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INVENTORY OF EMISSIONS FROM MUNICIPAL, HOSPITAL AND SEWAGE SLUDGE INCINERATORS IN BRITISH COLUMBIA (1982)

Regional Manuscript Report MS 87-01

By

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JANUARY 1987

ABSTRACT

This report presents the results of an inventory of hospital, municipal and sewage sludge waste incinerators operating in British Columbia during the base year 1982. A questionnaire was distributed during the summer of 1983.

The nature of the refuse, type of incinerator, and other pertinent data required for the compilation of an emissions inventory was determined for each incinerator investigated. This information was then employed to generate estimates of atmospheric emissions from these point sources.

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF FIGURES

LIST OF TABLES

SUMMARY

Of the 153 public hospitals operating in B.C. during 1982, 47 were found to have had a functional incinerator. No private hospitals utilized on-site incineration as a means of waste disposal/reduction. The hospital incinerators were categorized as follows: 10 single chamber units; 26 multiple chamber units; and 11 controlled air units.

There were seven municipal refuse incinerators and one sewage sludge incinerator operating during 1982. Six of seven municipal refuse units were controlled air models (specifically Consumat C-760's), the Powell River municipal unit was a single chamber model, and the Lulu Island sewage sludge incinerator was found to be a fluidized bed type.

An extensive literature search established representative emission factors for the primary contaminants (TSP, SO_2, NOx, CO, HC) as well as for HCl. These factors were employed to generate estimated emissions of the above mentioned contaminants, based on the mass of refuse incinerated in each respective incinerator model. In total, 42,003 tonnes of various categories of waste were estimated to have been incinerated during 1982, giving rise to approximately 4,650 tonnes of primary contaminant emissions emitted to the atmosphere. These composite results are presented in the following table. More detailed analyses of this data is given throughout the text of this report. While these estimated emissions afford good ballpark figures, Carotti and Smith, 1974 suggest that during shutdown and startup operations, incinerator units do not operate at design capacity and incinerator efficiencies may be low. Thus emissions during these one or two hour periods may possibly equal or exceed weekly total emissions. This suggestion was not incorporated when calculating emissions, but is probably not without basis.

Emissions of toxic contaminants (selected trace orgnaic compounds and heavy metals) from refuse incineration was also investigated. Because of the wide variance in combustion dynamics (i.e. temperature, residence time) between even similar units over time and the direct impact which this has on toxic contaminant formation, no existing emission factors were considered

suitable for the purposes of this report. Therefore, for the most part, rather than attempting to estimate toxic contaminant emissions, emission factors from recent stack sampling programs and reports have been presented.

SUMMARY OF ESTIMATED EMISSIONS

INCINERATOR MODEL	# OF UNITS	TONNES OF REFUSE INCINERATED (A)	TONNES OF PRIMARY CONTAMINANT* EMISSIONS (B)	PRIMARY POLLUTANT FORMATION (B/A x 100)
Single Chamber - Hospital	10	285.4	96.2	33.7%
Multiple Chamber - Hospital	26	4,128.3	65.1	1.6%
Controlled Air - Hospital	11	1,085.3	12.4	1.1%
Single Chamber - Municipal	1	13,209.0	4,362.3	33.0%
Controlled Air - Municipal	6	20,770.0	98.0	0.5%
Fluidized Bed - Municipal	1	2,525.0	11.1	0.4%
TOTAL	55	42,003.0	4,645.1	11.0%

* Primary Contaminants include: TSP, NOx, SO_2, CO, HC, HCl

1 INTRODUCTION

As part of the Nationwide Inventory of Emissions of Air Contaminants (NIEAC) an inventory of hospital waste, municipal waste and sewage sludge incinerators operating in B.C. during 1982 was undertaken. In view of the increased popularity of incineration as a means of waste reduction, the nature of airborne emissions from these sources is of current interest.

The mass and composition of waste, the incinerator model, and other relevant information was determined for each plant considered. This data was then combined with emission factors in order to estimate emissions of various contaminants.

The results are presented in two parts. In the first section, emphasis is placed on the five primary contaminants; particulates, sulphur dioxide, nitrogen oxides, hydrocarbons and carbon monoxide. Due to the high chlorinated plastic (ie. PVC) content of much of today's refuse, hydrogen chloride emissions were also of primary concern. As these contaminants have been previously studied in detail, a high degree of confidence may be placed in the emission factors applied within this group. Projected emissions of these major contaminants have been compiled and reported.

The second section deals with emissions of some of the more "exotic" and toxic contaminants; selected trace organic compounds, including dioxins and furans, and heavy metals. No conclusive, generally accepted emission factors exist for these substances, thus actual emissions were not calculated in most cases. However, recent stack sampling results are summarized and preliminary emission factors are presented.

