, and molten slag. As the bullion cools, copper dross forms on the surface and is skimmed off. The drossed bullion is then cast into anodes in preparation for refining operations.

Dross material is smelted at high temperature in a dross re-treatment furnace, producing slag, matte, and bullion. Slag is air-cooled and stockpiled, matte is sent for treatment to copper smelters, and bullion is returned to the drossing furnace. Slag from the blast furnace is treated in fuming furnaces for the recovery of lead and zinc in the form of oxides. The oxide fume is cooled, recovered in baghouses, and sent to a zinc plant for sulphuric acid leaching (see section 7.7).

In the Imperial smelting process (33), fluxing and sintering of the concentrate are also required to produce a suitable charge for the furnace.

In the Imperial furnace, however, as well as lead bullion and slag, zinc vapour is produced. This vapour is dissolved in molten lead as it passes through a condenser. The lead-zinc solution stratifies as it cools in separation tanks into a layer containing 98% zinc and a lead layer, which is recycled to the condenser. The zinc is sent to a refinery for further treatment. Molten lead bullion and slag are tapped from the furnace and purified in a manner similar to that described for blast furnace products.

Excellent emission data for the Trail smelter were furnished in a questionnaire reply and in Reference 35. Detailed emission factors are given in Table 17. Emissions from the New Brunswick smelter, however, were only given as a total emission figure in combination with refinery emissions. Estimates were made by using the ratio of smelting to refining and applying smelting emissions for the Trail smelter to the New Brunswick operation. The smelting emissions thereby estimated were divided by reported production to give an emission factor. Accordingly, lead emissions from smelting are summarized as follows.

Source	Emission factor (lb/ton lead produced)	1970 emissions (tons)
Trail smelter	1.53	141
New Brunswick smelter	35.8	316.8
TOTAL		457.8

Generally, a high degree of control is used on lead emissions from smelting operations. The relatively high emissions from the New Brunswick smelter result partly from expressing the emission factor in pounds of lead per ton of lead produced. The Imperial smelter also produced 31 300 tons of zinc in 1970 (36). On a total metal basis, the New Brunswick emission factor is reduced to approximately 16.5 lb/ton of metal produced.

Emissions were reported to be in the form of lead sulphides, oxides, and metallic fumes of undetermined particle size.

TABLE 17 PARTICULATE AND LEAD EMISSION FACTORS FOR PRIMARY LEAD SMELTERS (1970)

Source	Emission factor			
	Particulate ^a		Lead ^b	
	Uncontrolled	Controlled	Uncontrolled	Controlled
Sintering operations				
Dryers	36	0.69 ^c	24.5	0.49 ^c
Sintering machine	57	0.57 ^d	39.0	0.39 ^d
Miscellaneous	5.5	0.08 ^c	2.2	0.02 ^c
Smelting operations				
Blast furnace	70	0.70 ^e	57	0.57 ^e
Slag furnace	27	0.27 ^e	6	0.06 ^e
Dross furnace	0.4	-	0.2	-
Miscellaneous	0.8	-	0.2	-
TOTAL	196.7	2.31	129.1	1.53

^aExpressed as pounds per ton of concentrate processed.

^bExpressed as pounds per ton of lead processed.

^cImpinger scrubber collection efficiency, 98%.

^dScrubbing and electrostatic precipitation collection efficiency, 99%.

^eBaghouse collection efficiency, 99%.

4.4 Lead Refining

The final step in primary lead production is the purification of the lead bullion produced in the smelting operation. Precious metals are frequently recovered as by-products of the refining operation along with the purified lead metal.

A number of different purification processes can be used. At the Trail smelter, the Betts process is employed (35). Bullion is cast into anodes and treated in electrolytic cells. Purified lead is plated out on cathodes, and precious metals and other impurities are left behind in anode sludges. Refined lead cathodes are melted down and cast into ingots for shipment. The anode sludges are melted in a reverberatory furnace where arsenic and antimony oxide fumes are produced, then collected in a baghouse.

The other products consist of slag and black metal, which are further treated in furnaces to produce arsenic and antimony fumes, a bismuth-lead slag, and dore metal. Refining these latter two products produces silver, gold, and bismuth. The collected arsenic and antimony oxide fumes are mixed with lead dross and smelted in a reverberatory furnace to produce antimony-lead alloy and arsenic.

At the New Brunswick smelter, lead bullion is refined by softening and desilvering processes. Softening consists of treating the bullion in drossing or refining kettles to remove copper, tin, antimony and arsenic. Desilvering is done using the Parkes process, in which metallic zinc is poured into the bullion producing a silver-zinc alloy dross on the surface.

Atmospheric emissions during refining consist of fumes emitted from melting pots, kettles, and furnaces and miscellaneous losses produced during pouring, transfer, and casting. Detailed emission information supplied in a questionnaire reply and in Reference 35 is presented in Table 18. Only an overall figure was available for the New Brunswick plant. Refining losses have been estimated by applying the ratio of refining to total losses computed from the Trail data. On this basis, refining emissions are summarized as follows.

Source	Emission factor (lb/ton)	1970 emissions (tons)
B.C. Operation	0.21	19.3
N.B. Operation	4.15	43.2
TOTAL		62.5

Information on the form of the emission was not given in questionnaire returns. It is expected, however, that the majority of emissions will consist of lead oxide particles.

TABLE 18 LEAD EMISSION FACTORS FOR PRIMARY LEAD REFINERS (1970)

Source	Emission factor ^a	
	Uncontrolled	Controlled
Kettles	5.0	0.1 ^b
Reverberatory furnaces	8.5	0.085 ^c
Miscellaneous ventilation	1.3	0.025 ^b
TOTAL	14.8	0.21

^aExpressed as pounds of lead per ton of lead produced.

^bControlled by an impinger scrubber with an efficiency of 98%.

^cControlled by a baghouse with a collection efficiency of 99%.

4.5 Secondary Lead Production

The recovery of lead from battery plates, cable sheathing, type metal, and various slags and drosses accounted for 33 294 tons or about 36% of the lead consumed in Canada in 1970. Such materials as battery plate scrap are melted in blast or reverberatory furnaces at high temperatures, usually about 2300 °F. The molten lead product, generally making up about 65% of the weight of the charge, is drawn off and cast into large blocks, typically 2000 lb in weight. Although some of the 'button metal' from the furnace is used directly for such applications as ballast and counterweights, the bulk is remelted at 700 - 900 °F in melting kettles for further processing. Various compounds may be added to the molten lead to produce surface drosses containing copper or antimony impurities, for example. These drosses can be skimmed off to produce refined lead. Alternatively, metals may be added to the molten lead to produce a desired lead alloy. After this refining operation, lead or lead alloy ingots are cast for shipment.

In some cases, lead scrap is received in a pure enough condition that smelting is not required. Scrap cable sheathing, for example, may be melted directly in the alloying kettles without prior treatment.

The principal sources of emissions in secondary lead processing are the furnaces and the melting kettles. EPA reports uncontrolled emissions of 190 lb particulates/ton of secondary lead recovered in blast (cupola) furnaces, and 130 lb/ton in reverberatory furnaces. The corresponding uncontrolled emission factor for melting kettles is relatively low, estimated at 0.8 lb particulate/ton of lead. Although the lead content of these particulate emissions is not specified, process descriptions indicate that they would be high.

During the study, questionnaire replies were received from three companies operating the six major lead recovery plants in Canada. These plants are described in Table 19. Production figures for 1970 totalled approximately 41 204 tons, which is 7 910 tons more than the consumption reported by Statistics Canada. Discussion with the companies involved suggest that the additional 7 910 tons is accounted for by exports to the United States and inventory changes.

TABLE 19 LEAD EMISSIONS FROM SECONDARY LEAD PRODUCTION (1970)

Location	Secondary lead production (tons)	Process ^a	Lead emissions (tons)
Montreal, Que.	4 120	BF, MK	4.35
Toronto, Ont.			
Plant 1	5 785	BF, MK	6.10
Plant 2	15 000	RF, MK	14.25
Plant 3	12 000	RF, BF, MK	12.00
Winnipeg, Man.	2 191	RF, MK	2.08
Calgary, Alta.	1 804	RF, MK	1.71
Vancouver, B.C.	124	MK	0.02
TOTAL	41 204		40.5

^aAbbreviations: BF, blast furnace; RF, reverberatory furnace;
MK, melting kettle.

Furnace emission data were supplied by two plants operating blast furnaces and two operating reverberatory furnaces. Controls on furnace emissions consisted of baghouses of 98 - 99% efficiency. Assuming a 98.5% efficiency, the controlled emission factor becomes 1.85 lb/ton for blast furnaces and 1.64 lb/ton for reverberatory furnaces.

Five plants supplied emission data for their melting kettles. No control devices were reported. Calculated emission factors varied from 0.15 lb lead/ton of lead processed to 0.4 lb/ton, with a weighted average of 0.26 lb/ton. This figure is lower than the 0.8 lb/ton factor given by EPA. From the foregoing analysis, emissions from secondary lead production are given in Table 18 and are summarized as follows.

Source	Emission factor (lb lead/ton processed)	1970 emissions (tons)
Reverberatory furnaces	1.64	20.5
Blast furnaces	1.85	14.7
Melting kettles	0.26	5.3
TOTAL		40.5

Emissions were reported to be in the form of lead oxides with smaller amounts of lead metal and lead sulphate particulates. Particle size was reported to be under 10 μ m.

5 MANUFACTURING INDUSTRY EMISSIONS

5.1 Storage Battery Manufacture

The lead-acid battery is relatively inexpensive, can be recharged, and can deliver large currents at a constant voltage over a wide temperature range. It is extensively used to supply the ignition and lighting requirements of the internal-combustion engine. Other applications include the energy source for electrically powered vehicles and emergency power equipment for hospitals, telephone companies, railroad signals etc. (4).

Electrical energy from a lead-acid battery is generated by the chemical reactions that take place between the material in the battery plates and the sulphuric acid electrolyte. At the anode (sponge lead) plate, lead metal is converted into lead sulphate according to the reaction



whereas at the cathode (lead peroxide) plate,



Dissociation of sulphuric acid produces the hydrogen (H^+) and sulphate (SO_4^{2-}) ions (36, 37).

Power is no longer produced when the plates are covered with lead sulphate. Recharging is accomplished by applying electrical energy to reverse the reaction shown above. However, mechanical damage, and the formation of large-grained chemical lead sulphate on the electrode plates eventually make recharging impossible, and the battery must be replaced. The average life of an automobile battery is now about three years. Over 80% of the old batteries are recovered to become the largest single source of secondary lead production (4, 5).

To manufacture a lead-acid battery, plate grids are first cast by pouring a molten antimony-lead alloy into moulds. Antimony alloy is required to produce strong, thin (0.05 - 0.25 in. thick) grids. However, as the reaction of antimony with sulphuric acid tends to produce self-discharge in the battery, modern alloys contain less antimony and small quantities of tin, arsenic, or calcium. These grids form the framework of the battery plates, supplying mechanical strength for the active chemical ingredients and a conductive path for the electricity produced.

Lead compounds are pressed onto the plate grid in the form of a paste, made by mixing powdered black oxide (a mixture of PbO , Pb), water, and dilute sulphuric acid in a batch mixer. For negative plates, expanders such as barium sulphate, carbon-black, or other organic materials are added to the mix to prevent plate shrinkage during use. These expanders give the negative plates a darker colour than are the positive plates.

After the thick, wet paste is formed into a plate around the lead-antimony grid, the plates are dried, cured, formed, and assembled into cells. 'Forming' is the name given to the initial charging of the plates, which oxidizes the lead oxide - sulphate - metallic lead compound on the positive plates to lead peroxide and reduces the mixture on the negative plates to lead metal. This step may either be done by charging a group of plates in a sulphuric acid bath before battery assembly, or by charging a finished battery which has been filled with sulphuric acid. The former method is usually employed for replacement batteries since it allows the batteries to be shipped dry. The dealer has only to add acid, and the battery has a sufficient residual charge for immediate use. The latter method is usually employed in batteries for new vehicles since car makers are not required to handle acid.

The final manufacturing steps begin by stacking together several positive and negative plates, separated by cellulose insulators, into cells. As was mentioned above, the plates may or may not be 'formed' at this stage. Individual plates are connected together by welding or 'burning' a lead alloy bar across tabs on the plates. Each cell is capable of delivering the required current at 2 V. Sufficient cells to generate the desired multiple of 2 V are next connected together in a rubber or polypropylene case. The battery top is cemented on and sealed, and the battery posts are attached. Dry batteries are then packaged and shipped, and wet batteries are filled with acid, charged, packaged, and shipped. A finished automobile battery contains about 20 lb lead, approximately evenly divided between lead metal components and lead compounds on the plates (4, 5).

Atmospheric lead emissions from battery manufacturers result from several operations.

- (a) Some manufacturers in the United States have their own smelting operation for the recovery of lead from used batteries. Questionnaire replies indicate that the majority of Canadian battery manufacturers purchase their lead from primary or secondary lead refiners and do not perform their own recovery.

- (b) A few large Canadian companies produce their own lead oxides from lead metal, whereas smaller operations usually purchase the oxides in compound form. Of the plants contacted during the study, four reported that they produced lead oxide by milling lead metal. Details of this procedure and accompanying emissions are discussed in section 5.2.
- (c) Some dust is also created during mixing of the oxide pastes, particularly when pouring dry powder into the mixer. To protect the health of the worker, however, this operation is usually enclosed and vented to the atmosphere through a scrubber or baghouse. Once the paste is wetted, the emission potential is decreased, although some dust may be created by handling and stacking the dried electrode plates.
- (d) The various casting and lead burning operations release lead fumes into the air. Casting at under 1000 °F is considered to produce negligible emissions. Burning operations, on the other hand, do produce fumes, and ventilation hooding along with respirators for workers are used. Similarly, cleaning machines, which prepare stacks of plates for welding, produce lead particulate emissions.

Workers in battery plants are regularly checked for lead intake, and if the lead level in the blood or urine exceeds permissible levels, the worker is transferred to a low-lead area. Emission controls on the atmospheric exhaust are usually placed only on the oxide mill and the paste mixer. Lead fumes and particulate produced in other operations are usually uncontrolled.

The number and relative size of Canadian battery manufacturers in various provinces are listed in Table 20.

TABLE 20 CANADIAN BATTERY MANUFACTURERS (1970) (38)

Province	Number of plants	Value of shipments	
		Thousands of dollars	Percent
Nova Scotia	1	2 772 ^a	4.3
Quebec	3	8 432	13.3
Ontario	11	39 340	61.7
Manitoba	2	5 542 ^a	8.6
Alberta	2	5 542 ^a	8.6
British Columbia	6	2 242	3.5
TOTAL	25	63 870	100.0

^aThese figures were not available from Statistics Canada. Estimates were made by dividing the \$13 856 000 not accounted for in the total by the number of plants.

During the study, 12 of these plants were contacted; however, emission data could be supplied by only one company that did not produce its own oxide. Emissions were reported for the paste mixing operation, from which an emission factor of 0.02 lb lead/ton of lead processed in compound form was calculated. Because a baghouse was used for control, the uncontrolled emission factor for paste mixing becomes 2 lb/ton. Emissions from casting and welding are similar to those produced by melting operations in secondary lead production. As discussed in section 4.5, an uncontrolled emission factor of 0.26 lb lead/ton of lead processed is accordingly applied.

Since approximately half the lead used by battery manufacturers is in lead metal form and half in compound form, these emission factors must be halved when expressed in terms of total lead consumed. The paste mixing factor accordingly becomes 0.01 lb/ton, the melting, casting, and welding factor 0.13 lb/ton, and the total 0.14 lb lead/ton of lead consumed. For those manufacturers making their own oxide, the factor of 0.12 lb/ton given in section 5.2 is halved to produce another emission

factor of 0.06 lb/ton of lead consumed. From the foregoing analysis, emissions given in Table 21 were calculated and summarized as follows.

Source	Emission factor (lb/ton lead consumed)	1970 emissions (tons)
Battery manufacturers		
Oxide purchased	0.14	1.45
Oxide manufactured	0.20	1.98
		<hr/>
TOTAL		3.43

When emissions are uncontrolled, the emission factors given above become 1.13 lb/ton of lead processed when oxide is purchased and 25.1 lb/ton when oxide is manufactured. Emissions consist of lead oxide particles from melting and welding processes and lead oxide, lead sulphate, and lead metal particles from paste-mixing operations.

TABLE 21 LEAD EMISSIONS FROM BATTERY MANUFACTURE (1970)

Province	Plants	Lead consumption ^a (tons)	Lead emissions (tons)
Oxide purchased			
Nova Scotia	1	1 743	0.12
Quebec	2	1 834	0.13
Ontario	9	11 200	0.79
Manitoba	2	3 486	0.25
Alberta	1	1 031	0.07
British Columbia	6	1 415	0.09
		<hr/>	<hr/>
Total		20 709	1.45
Oxide manufactured ^b			
Quebec	1	3 548	0.35
Ontario	2	13 760	1.38
Alberta	1	2 455	0.25
		<hr/>	<hr/>
Total		19 763	1.98
TOTAL	25	40 472	3.43

^aEstimated from questionnaire returns and by dividing the total of 40 472 tons by the number of plants.

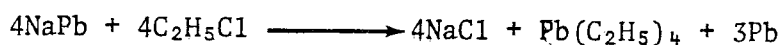
^bPlants reporting oxide manufacture in questionnaire returns.

5.2 Lead Compound Manufacture

The second largest use of lead in Canada is in the manufacture of lead compounds. The principal compounds manufactured and emissions arising from their manufacture are discussed in this section.

5.2.1 Gasoline Additives. Questionnaire replies indicate that approximately 17 800 tons of lead, or 70% of all lead in compound form in 1970, were consumed as alkyl lead gasoline additives. These compounds, tetraethyl lead (TEL), tetramethyl lead (TML), or a combination of the two, raise the octane number of a gasoline, allowing high compression ratios in internal combustion engines without spontaneous fuel ignition or 'knocking' occurring. Lead compounds have performed this task since the 1920's (2).

To make TEL, primary or secondary pig lead is melted and mixed with molten sodium to form a highly reactive lead-sodium alloy, containing about 10% sodium by weight. The solidified alloy, blanketed by nitrogen, is ground and charged to an autoclave at about 160 °F where ethyl chloride is added over a period of a few hours. The TEL compound is formed according to the reaction



The reaction products are discharged from the autoclave into a water-filled batch still, where TEL is transported to a condenser by steam injected into the system. Lead, salt, and some TEL remain as a sludge in the still. Drying the sludge vaporizes the TEL, and lead is separated by heating the sludge in a reverberatory furnace. Molten lead then flows to a melt pot, where lead ingots are added to make up the original volume, and the process is repeated. Recovery of lead is an important economic step, since only about 25% of the lead in the sodium-lead alloy is converted to TEL during the autoclave reaction.

The steam distillation process produces the clear, colourless, oily TEL liquid, which is washed with water and separated by gravity stratification. Chemicals listed in Table 22 are blended with the purified TEL to produce the anti-knock compound, which is analyzed and filtered before being shipped.

To produce TML, a similar procedure is followed, except that the sodium-lead alloy is reacted with methyl chloride in the presence of an aluminium chloride catalyst. Anti-knock ingredients may be formulated from TML alone, from mixtures of TML and TEL (the TELMEL compounds), or from the mixed lead alkyls (MLA) formed by further reacting TEL with TML in the presence of a catalyst. Typical compositions of these various compounds are given in Table 22.

TABLE 22 COMPOSITION OF ANTI-KNOCK ADDITIVES^a (39, 40)

	% by weight				Aviation additive TEL
	Automobile additives				
	TEL	TML	TELMEL	MLA	
Lead alkyl	61.48	50.82	60.41	58.82	61.41
Ethylene dibromide	17.86	17.86	17.86	17.86	-
Ethylene dichloride	18.81	18.81	18.81	18.81	35.68
Orange dye	0.06	0.06	0.06	0.06	0.03
Kerosene, inhibitors	1.79	12.45	2.86	4.45	2.88

^aCompound densities: automobile mixes, 13.2 lb/gal; aviation mixes, 14.5 lb/gal. Lead content (% by weight): automobile mixes, 36.8 - 39.4; aviation mixes, 39.3.

Atmospheric lead emissions from these operations consist of lead particulates from melting and recovering the lead and organic lead vapours from the manufacture, recovery, and storage of alkyl lead compounds.

During the study, questionnaire replies were received from the two plants in Canada that produce anti-knock compounds. The plant at Maitland, Ontario, manufactured TEL compounds only (39), whereas the one at Corunna, Ontario, manufactured the full range of compounds discussed previously (41). Additives were sold directly to petroleum refineries.

From information supplied by these two companies, emissions have been divided into those from the chemical process itself, those carried with general ventilation air, and those emitted from storage tanks.

An average of 83% control was exercised on the process emissions from operation of scrubbers and cyclones. No controls were reported on ventilation air and storage tank emissions. Lead emissions to the atmosphere are accordingly summarized as follows.

Source	Emission factor (lb/ton lead consumed)	1970 emissions (tons)
Manufacturing	6.65	59.2
Building ventilation	0.34	3.0
Storage tanks	0.26	2.3
	—	—
TOTAL	7.25	64.5

On an uncontrolled basis, the manufacturing loss becomes 39.1 lb/ton, and the total emission factor is increased to 39.7 lb lead/ton of lead consumed. Particulate emissions were reported to be lead oxide particles in the 0.1 - 1 μ m diameter range.

An additional emission not discussed elsewhere in this report is the further loss of alkyl lead vapours when transferring the compounds to storage tanks at refineries and, once diluted in the gasoline, to gasoline storage tanks, gasoline tanker trucks, and eventually automobile gas tanks. Allowing four storage tank changes, an additional emission factor of $0.26 \times 4 = 1.04$ lb/ton and corresponding lead emissions of 9.2 tons may therefore be charged to the transport and storage of alkyl lead compounds.

5.2.2 Litharge. Lead oxide (PbO), or litharge, is a reddish-brown powder used by a variety of consumers, including the storage battery, paint, and ceramic industries. It is also the principal starting ingredient in the manufacture of many other lead compounds. Questionnaire replies from two major plants suggest that approximately 9 200 tons of lead as litharge were produced in 1970. This figure does not include the oxide produced by battery manufacturers for their own use.

Two processes are employed to make litharge. The ball mill method involves grinding pieces of lead metal in a mill to produce lead and lead oxide dust. Oxidation is accelerated by the heat of friction

and by the heat generated in the exothermic oxidation reaction. Screening and further milling produces oxide of the desired particle size.

The second method of litharge manufacture, the Barton process, involves melting pig lead and agitating the molten metal in a furnace. This agitation, combined with baffles in the furnace, atomizes the lead into droplets that are oxidized by a forced warm-air stream. The oxide is separated from the air stream by bag filters.

Emissions from litharge manufacture consist of lead oxide and lead metal particulates. Baghouse control on exhaust air is used to trap most of the particulate produced.

During the study, emission data were supplied by a litharge plant in Toronto and one in Winnipeg. Reported emissions from both plants with baghouses of 99.5% efficiency in operation, resulted in an identical emission factor of 0.12 lb lead/ton of lead processed. On an uncontrolled basis, this factor would become 24 lb/ton. According to this information, emissions are summarized as follows.

Source	Emission factor (lb/ton of lead processed)	1970 emissions (tons)
Litharge manufacture	0.12	0.55

Emissions were reported to consist mainly of lead oxide particles under 5 μ m in diameter.

5.2.3 Other compounds. Other important lead compounds include the lead soaps such as lead naphthanate used as driers in paints and as lubricant additives, lead chromates and red oxides used as pigments and protective additives in paints, and lead arsenate used as an insecticide. Others are listed in Table 8.

These compounds are generally manufactured from litharge using standard chemical procedures. Lead arsenate, for example, is produced as a precipitate when arsenic acid is reacted with a water slurry of litharge (42). Similarly, the lead soaps are produced from the reaction between

organic acid and litharge (43). Generally, these processes are wet, and dust emissions are produced only in handling the litharge reagent and in drying, grinding, and packaging the compound product (47).

During the study, the two Canadian manufacturers of lead soaps, the one major manufacturer of lead pigments, and two of the four suppliers of lead arsenate (44) were contacted. From the information supplied, the quantities of compounds manufactured in 1970 are estimated in Table 23. Although this table is not a complete listing of compound consumption, the estimate of 3000 tons of lead consumed in various compound forms other than litharge and lead alkyls is believed to be reasonable.

TABLE 23 LEAD COMPOUNDS CONSUMED IN 1970

Compound	Amount (tons)	Lead content	
		Percent	Tons
Lead arsenate (44, 45)	123	19.5	24
Lead soaps (43, 46, 48)			
Paint driers	500	24	120
Lubricant additives	350	28	98
Lead pigments (47, 48)			
Chrome yellows	1 173	60	705
Chrome orange	59	74	44
Molybdate orange	545	59	322
Chrome green	216	44 ^a	95
White lead carbonate	290	- ^a	465
White lead silicate	282	- ^a	252
Calcium plumbate	12	- ^a	11
Red lead	677	95-98	655
Litharge	51	95 ^a	49
Others	160	- ^a	152
TOTAL	4 638		2 992

^aIn the absence of detailed information, a 95% lead content has been assumed.

Detailed information on atmospheric emissions was supplied by one company. Calculated controlled and uncontrolled emissions based on this single reply are given in Table 24. The indicated controlled emission factor is 0.0075 lb lead/ton processed, whereas on an uncontrolled basis, this figure becomes 1.5 lb/ton. Using the 3000 ton estimate for

the lead content of various chemicals, emissions from manufacturing processes are summarized as follows.

Source	Emission factor (lb/ton lead processed)	1970 emissions (tons)
Lead compound manufacture	0.0075	0.01

Emissions will be in the form of particulates of litharge and the various compounds produced.

TABLE 24 LEAD EMISSIONS FROM COMPOUND MANUFACTURE (1970)

Source	Emission factor ^a	
	Controlled	Uncontrolled ^b
Litharge storing and handling	1.2×10^{-4}	0.024
Spray drier	7×10^{-3}	1.40
Grinding, bagging	3.7×10^{-4}	0.074
TOTAL	0.0075	1.5

^aGiven in pounds of lead per ton of lead processed.

^bCalculated assuming a 99.5% baghouse control efficiency.

5.3 Metal Fabricating Industries

During the study, approximately 150 questionnaire replies were received from plants using lead and lead alloys to produce a variety of metal goods. Common operations described included production of lead alloys in melting pots, manufacture of collapsible tubes, ammunition, and plumbing goods, coating of electrical cables, and casting, grinding, and machining of such lead alloys as brasses and bronzes in foundries. Less common operations included casting of trophy figures, sailboat keels, and electrolytic cell electrodes, use of molten lead baths in metal hardening processes, and casting of lead into vessels or cavity linings for the containment of radioactive isotopes.

Emission data in questionnaire replies were sparse. The majority of plants contacted stated that emissions of lead were nonexistent or negligible and that no emission controls were required. Some indicated that hoods on grinding and machining operations were used for worker protection.

Actual emission figures were supplied by only four plants. As indicated in Table 25, three of these figures were estimates only, and the fourth was calculated from the quantity of solids collected in a baghouse.

On the basis of the little information available, an uncontrolled emission factor of 4 lb lead/ton of lead processed has been assumed for operations involving casting and machining. An additional 7 lb/ton has been used to account for grinding losses. However, these figures are probably overestimated; if they are compared with those calculated for other manufacturing processes such as melting operations in secondary lead refineries, they are much higher than the 0.26 lb/ton factor calculated there.

The emission factors of 0.26, 4, and 11 lb/ton have been applied to the consumption estimates of Table 14 as shown in Table 26. The 11 lb/ton figure has only been used for copper alloys as most of these will be consumed in foundries where grinding will take place. The 4 lb/ton factor has been applied to all other classifications except solder manufacture, where the estimate of 0.26 lb/ton (section 4.5) is believed to be more representative. Uncontrolled fabricating emissions are accordingly summarized as follows.

Source	Emission factor (lb/ton lead consumed)	1970 emissions (tons)
Metal fabricating	0.26 - 11	38.0

Emissions are in the form of lead oxides and metallic dusts from melting, casting, and fabricating. Although the approach used in this section gives a rough approximation at best, the lack of definitive data makes more accurate figures difficult to obtain. Provincial emissions have been estimated in Table 27 from Statistics Canada data on metal fabricating industries.

TABLE 25 LEAD EMISSIONS FROM METAL FABRICATING OPERATIONS (1970)

Industry	Operations	Lead usage ^a (tons)	Controls	Emission factor ^b	
				Controlled	Uncontrolled
Foundry ^c	Alloy melting, casting, machining	35	None	-	30 - 40
Foundry ^c	Alloy melting, casting, machining	2.2	None	-	1.8
Foundry ^c	Alloy melting, casting, machining	0.2	None	-	4.0
Foundry ^d	Melting, casting, machining, grinding	40	Baghouse	0.04	4.0 ^e
			Baghouse	0.07	7.0 ^e

^aLead entering plant as pure lead and alloys.

^bGiven in pounds of lead per ton of lead processed

^cOnly very rough estimates supplied.

^dCalculated from baghouse collection data.

^eCalculated assuming a 99% baghouse efficiency.

TABLE 26 LEAD EMISSIONS FROM METAL FABRICATING INDUSTRIES (1970)

Product	Lead usage (tons)	Emission factor (lb/ton)	1970 emissions	
			Tons	Percent
Semifinished products	9 049	4	18.1	47.8
Solders	5 504	0.26	0.7	1.8
Alloys (babbitts, type, etc.)	3 143	4	6.3	16.6
Cable sheathing	3 066	4	6.1	16.1
Antimony-lead	2 374	4	4.7	12.4
Copper alloys	365	11	2.1	5.3
TOTAL	23 501		38.0	100.0

TABLE 27 METAL FABRICATING INDUSTRIES (1970) (102)

Province	Plants	Value of shipments (\$1000)	Percent	Lead emissions (tons)
Newfoundland	10	7 310	0.2	0.08
Prince Edward Island	6	657 ^a	-	-
Nova Scotia	50	20 561	0.7	0.27
New Brunswick	40	25 598	0.8	0.30
Quebec	959	728 390	23.0	8.74
Ontario	2 066	1 915 275	60.5	23.00
Manitoba	132	95 572	3.0	1.13
Saskatchewan	81	20 554	0.7	0.27
Alberta	229	134 229	4.3	1.63
British Columbia	415	213 564	6.8	2.58
Yukon and N.W.T.	3	329 ^a	-	-
TOTAL	3 991	3 162 039	100.0	38.0

^aStatistics Canada did not supply these figures. Estimates have been made by dividing the \$986 000 unaccounted for in the total by the number of plants.

6 EMISSIONS FROM THE CONSUMPTION OF LEAD PRODUCTS

6.1 Gasoline Combustion

Section 5.2 discussed the manufacture of lead gasoline additives. The behaviour of these additives during gasoline combustion is now studied here. As mentioned in section 5.2, there is some evaporative loss of additives through gasoline handling. However, 98% of lead emissions from gasoline are estimated to have been produced during combustion (11) and these are the losses treated here. Studies of lead in automobile exhaust may be found in References 49 - 56.

During combustion, lead compounds in gasoline are converted to lead oxide. To prevent buildup of oxide in the combustion chamber, scavengers such as ethylene dibromide and ethylene dichloride are included in additive formulations (see Table 22). These chemicals

convert lead oxides into lead halides, predominantly PbClBr and $(\text{NH}_4\text{Cl}) \cdot 2\text{PbClBr}$, which are relatively volatile at engine temperatures. Lead oxides and some organic lead compounds have also been identified in automobile exhaust gases. Because of variations in thermal stability, the distribution of these additives varies with vehicle type and operating conditions (51).

Some of the lead in the combustion products is trapped in the exhaust system of the car. As the car becomes older, these deposits start to flake off to become an additional emission. Other lead particles are trapped in permanent deposits in the engine and exhaust system, and some enter the engine oil (49, 50).

Apparently, then, the quantity, chemical form, and particulate distribution of emissions to the atmosphere vary with the type and condition of the vehicle and with operating conditions. Further variability arises through the method of measurement; for example, samples taken inside the exhaust pipe have a different size distribution than those taken in the ambient air since larger particles tend to settle out. Table 28 illustrates some of the variability in lead emissions. It is difficult to assign a definite percentage of input lead emitted and a definite particle size distribution that will apply to all cars in all cases.

From the data of Table 28 75% of lead in gasoline is assumed to become an atmospheric emission for the purposes of this study. Questionnaire replies from oil companies indicate that lead levels vary from 1.5 to 4.05 g/imp gal, with an average of about 2.8 g/gal. Lead content varies with the oil company involved, grade of gasoline, and elevation (less lead is required at higher elevations). This variation is illustrated in Table 29. Emissions have been estimated using the 75% loss figure and the gasoline consumption data of Table 30.

Although some work on aircraft emissions has been done, emission factors are given in terms of landing and takeoff cycles (32), since these are the major source of lead emissions. However, the 75% average loss figure

used for automobiles has also been applied to emissions from piston-engined aircraft. The average lead content of aircraft gasoline is estimated at 3.58 g/gallon. Following the above approach, emissions are summarized as follows.

Source	Emission factor (lb/ton of lead in fuel)	1970 emissions (tons)
Automobile gasoline	1 500	14 083
Aviation gasoline	1 500	152
TOTAL		14 235

In terms of lead emitted per gallon of fuel burned, the emission factor becomes 0.0048 lb/gal for automobiles and 0.0060 lb/gal for aircraft. In terms of lead emitted per mile of automobile travel, the average gasoline mileage figure of 17.8 miles/gal (78) leads to an emission factor of 2.70 lb / 10 000 miles driven.

TABLE 28 AUTOMOBILE LEAD EMISSIONS (1970)

	Speed	Percentage of input lead emitted
Cruising speed (49) (no acceleration) ^a	25	14
	45	27.6
	60	54.3
All driving conditions		75 (Ref. 49)
		75 (Ref. 50)
	70 - 80	(Ref. 52)
		50 (Ref. 53)
		48 (Ref. 54)
		75 (Ref. 55)
		80 (Ref. 56)
Particle size distribution (% weight) (Ref. 54)		
	>9.0 µm	1.0 µm <0.3 µm
Average	57	25 16

^aDuring acceleration up to 100% may be emitted.

TABLE 29 AVERAGE LEAD CONCENTRATION OF GASOLINE PRODUCED (1970)

Refinery location	Lead content (g/imp gal)		
	Premium	Regular	Low-lead
Maritimes			
Plant 1	3.06	2.51	-
Plant 2	2.90	2.05	-
Plant 3	3.60	2.16	-
Quebec			
Plant 1	3.77	3.46	-
Plant 2	3.60	2.16	-
Plant 3	3.75	2.74	0.41
Plant 4	3.50	3.53	-
Ontario			
Plant 1	2.76	1.92	0.61
Plant 2	3.28	2.78	-
Plant 3	3.62	2.62	-
Plant 4	3.26	2.44	-
Plant 5	4.05	-	-
Plant 6	3.43	2.91	-
Manitoba			
Plant 1	3.60	2.80	-
Plant 2	2.52	2.52	-
Saskatchewan			
Plant 1	3.01	2.08	0.43
Plant 2	3.75	-	-
Plant 3	3.24	2.67	-
Plant 4	3.16	3.12	-
Alberta			
Plant 1	2.43	1.94	0.18
Plant 2	3.60	2.28	-
Plant 3	3.36	2.88	-
Plant 4	3.12	1.81	-
British Columbia			
Plant 1	3.11	1.89	0.16
Plant 2	3.01	2.83	-

TABLE 30 COMBUSTION OF PETROLEUM PRODUCTS IN 1970 (57, 58)

Province	Automobile gasoline (1000 bbl)	Lead emissions (tons)	Aviation gasoline (1000 bbl)	Lead emissions (tons)
Newfoundland	2 348.4	197	49.1	5.2
Nova Scotia	5 600.8 ^a	471	115.0 ^a	12.1
New Brunswick	4 501.3 ^a	378	92.4 ^a	9.7
Prince Edward Island	760.3 ^a	64	15.6 ^a	1.6
Quebec	42 147.8	3 544	157.8	16.6
Ontario	60 957.3	5 125	260.1	27.3
Manitoba	7 795.6	655	165.9	17.4
Saskatchewan	9 864.9	829	61.1	6.4
Alberta	16 590.9	1 395	151.7	15.9
British Columbia	16 448.9	1 383	218.5	23.0
Yukon and N.W.T.	481.6	41	159.5	16.7
TOTAL	167 497.6	14 083	1446.7	151.9

^aStatistics Canada reports only a total figure for the Maritime provinces. Provincial figures have been estimated according to population.

6.2 Soldering

Solder is employed in a variety of applications including, for example, sealing pipe connections in plumbing, sealing seams in tin cans, establishing connection between elements in electrical circuits, and body filling in automobiles. The solder may be purchased in bar, pellet, or wire form, and is applied to a clean fluxed joint by melting. The joint is sealed mechanically and electrically once the solder hardens.

The actual soldering process may be performed manually or automatically. Manual operations usually involve melting the solder around the joint using a torch flame or an electric soldering iron. In electric circuit board work, several connections may be soldered simultaneously by dipping the circuit board into a solder bath. A roller and molten solder bath are used to automatically solder seams in tin cans.

Whatever the operation, emissions are created by melting the solder and buffing the finished joint. During the study, several replies from manufacturers of automobiles, electrical equipment, tin cans, and other items reported consumption of lead in the form of solder. It was generally stated that emissions were negligible, and no controls were required. Seven plants manufacturing tin cans, however, reported that emissions were created during buffing of the soldered seams. Cyclones were used to trap the solder dust, which was then recycled to the solder bath. The efficiency of control was reported to be 99.7% with atmospheric lead emissions varying from 3.2 to 7.0 lb/ton of lead contained in the solder. These seven plants consumed approximately 1320 tons of lead in solder form, a figure that represents almost one-quarter of the total of 5504 tons used in 1970 according to Table 14.

Emissions from the use of solder have been estimated by applying the melting loss of 0.26 lb/ton calculated in section 4.5 to the total of 5504 tons of lead consumed in solder form. An additional buffing loss of 4.1 lb/ton, a weighted average of the numbers reported above, has been applied to one-third of total solder consumption. Emissions are accordingly summarized as follows.

Source	Emission factor (lb/ton)	1970 emissions (tons)
Soldering	0.26	0.7
Joint buffing	4.1	3.8
		—
TOTAL		4.5

No controls are assumed on the soldering operation. As controls of 99.7% efficiency have been reported on the buffing process, the controlled emission factor of 4.1 lb/ton becomes 1370 lb/ton for uncontrolled emissions. Emissions from buffing were reported to be fine metallic solder droplets along with traces of lead oxide. Particle size was reported to be under 20 μm .

6.3 Printing Industry

Newspapers in Canada are produced by either a hot or cold letterpress operation. The cold method, which is gradually capturing most of the market, employs plastic or nylon plates prepared photographically. The hot process, which involves the use of lead alloys, is discussed in this section.

In the composing room, molten lead, maintained at 580 - 600 °F, is cast into lines of type by linotype machines. Individual lines are assembled with headlines and illustrations, which have also been cast into lead, to form a page. A paper-based mat or master is made from the typeset page.

In the stereotype department, the mat is used to produce multiple lead castings or 'stereos' which mount on the printing presses. Stereometal pots maintain molten lead at temperatures of 560 - 580 °F for the casting operation. Although smaller newspapers may use the same alloy for both type and stereometal, larger newspapers usually employ two separate alloys, selected for the desired combination of low melting point, fluidity, hardness, and smoothness of finish. Typical alloy added to typemetal pots might contain 84% lead, 12% antimony, and 4% tin, whereas that for stereometal pots might consist of 80% lead, 14% antimony, and 6% tin. Some questionnaire replies suggested that newly added alloy contains relatively more tin than is contained in the actual molten alloy since tin tends to be lost during use.

In printing operations, these metals are continually recycled. After use, stereos and linotype, along with lead chips and scrap produced during casting, are returned to the melting pots. Periodically, dross containing ink, dirt, and other impurities is skimmed from the surface of the molten lead and sent to secondary lead refiners. Alloy ingots are added as required to make up lost volume.

Depending on the size of the newspaper, molten lead is required for a period of 4 - 8 h daily while the casting operations are performed. Where more than one daily edition is published, however, the melting pots may be operated continuously.

During the study, questionnaires were sent to the 80 newspapers across Canada which were members of the Canadian Weekly Newspapers Association. Information gathered from the 47 replies received is given in Table 31, where the trend away from use of lead is clear. In 1970, only five of the 47 newspapers contacted did not use lead. Either at present or in the near future 35 of the 47 respondents stated that the lead process has been or will be replaced.

Extrapolating from the lead consumption figures given, it is estimated that the 47 newspapers replying to our questionnaire had a total of 905 tons of lead on hand in 1970 with a daily use of 195 tons. Further extrapolation to the total 80 newspapers suggests figures of 1540 tons on hand, with a daily use of 332 tons. The actual amount of lead melted daily will lie somewhere between the total lead available and the amount required in the process. To estimate this figure the 332 tons required has been doubled to give a daily melting estimate of 664 tons. Over a yearly period, assuming six publishing days per week, the lead melted is estimated at 210 000 tons.

Emission data could not be supplied by any of the newspapers contacted. One reported that their lead suppliers estimated emissions varying from 0.5 lb lead/ton melted on an overall basis, to 0.125 lb/ton for each hour the metal is heated. The basis for these estimates is unknown. Lacking definite data, the uncontrolled melting loss emission factor of 0.26 lb/ton calculated in section 4.5 has again been applied. Emissions are accordingly summarized as follows.

Source	Emission factor (lb/ton lead melted)	1970 emissions (tons)
Printing industry	0.26	27.3

Emissions are expected to be mainly in the form of lead oxide fume.

Some newspapers noted in their replies that red inks containing about 2% lead as phloxine pigment were occasionally used. However, the limited and careful use of these inks would indicate negligible lead emissions from this source.

TABLE 31 LEAD USE IN NEWSPAPER PRINTING

Province	Questionnaires		Lead quantity in 1970a (tons)		Number of plants			
					Lead use in 1970		Lead use in 1973 or near future	
	Sent	Returned	On hand	Daily use	Not used	Used	Not used	Used
Newfoundland	3	2	9	4	1	1	1	1
Prince Edward Island	2	0	-	-	-	-	-	-
Nova Scotia	5	3	26	5	0	3	3	0
New Brunswick	4	4	38	8	1	3	3	1
Quebec	9	3	145	28	0	3	3	0
Ontario	34	23	445	103	2	21	16	7
Manitoba	4	2	33	39	0	2	2	0
Saskatchewan	3	2	39	7	0	2	1	1
Alberta	7	3	106	22	0	3	3	0
British Columbia	9	5	54	8	1	4	3	2
	—	—	—	—	—	—	—	—
TOTAL	80	47	905	195	5	42	35	12

^aEstimated from incomplete data in many questionnaire replies.

Provincial lead emissions from the printing industry have been calculated from Statistics Canada data. These figures are also given in Table 32.

TABLE 32 PRINTING EMISSIONS (1970) (102)

Province	Plants	Shipments (\$1000)	Lead emissions	
			Percent	Tons
Newfoundland	26	5 917	0.4	0.11
Prince Edward Island	7	1 360 ^a	0.1	0.03
Nova Scotia	74	18 231	1.2	0.32
New Brunswick	48	12 425	0.9	0.25
Quebec	1 053	426 917	28.7	7.84
Ontario	1 583	774 718	52.0	14.19
Manitoba	187	63 423	4.3	1.17
Saskatchewan	121	21 407	1.4	0.38
Alberta	225	58 544	3.9	1.07
British Columbia	321	104 383	7.0	1.91
Yukon and N.W.T.	5	977 ^a	0.1	0.03
TOTAL	3 650	1 488 302	100.0	27.3

^aThese figures were not supplied by Statistics Canada. Estimates were made by dividing the \$2 331 000 unaccounted for in the total by the number of plants, and computing provincial totals.

6.4 Insecticide Application

As mentioned in section 5.2, 112 tons of lead arsenate containing 24 tons of lead were used in Canada in 1970 (45). This compound was sold as dust or wettable powder and was supplied to control a variety of insects in orchards and field crops (42, 44).

Emission data for pesticide application were not available. Clearly, however, some of the insecticide will eventually enter the air, soil, and water and some will remain as a residue on the plant. In the absence of detailed information, 25% of the lead applied is assumed to

enter the atmosphere. Provincial emissions are based on the farm income figures of Table 33, and total Canadian emissions are summarized as follows.

Source	Emission factor (lb/ton of contained lead)	1970 emissions (tons)
Insecticide application	500	6

TABLE 33 LEAD EMISSIONS FROM INSECTICIDE APPLICATION (1970) (103)

Province	Farm Income ^a (\$1000)	Lead emissions	
		Percent	Tons
Newfoundland	700 ^b	2.0	0.12
Prince Edward Island	555	1.6	0.10
Nova Scotia	716	2.1	0.13
New Brunswick	705	2.1	0.13
Quebec	7 397	21.6	1.30
Ontario	10 323	30.2	1.81
Manitoba	2 784	8.1	0.48
Saskatchewan	4 348	12.7	0.76
Alberta	4 530	13.2	0.79
British Columbia	2 178	6.4	0.38
TOTAL	34 236	100.0	6.0

^aFruit and vegetable sales only.

^bEstimated from Nova Scotia and New Brunswick figures.

6.5 Paint Manufacture and Use

The paint industry consumed approximately 120 tons of lead in the form of lead soaps for latex emulsions and 2750 tons of lead in various pigments in 1970 (see Table 23). Pigments are received in a powder and are dispersed in a vehicle by grinding or milling to produce a paint.

Lead soaps are employed in liquid form, and so are unlikely to result in atmospheric emissions.

Questionnaire replies from paint manufacturers contained little emission information. The Canadian Paint Manufacturer's Association (59) estimated a 1% manufacturing loss of lead, but the fraction entering the air was not available. Generally, replies stated that emissions were negligible, and that adequate control equipment such as hoods connected to scrubbers and cyclones were used.

One company did, however, supply atmospheric emission figures. The calculated emission factor was 0.03 lb lead/ton of lead consumed, with a scrubber of 98% efficiency used for control. The corresponding uncontrolled factor becomes 1.5 lb/ton. Using the lead consumption of 2750 tons indicated earlier, lead emissions from paint manufacture are summarized as follows.

Source	Emission factor (lb/ton contained lead)	1970 emissions (tons)
Paint manufacture	0.03	0.04

Emissions are in the form of pigment dust lost during handling of the dry powder. Once the paint is mixed, however, the further release of lead through the final manufacturing steps and packaging and application of the paint will be negligible.

7 INADVERTENT LEAD EMISSIONS

In this section, lead emissions from sources not connected with the production or consumption of lead will be examined. Trace quantities of lead present in various materials are the main source of these emissions.

7.1 Coal Combustion

Most coals contain small amounts of lead that are retained in the ash, probably as lead oxide, during combustion (60). Studies carried out in the United States have found lead concentrations in coal to vary

from 0.6 ppm for Wyoming coals to 33.1 ppm for Missouri coals; concentrations in coal ash vary from 7 to 279 ppm. Ash content of the coals analyzed varied from 7 to 15.5% (61). Ontario Hydro, which uses mostly imported West Virginia coals, has measured a lead level of 71± 4 ppm in fly ash, which corresponds to a 6.4 ppm concentration in coal (62). These figures compare with American data for West Virginia coals, viz. 4.9 ppm in coals and 58 ppm in coal ash (61). Alberta Power Ltd. have indicated that the coal being used at the Battle River Generating Station contains 9.2 ppm lead, and the ash contains 138 ppm lead (63). At the Wabamum River plant, 6.98 ppm lead in coal has been measured (64).

For the purposes of the report, the Ontario Hydro figures of 6.4 ppm lead in coal and 71 ppm lead in fly ash have been used. That fraction of fly ash which escapes pollution control equipment is therefore assumed to carry 71 ppm lead into the atmosphere.

Reported coal consumption in 1970 was 29 657 827 tons of which 18 863 779 tons were imported from the United States (65, 66). Provincial consumption figures are subdivided into use by thermal power plants, coke producers, and others in Table 34. Nationally, power plants accounted for 51% and coke producers 32% of consumption; other users made up the remaining 17% (65).

7.1.1 Thermal Power Plants. During the study, power companies across Canada were contacted to determine the nature of their control equipment and their estimate of particulate emissions. From the figures quoted, fly ash emissions and corresponding lead releases were computed. When particulate emission figures were not available, EPA emission factors (32) for particulate emissions during coal combustion were used making allowance for the ash content of the coal and the control equipment reported. Lead emissions from thermal power plants are given in Table 35 and are summarized as follows.

Source	Emission factor (lb lead/1000 tons coal)	1970 emissions (tons)
Thermal power plants	9.9	9.4

The emission factor of 9.9 lb lead/1000 tons of coal burned is an average of the uncontrolled emission given in Table 35, weighted by the amount of coal consumed.

TABLE 34 COAL CONSUMPTION IN 1970 (65, 66)

Province	Consumption (tons)			Total
	Thermal power	Coke ^a	Other	
Newfoundland	-	-	17 100	17 100
Prince Edward Island	-	-	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	6 320 800	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
Unaccounted for				1 136 650
TOTAL	15 199 471	7 910 000	5 344 706	29 657 827

^aMajor producers only (98% of total production).

TABLE 35 LEAD EMISSIONS FROM POWER PLANTS (1970)

Province	Coal consumption (tons)	Control efficiency ^a (% removal)	Uncontrolled emissions		Controlled emissions (tons)
			Emission factor (lb/1000 tons coal)	Emissions (tons)	
Nova Scotia (67)	609 362	One plant, 98.5% Others, N.C.	14.6	4.4	1.6
New Brunswick (68)	125 000	N.C.	22.4	1.4	1.4
Ontario (69)	8 486 426	Average 97.5%	10.5	44.3	1.1
Manitoba (70)	555 000	Average 70%	7.6	2.1	0.6
Saskatchewan (71)	2 170 638	Average 70%	7.9	8.5	2.6
Alberta (63)	3 253 000	Average 85%	8.7	14.2	2.1
Weighted average			9.9	Total	9.4

^aAbbreviations: N.C., no control.

7.1.2 Coke Production. Coke production involves heating suitably cleaned and sized coal in a low oxygen atmosphere, driving off volatile matter, and leaving a porous carbonaceous product. The glowing coke is pushed from the oven with a ram and quenched with water (72). Emissions occur during charging of coal into the ovens, during heating through oven leakage, and during removal and quenching of the finished coke. Few controls are now used in coking operations (32).

Of the total 5 668 219 tons of coke produced from 8 092 379 tons of coal in 1970, approximately 80% was used in the blast furnace production of pig iron, 5% was exported, and the remaining 15% was used in foundries as fuel and in other metallurgical processing (65, 66).

Although the fate of lead in coal during coking has apparently not been studied, from its behaviour during combustion it seems reasonable that the lead will remain in the coke and in the particulate emissions. As coke production figures indicate that 1.42 tons of coal are required to make 1 ton of coke, the lead content of coke is estimated at 6.4 ppm (Pb in coal) \times 1.42 = 9.1 ppm. Assuming this figure to apply also to the particulate emissions, lead from coking has been computed from EPA data, which suggests an emission of 3.5 lb particulate/ton of coal charged (32). Coking emissions are accordingly summarized as follows.

Source	Emission factor (lb lead/1000 tons coal)	1970 emissions (tons)
Coke production	0.032	0.13

In terms of pounds of lead per 1000 tons of coke produced, the emission factor becomes 0.045.

7.1.3 Other Uses. Lacking definite information, it has been assumed that no emission controls are used in the combustion of coal by numerous relatively small consumers. From EPA data (32) about 20 lb/ton of particulates containing 71 ppm lead are accordingly assumed to be lost to the atmosphere. On this basis emissions are summarized as follows.

Source	Emission factor (lb lead/1000 tons coal)	1970 emissions (tons)
Other uses of coal	1.42	3.76

7.2 Oil Combustion

Data on lead concentrations in oil are sparse. Fancher (73) reports 0.3 ppm based on limited studies, whereas questionnaire replies from Canadian oil companies indicate 5.0 ppm (74) to 6.0 ppm (75) in residual fuels and only 8 ppb in distilled fuels. These figures are consistent with the idea that heavy metals concentrate in the heavy oil fractions during distillation (76). One source of lead in refineries is litharge used in the Doctor treating process to remove sulphur contaminants such as lead sulphide from oil. This process has generally been replaced by non-lead processes in Canadian refineries. Crude oil naturally contains traces of lead, estimated at 2-10 ppb (74, 77).

From the limited data available, emissions have been computed assuming that only heavy fuel oil contains traces of lead from natural sources and that all the lead is lost during combustion. Using a lead concentration figure of 6 ppm and the consumption data of Table 36, emissions are summarized as follows.

Source	Emission factor (lb lead/1000 tons oil)	1970 emissions (tons)
Heavy oil	12	105.4

Using an oil density of 7.88 lb/U.S. gal (32) and the definition of 1 bbl as 42 U.S. gal produces an emission factor of 1.98 lb lead/1000 bbl burned.

TABLE 36 LEAD EMISSIONS FROM OIL COMBUSTION (1970)

Province	Heavy oil consumption (58) (1000 bbl)	Lead emissions (tons)
Newfoundland	5 988.0	5.9
Prince Edward Island	1 228.1 ^a	1.2
Nova Scotia	8 837.0 ^a	8.7
New Brunswick	7 138.1 ^a	7.0
Quebec	45 743.6	45.3
Ontario	27 473.1	26.8
Manitoba	986.4	1.0
Saskatchewan	475.1	0.5
Alberta	510.7	0.6
British Columbia	8 351.8	8.3
Yukon and N.W.T.	114.2	0.1
TOTAL	106 846.1	105.4

^aOnly a total figure for the Maritimes was given by Statistics Canada. Provincial figures have been estimated according to population.

7.3 Wood Combustion

As indicated in Table 12, wood contains trace amounts of lead. Human activities have been shown, however, to influence concentrations measured in wood; for example, Danielson (52) quotes figures showing that annual rings in an elm tree between 1865 and 1870 contained a lead concentration of 0.16 ppm, whereas over the 1956 - 1959 period, this concentration had increased to 0.74 ppm. British Columbia Douglas and balm fir growing near a road in Stanley Park contain 350-1400 ppm lead in the ash (52).

For the purposes of this study, a figure of 100 ppm lead in wood ash has been taken as representative. This figure was computed by using a 500 ppm value for the Stanley Park measurements and dividing by 5 to account for the effect of human activities as recorded in the elm tree

measurements. The 100 ppm figure may require modification on the basis of future measurements on wood from trees in remote locations.

Major sources of wood particulates in Canada are forest fires, slash burning operations carried out by the lumber industry, and wigwam burners used by the lumber industry for the disposal of wood waste. Lead emissions from these sources have been estimated from the particulate emission data reported by Environment Canada (78) assuming a 100 ppm lead concentration in the particulate. For slash burning and forest fires, an emission factor of 17 lb of particulate per ton of wood burned has been estimated; therefore, the lead emission factor becomes 1.7×10^{-3} lb lead/ton of wood burned. Similarly, an 11 lb/ton particulate estimate for wigwam burners results in a lead emission factor of 1.1×10^{-3} lb/ton of wood.

Using the figures given in Table 37, lead emissions to the atmosphere from wood combustion are summarized as follows.

Source	Emission factor (lb lead/1000 tons wood burned)	1970 emissions (tons)
Forest fires	1.7	35.73
Slash burning	1.7	6.26
Wigwam burners	1.1	4.39
TOTAL		46.38

7.4 Sewage Sludge Incineration

Trace amounts of lead have been measured in sewage sludges. A British study reported that 86% of 42 dried sludges analyzed had lead concentrations in the 100 - 1000 ppm range, where the mean concentration was 820 ppm (79). Dried sludges from three treatment plants in Ontario had a mean lead level of 611 ppm (80). In an American study, lead levels of 2740 ppm in dried sludge and 6040 ppm in ash from sludge incineration have been recorded (81). These data are consistent with the idea that

TABLE 37 LEAD EMISSIONS FROM WOOD COMBUSTION (1970) (78)

Province	Wood burned (1000 tons)			Lead emissions (tons)
	Forest fires	Slash burning	Wigwam burners	Total
Newfoundland	3 404.4	170.0	7.5	3 581.9
Prince Edward Island	-	-	2.9	2.9
Nova Scotia	122.1	332.0	220.3	674.4
New Brunswick	233.9	-	325.4	559.3
Quebec	2 528.1	2638.8	3265.5	8 432.4
Ontario	2 291.0	1529.3	768.8	4 589.1
Manitoba	8 550.2	32.4	34.7	8 617.3
Saskatchewan	6 903.2	121.1	86.2	7 110.5
Alberta	2 676.2	97.2	347.6	3 121.0
British Columbia	7 188.3	2444.9	2919.7	12 552.9
Yukon and N.W.T.	8 141.7	-	-	8 141.7
TOTAL	42 039.1	7365.7	7978.6	57 383.4

lead is retained in the ash and particulates during combustion, probably as lead oxide. The relatively high levels of lead and other heavy metals in sludges are of concern in all methods of sludge disposal.

To estimate lead emissions from this source, the three Canadian municipalities which operate incinerators, Toronto, London, and Winnipeg, were contacted by questionnaire. Measurements had only been made at the Toronto incinerator. These indicated a lead level of 1430 ppm in the dried sludge (80). Particulate control equipment consisting of cyclones of 65% efficiency and wet plate impingement scrubbers of 97.9% efficiency were reported (82).

From information collected, lead emissions have been calculated assuming the lead concentration in particulates and ash to be 2.2 times that in the dried sludge. This factor was obtained from American data. A weighted average of Canadian sludge measurements produced a lead level of 895 ppm in dried sludge. The ash and particulate levels accordingly become $895 \times 2.2 = 1970$ ppm, which, with the uncontrolled emission factor of 21 lb particulate/ton of wet sludge burned, calculated from the data reported by London (83), results in an uncontrolled lead emission of 0.0415 lb lead/ton of wet sludge burned. Using the tonnages listed in Table 38, the uncontrolled lead emission factor and actual 1970 emissions are estimated as follows.

Source	Emission factor (lb lead/1000 tons sludge)	1970 emissions (tons)
Sewage sludge incineration	41.5	2.17

7.5 Refuse Incineration

Table 39 illustrates that typical refuse contains approximately 8% metals, of which tin cans make up a sizeable fraction (84). Since lead is used in soldering tin cans, as well as in the manufacture of toothpaste tubes, paint enamels etc., refuse may be assumed to contain some traces of lead. If metal separation is employed before incineration, the lead level will decrease. However, no metal separation processes were reported at Canadian incinerators in 1970.

TABLE 38 LEAD EMISSIONS FROM SEWAGE SLUDGE INCINERATION (1970)

City	Sludge burned ^a (tons)	Particulate emissions (lb/ton of sludge)	Lead emissions (tons)
Toronto	36 500	4.2 ^b	0.15
London	57 400	21 ^c	1.19
Winnipeg	40 000 ^d	21 ^{c, d}	0.83
TOTAL	133 900		2.17

^aIncluding moisture (usually 80-85% by weight of sludge).

^bCyclones and scrubbers used for control. An overall efficiency of 80% has been assumed.

^cNo controls.

^dAssumed value. No questionnaire reply received.

A study of six incinerators in the United States identified an average of 44.3 ppm lead in the refuse, with a range of 10.1 - 91.1 ppm. Fly ash measurements revealed a range of 26.8 - 51.9 ppm lead, with an average of 36.9 ppm (85). A study done on a Toronto incinerator found that 0.5% of the total particulate emissions was in the form of lead (82). This figure suggests that fly ash contains 5000 ppm lead.

The Toronto figure appears to be more realistic based on the amount of lead in refuse. Empty tin cans, for example, contain 1.6% lead by weight in the form of solder (86) and, from Table 39, they alone would contribute $0.066 \times 0.016 = 1050$ ppm lead to refuse. From other combustion data, the level in ash and particulates is expected to be two or three times higher. Accordingly, the 5000 ppm lead level in particulates has been used in this report. The lower United States figures may describe emissions when metal separation is practised, although this was not stated in the report.

Information on quantities of refuse incinerated and on particulate emissions was gathered by sending questionnaires to cities across Canada.

TABLE 39 TYPICAL MUNICIPAL REFUSE COMPOSITION (84)

Component	% by weight
Paper	
Newsprint	3.5
Cardboard	8.1
Other	24.8
	<hr/>
Total	36.4
Organics	25.0
Wood	19.9
Metals	
Ferrous	0.8
Cans	6.6
Coloured	0.8
	<hr/>
Total	8.2
Glass	7.2
Rock and rubble	3.6
Textiles	2.5
Plastic	1.7
Tires	0.5
	<hr/>
TOTAL	100.0

Where no figures were reported, estimates made in Reference 84 have been used. The information obtained is given in Table 40.

To compute the lead emissions, the EPA uncontrolled particulate emission figure of 30 lb particulate/ton of refuse burned (32) has been used in conjunction with the 5000 ppm lead content figure, making allowance for the appropriate control equipment. Questionnaire replies generally indicated that water spray baffles were used for particulate control. (A teepee burner is used in Charlottetown; with no control, its emission factor is 60 lb particulate/ton of refuse burned.) The estimated efficiency of these devices is 60% (32). Using an uncontrolled emission factor and controlled emission figures, lead emissions from refuse incineration are summarized as follows.

Source	Emission factor (lb/1000 tons refuse)	1970 emissions (tons)
Refuse incineration	150	58.26

These emissions are expected to be in the form of lead oxide particulate.

TABLE 40 LEAD EMISSIONS FROM REFUSE INCINERATION IN 1970

City	Refuse burned (1000 tons)	Lead emissions (tons)
Charlottetown, P.E.I.	26.0 ^a	3.9 ^b
Dartmouth, N.S.	26.0	0.29 ^c
Halifax, N.S.	88.4	2.65 ^d
Montreal, Que.	898.0 ^a	26.94 ^d
Quebec, Que.	45.0 ^a	1.35 ^d
Toronto, Ont.	547.9	16.44 ^e
Winnipeg, Man.	105.7	3.17 ^e
Regina, Sask.	51.7	1.55 ^e
Edmonton, Alta.	65.8	1.97 ^e
TOTAL	1 554.5	58.26

^aEstimates taken from Reference 84.

^bTeepee burner with no control.

^cEfficiency of particulate control of 85% reported.

^dControls of 60% efficiency assumed.

^eWater spray baffle equipment reported. Estimated particulate removal efficiency is 60%.

7.6 Liquid Waste Incineration

The two liquid wastes that may both contain lead which are disposed of by incineration are industrial liquid effluents and used engine oil. Data on incineration of industrial effluents were not available. However, the incineration of waste oil is probably the most

significant source of emissions. Therefore only waste oil incineration will be considered here.

Three privately owned liquid waste incinerators are known to operate in Canada. These are located in Montreal, Mississauga, and Sarnia. At these locations, both industrial wastes and waste oils are incinerated. In many places across Canada, waste oils are also mixed with residual oil and burned as a fuel. This practice is banned in the four western provinces because of danger of explosion of trapped gasoline, but it is apparently common in other areas of the country (87).

Information on the quantities of waste oil incinerated is not available, although a joint study currently underway by the major Canadian oil companies may soon provide figures (88). Alternatively, the order of magnitude of lead emissions from this source can be estimated from the data of Hirschler (49). These measurements indicate that 3% of the lead contained in gasoline enters the engine oil, whereas an additional 9.7% is trapped in the oil filter. Using the 1970 gasoline consumption figures of section 6.1, approximately 530 tons of lead have been calculated to enter engine oil in 1970. Taking an average fuel economy of 17.8 miles/gal of gasoline (78) and assuming that a car with an oil capacity of 1 gal has an oil change every 6000 miles, a lead concentration of about 1% by weight in waste oil is indicated.

An uncontrolled emission factor for waste oil incineration can be computed by assuming that all the contained lead is lost to the atmosphere, giving a factor of 20 lb lead/ton of oil burned, 0.084 lb/imp gal burned, or 2.94 lb/bbl burned. In the absence of definite data, total 1970 emissions have been estimated assuming that 25% of all waste oil is burned. Although this figure may be questioned, significant quantities of waste oil are known to be recovered by chemical treatment for re-use, whereas large amounts are also used for suppressing road dust.

From the above figures lead emissions from waste-oil incineration are estimated in Table 41 and are summarized as follows.

Source	Emission factor (lb lead/ton oil)	1970 emissions (tons)
Waste-oil incineration	20	134

TABLE 41 LEAD EMISSIONS FROM WASTE-OIL COMBUSTION (1970)

Province	Lubricating oil consumption (58) (1000 bbl)	Percent	Lead emissions (tons)
Newfoundland	129.7	3.8	5.1
Prince Edward Island	19.9 ^a	0.6	0.8
Nova Scotia	115.0 ^a	3.4	4.6
New Brunswick	143.0 ^a	4.2	5.6
Quebec	1024.2	30.2	40.4
Ontario	1933.9	57.0	76.4
Yukon and N.W.T.	28.6	0.8	1.1
TOTAL (FOR SEVEN PROVINCES) ^b	3394.3	100.0	134

^aStatistics Canada reports a total Maritime figure only. Estimates have been made according to population.

^bThe use of waste oil as a fuel is illegal in Manitoba, Saskatchewan, Alberta, and British Columbia (87).

7.7 Zinc Production

As zinc is produced from a combined lead-zinc ore, some lead is retained in the zinc concentrate produced during milling (see section 4.2). Depending on the ore processed and the efficiency of the flotation process, the zinc concentrate may contain 0.02 - 1.5% lead. This lead can be released during zinc recovery.

At three of the four zinc recovery plants in Canada (89) conventional processes are used. These involve roasting the concentrate to convert zinc sulphide to oxide, followed by sulphuric acid leaching to produce a zinc solution from which zinc can be recovered electrolytically.

The zinc metal is then melted and cast into ingots (35. 90). The fourth plant used the Imperial smelting process to recover lead and zinc simultaneously (33). As emissions from the Imperial smelter were discussed in section 4.3, they will not be included here. Besides these four plants, there are two concentrate-roasting operations that ship pelletized roasted concentrate.

Atmospheric lead emissions from zinc recovery are confined mainly to concentrate unloading, handling, and roasting. The industry generally maintains effective dust controls, commonly using bag filters on ventilation air from conveyors, storage bins, and transfer points. Hot roaster exhaust gases must be treated for particulate removal before recovery of sulphur oxide to make sulphuric acid. Gases are usually cooled in waste heat boilers with cyclones and electrostatic precipitators used in series to remove the particulate material. Efficiencies in dust control of 98% were reported.

Information on lead emissions from roaster operations was provided in questionnaire replies by all three metallurgical plants. Controlled emission factors were calculated to vary from 0.028 to 0.22 lb lead/ton of zinc produced. Most of this variation can be attributed to variations in the lead content of the zinc concentrates treated. In terms of pounds of lead per ton of lead processed, the factors given above only vary from 10 - 15 lb/ton with an average, weighted by zinc production, of 12 lb/ton.

These figures seem rather high considering the degree of control exercised by the industry. However, an explanation has been furnished by analyses of the dust collected from the control equipment. It is apparent both from questionnaire replies and from the data of References 91 and 92 that the lead content of smelting particulates increases as the particle size decreases. Accordingly, the 98% degree of control does not apply to the lead particles, many of which are small enough to pass through the cyclones and precipitators.

From the foregoing analysis and production figures presented in Table 42, lead emissions from zinc production in 1970 are summarized as follows.

Source	Emission factor (lb lead/ton lead)	1970 emissions (tons)
Zinc production	12	37.3

Emissions consist of lead sulphide and lead oxide particles. The majority, however, are lead oxide particles with diameters under 5 μ m.

TABLE 42 LEAD EMISSIONS FROM ZINC PRODUCTION (1970)

Location	Zinc production (89) (tons)	Lead content (tons)	Lead emissions (tons)
Belledune, N.B.	36 100	-	See section 4.3
Valleyfield, Que.			
Total	124 100	170.3 ^b	1.0
Roaster operations	-	330.3 ^b	2.0
Port Maitland, Ont. ^a	-	825.0 ^b	4.9
Flin Flon, Man.	78 622	904.7	5.4
Trail, B.C.	221 600	4 000.0 ^b	24.0
TOTAL	460 422		37.3

^aRoaster operations only.

^bEstimates based on mine data.

7.8 Copper and Nickel Production

Just as in zinc recovery, traces of lead in copper and nickel concentrates result in an atmospheric emission of lead during nickel and copper recovery. Copper, nickel, and copper-nickel smelters have been considered together in this report because the basic pyrometallurgical steps involved are similar and many of the smelters in Canada produce both these metals in the same plant. Lead emissions are therefore difficult to separate into emissions from copper production and nickel production.

Metal recovery begins by roasting the concentrate in multiple-hearth, fluidized bed, sintering machine, or rotary kiln roasters to drive off sulphur as sulphur oxides and to convert metal sulphides to oxides. The roaster product is then smelted with a silica flux at 1450 - 2500 °F to produce a matte which contains the metals, and a slag which contains most of the impurities. Blast, reverberatory, flash-smelting, or electric furnaces may be used. Smelter matte is further treated in a converter in which air is blown through the liquid matte to convert sulphur and iron impurities to oxides. Sulphur oxides pass off as a gas, while the iron oxides combine with a silica flux to form a slag. The finished or "bessemer" matte from the converter is made up of impure copper, nickel, or a copper-nickel combination, which is separated into copper and nickel. These impure metals are sent to refineries where they are cast into electrodes and refined electrolytically. Trace quantities of precious metals are also recovered in the refining operation (94).

Lead emissions are produced primarily during roasting, smelting, and conversion. Detailed studies of the behaviour of lead and other trace metals at copper and copper-zinc smelters have been published (91, 92). Typical figures for a copper smelter show that lead makes up 0.6% by weight of dryer dusts, 1.5% of roaster dusts, 4.9% of reverberatory furnace dusts, and 21.2% of converter dusts. On a total flow basis, 14.1% by weight of particulate generated is lead (92).

The seven nickel, copper, and copper-nickel smelters in Canada are described in Table 43. During the study, questionnaire replies were received from six of these plants. Lead emissions varying from 5.8 to 2020 tons were reported for 1970, with computed emission factors varying from 82-910 lb lead/ton of lead processed in the concentrate.

These emission factors are relatively high considering that a full range of control equipment including cyclones, scrubbers, precipitators, and bag filters was generally employed. From data supplied in References 91 and 92, the lead content of smelter dusts apparently increases with decreasing particle size. Therefore the overall particulate collection efficiency of a piece of equipment cannot be applied to lead particulate,

since the high percentage of lead particulates of small diameter is not collected efficiently. An electrostatic precipitator, for example, collected 96.2% of lead particulate in roaster gases, 48.7% in reverberatory furnace gases, and only 13% in converter gases (91).

Table 43 lists lead emissions from Canadian copper, nickel, and copper-nickel smelters. The effective degree of control on lead particulate has also been calculated by dividing the controlled emission factor by the uncontrolled estimate made earlier from EPA data. Based on the foregoing analysis, the uncontrolled lead emission factor and actual lead emissions in 1970 are summarized as follows.

Source	Emission factor (lb lead/ton contained lead)	1970 emissions (tons)
Copper, nickel, copper-nickel smelters	82-910	2437

Emissions were reported to be in the form of lead oxide particulates under 5 μ m in diameter.

7.9 Iron and Steel Production

Trace amounts of lead in the raw materials may be released to the atmosphere during iron and steel production. Iron smelting is similar to other smelting processes described in earlier sections. Iron ore is roasted to produce a porous iron oxide sinter. Sinter material, limestone, and coke are then smelted in either blast or electric furnaces to produce pig iron.

Steel is basically an alloy of iron, carbon, manganese, and smaller amounts of other elements. It is produced by treating pig iron with limestone, iron oxide, and scrap iron and steel in a basic oxygen, open-hearth, or electric furnace. These furnaces raise the temperature of the charge, expelling impurities as a gas or a slag. Steel of the desired properties is produced by alloying the purified pig iron with such elements as manganese, chromium, and silicon added as ferromanganese,

TABLE 43 LEAD EMISSIONS FROM COPPER, NICKEL, AND COPPER-NICKEL SMELTERS (1970)

Location	Product	Production ^a (tons)	Lead emissions (tons)	Emission ^b factor	Control ^c efficiency (%)
Noranda, Que.	Copper	210 900	2020	910	0
Murdochville, Que.	Copper	69 800	59 ^e	-	-
Sudbury, Ont. ^d	Copper, nickel	-	305	437	60
Falconbridge, Ont.	Copper-nickel	-	11	-	-
Thompson, Man.	Nickel	-	6	200	82
Flin Flon, Man.	Copper	42 816	36	82	93
TOTAL			2437		

^aOnly copper figures available in Reference 93.^bExpressed in pounds of lead per ton of lead contained in the concentrates processed.^cOne minus controlled emission factor divided by EPA uncontrolled factor.^dTwo smelters (Coniston and Copper Cliff).^eEstimated from Flin Flon data since no questionnaire reply received.

ferrochromium, and ferrosilicon, which are alloys of the desired element with iron.

Some data on lead emissions from iron and steel plants have been published. A study of 48 plants in the United States found that the percentage by weight of lead in particulate emissions constituted 0.4% in basic oxygen furnaces, 0.8% in open-hearth furnaces, and 2.0% in electric furnaces (95). A study of a Canadian operation indicated that sintering particulate emissions were 4% by weight lead, that pig iron electric furnace particulates were 4% by weight lead, and that particulates from a basic oxygen furnace were 0.13% lead (35).

Some data on lead emission from ferroalloy production were also obtained. Particulates emitted from an electric furnace producing ferromanganese contained 0.9% lead, and for silicomanganese 0.45% (96).

To estimate lead emissions from the iron and steel industry, EPA emission factors (32) have been applied in conjunction with lead percentages given above and with iron, steel, and ferroalloy production figures. The calculations made are presented in Tables 44 and 45. Uncontrolled lead emission factors and controlled 1970 lead emissions from the iron and steel industry are summarized as follows.

Source	Emission factor (lb lead/ton metal processed)	1970 controlled emissions (tons)
Iron production	4.68	2319
Steel production	0.14 - 0.18	142
Ferroalloy production	0.9 - 1.4	71
TOTAL		2532

Source	Metal ^a processed (1000 tons)	Emission factor ^b			Control ^e efficiency (%)	Lead emissions (tons)	
		Particulate ^c	Percent ^d			Uncon- trolled	Controlled ^e
			lead	Lead			
IRON PRODUCTION							
Sintering	9086	42	4.0 ^f	1.68	80 ^h	7 640	1528.0
Blast furnace	8518	75 ^f	4.0	3.0	99 ^h	12 750	705.7
Electric furnace	568	75	4.0	3.0	90	850	85.0
STEEL PRODUCTION							
Basic oxygen furnace	3618	46	0.4	0.18	97.5	325	8.13
Open-hearth furnace	6906	17	0.8	0.14	85 ⁱ	484	105.7
Electric furnace	1630	9	2.0	0.18	80	147	29.0
FERROALLOY PRODUCTION (98, 99)							
Ferrosilicon (100)	117	200 ^f	0.45 ^g	0.9	20	53	42.1
Others	51	200 ^f	0.79	1.4	20	36	28.6
TOTAL							2532.0

^aIron production figures of Reference 98 indicate furnaces operating at 80% capacity.

^bUncontrolled pounds per ton of metal processed.

^cAverage of EPA estimates (32).

^dCombination of results from Canadian (35) and U.S. (95) studies.

^eControl efficiency assumed from Reference 104.

^fAssumed value in the absence of published data.

^gAverage of U.S. figures on ferrosilicon and ferromanganese production (95).

^hNova Scotia control 50% (104).

ⁱNova Scotia control 0% (104).

TABLE 45 IRON AND STEEL INDUSTRY IN CANADA (1970) (97, 99, 102)

Location	Capacity (1000 tons) per year)	Percent of total	Controlled* emissions (tons)
IRON FURNACES*			
Sydney, N.S.	875	31.9	738.6
Sorel, Que.	465	3.7	85.6
Hamilton, Ont.			
Plant 1	1 650	13.1	303.2
Plant 2	3 800	30.1	698.0
Sault Ste. Marie, Ont.	2 335	18.5	429.0
Port Colbourne, Ont.	240	1.9	44.1
Kimberley, B.C.	110	2.8	20.2
Total	9 475	100.0	2318.7
STEEL FURNACES*			
Newfoundland	60	0.4	0.5
Nova Scotia	1 123	31.2	44.5
Quebec	656	3.7	5.3
Ontario	10 535	60.3	86.1
Manitoba	239	1.4	2.0
Saskatchewan	150	0.8	1.2
Alberta	168	0.9	1.4
British Columbia	222	1.3	1.8
Total	13 153	100.0	142.8

* Same controls as in Table 44.

7.10 Ferrous Foundries

In iron foundries, castings are made from molten pig and scrap iron produced in a furnace charged with layers of metal, coke, and flux (32). Lead emissions result from lead impurities contained in the raw materials.

On an uncontrolled basis, 17 lb particulate are produced per ton of metal processed (32). Studies in the United States have shown that the lead content of these particulates varies from 0.5 to 2.0% by weight, averaging 1.2% (96). The uncontrolled lead particulate emissions accordingly become 0.2 lb lead/ton of metal processed.

To calculate lead emissions, the emission factor estimated above has been used with the reported consumption of 1.16 million tons of iron by iron foundries in 1970 (97). A control efficiency of 80% has been assumed. The uncontrolled emission factor and controlled emissions are given in Table 46 and are summarized as follows.

Source	Emission factor (lb lead/ton metal processed)	1970 emissions (tons)	
		Uncontrolled	Controlled
Iron foundries	0.2	116	23.2

No data on lead emissions from steel foundries were available. However, as both particulate emissions and levels of lead in the raw materials of steel foundries are relatively low, lead emissions are expected to be small.

7.11 Cement Manufacture

Portland cement manufacture involves mixing measured quantities of finely ground limestone, silica, alumina, and iron oxide. The powdered mixture is calcined in long sloping kilns, and the clinker thus produced is ground and mixed with gypsum to form the finished cement powder (32, 101). Trace quantities of lead in the raw materials and fuels used may be released to the atmosphere during processing.

EPA uncontrolled emission estimates in the U.S. vary from 234 lb particulate/ton of cement produced using the wet method of production to 340 lb/ton for the dry process (32). Approximately 450 ppm lead have been measured in the particulates (96). Uncontrolled lead emission factors therefore become 0.11 lb lead/ton of cement produced by the wet process, and 0.15 lb/ton for the dry process.

To estimate lead emissions from cement manufacture, controlled particulate emissions as reported by Environment Canada have been used in conjunction with the 450 ppm lead level. Particulate figures, listed in Table 47, have been calculated assuming that the wet process accounts for 65% of Canadian cement production and that 92% of cement plants have controls of 80 - 95% efficiency (78). Lead emissions from cement

TABLE 46 LEAD EMISSIONS FROM IRON FOUNDRIES (1970)

Province	Plants	Value of shipments (1000 dollars)	Percent	Lead emissions (tons)	
				Uncontrolled	Controlled ^a
Newfoundland	1	299 ^b	0.1	0.1	0.02
Nova Scotia	3	897 ^b	0.4	0.5	0.1
New Brunswick	3	897 ^b	0.4	0.5	0.1
Quebec	35	32 436	15.5	18.0	3.6
Ontario	59	151 272	72.4	84.0	16.8
Manitoba	5	4 378	2.1	2.4	0.48
Saskatchewan	1	299 ^b	0.1	0.1	0.02
Alberta	6	8 456	4.1	4.7	0.94
British Columbia	13	10 190	4.9	5.7	1.14
TOTAL	126	209 124	100.0	116.0	23.2

^a Assumed control of 80% (104).

^b 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.

manufacture are given in Table 47 and are summarized, along with uncontrolled emission factors, as follows.

Source	Emission factor (lb lead/ton cement produced)	1970 emissions (tons)
Cement manufacture	0.11 - 0.15	111.5

On an uncontrolled basis, lead emissions would increase to 513 tons. The emission data given in Table 47 therefore assume an average degree of control for the industry of approximately 78%.

TABLE 47 LEAD EMISSIONS FROM CEMENT MANUFACTURE (1970)

Province	Lead emissions (tons)	
	Particulate (78)	Lead
Newfoundland	14 544	6.6
Nova Scotia	2 437	1.1
New Brunswick	3 460	1.6
Quebec	65 103	29.3
Ontario	128 529	57.8
Manitoba	7 219	3.3
Saskatchewan	3 578	1.6
Alberta	8 683	3.9
British Columbia	14 130	6.3
TOTAL	247 683	111.5

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