Appendix 1 gives a brief description of the various incinerator models encompassed within this study, as well as their individual combustion characteristics.

2 METHODOLOGY

Data required for this study was primarily obtained via a mailed questionnaire (Appendix 2) and through telephone conversations. Suitable emission factors were determined through an extensive literature search.

2.1 Hospital Incinerators

Lists of all the public and private hospitals operating in B.C. in 1982 were obtained from the British Columbia Health Association and from the British Columbia Association of Private Care Facilities respectively. Each hospital with more than 50 beds was contacted by telephone to initially identify those which had an incinerator operating in 1982. A detailed questionnaire was then mailed as required.

2.2 Municipal and Sewage Sludge Incinerators

The names and locations of municipal waste and sewage sludge incinerators in B.C. were obtained from the Ministry of Environment's Waste Management Branch and from EPS registry files. This data base proved sufficient to provide the necessary information regarding the 7 operating municipal waste incinerators in the province. The lone operating sewage sludge incinerator at Lulu Island in Richmond was contacted and visited directly.

3 PRIMARY CONTAMINANTS

"Primary contaminants" usually refers to a group of pollutants which include particulates, sulphur dioxide, oxides of nitrogen, carbon monoxide, and hydrocarbons. Hydrogen chloride was also viewed as a primary contaminant in this report. Established (legislated) criteria exist either federally and/or provincially for these parameters with the exceptions of hydrocarbons and HCl. The applicable ambient air quality objectives and guidelines are given in Table 1.

A thorough review of existing emission factors was conducted to assure that the values applied here were representative of the type of incinerator being used and of the nature of the waste being burned. The factors which were ultimately arrived at for the various incinerator models and subsequently utilized are presented in Table 2.

3.1 Auxiliary Fuel

Many incinerators use oil as auxiliary fuel either for "start up" or to maintain desirable combustion temperatures during incineration. This situation was investigated to determine SO_2 formation from this source.

In B.C., number 2 diesel oil (the most common auxiliary fuel) contains about 0.02% sulphur. Material balance calculations (Appendix III) showed this SO_2 contribution to be minor compared to that sulphur dioxide which is generated from the combustion of waste itself. As well, SO_2 from auxiliary fuel was likely accounted for in existing SO_2 emission factors.

3.2 Municipal Waste Incinerator Emission Factors

Abundant emission factor data has been published by various regulatory agencies, including previous studies by the EPS. Of particular value to this report was a series of EPS studies conducted on the Consumat 760 (controlled air) municipal incinerator at Lake Cowichan, Vancouver Island, which reported emission factors for all primary contaminants. As six of seven municipal waste incinerators in B.C. are Consumat 760's, a high degree of integrity is placed in the primary emission factors associated with these units. A HCl emission factor of 1.8 Kg/tonne for municipal Consumat

TABLE 1 AIR QUALITY OBJECTIVES AND GUIDELINES FOR PRIMARY CONTAMINANTS

AIR CONTAMINANT	TIME BASE	UNITS	GOVERNMENT OF CANADA AIR QUALITY OBJECTIVES			BRITISH COLUMBIA AIR QUALITY GUIDELINES AND OBJECTIVES		
			Maximum Desirable Level	Maximum Acceptable Level	Maximum Tolerable Level	Desirable Level	Interim Level	Maximum Level
Sulphur Dioxide	1 hour	ug/m^3	450	900	-	450	900	-
		ppm	0.17	0.34	-	0.17	0.34	-
	3 hour	ug/m^3	-	-	-	375	665	-
		ppm	-	-	-	0.14	0.25	-
	24 hour	ug/m^3	150	300	800	160	260	-
		ppm	0.06	0.11	0.31	0.06	0.10	-
	1 year arith. mean	ug/m^3	30	60	-	25	75	-
		ppm	0.01	0.02	-	0.01	0.03	-
Carbon Monoxide	1 hour	ug/m^3	15000	35000	-	14300	28000	35000
		ppm	13	30	-	13	25	30
	8 hour	ug/m^3	6000	15000	20000	5500	11000	14300
		ppm	5	13	18	5	10	13
Nitrogen Dioxide	1 hour	ug/m^3	-	400	1000	-	-	-
		ppm	-	0.21	0.53	-	-	-
	24 hour	ug/m^3	-	200	300	-	-	-
		ppm	-	0.11	0.16	-	-	-
	1 year arith. mean	ug/m^3	60	100	-	-	-	-
		ppm	0.03	0.05	-	-	-	-
Suspended Particulate Matter - (Total)	24 hour	ug/m^3	-	120	400	150	200	-
	1 year geo. mean	ppm	60	70	-	60	70	-

TABLE 2 EMISSION FACTOR SUMMARY SHEET - PRIMARY CONTAMINANTS (UNITS KG PER TONNE OF WASTE)

INCINERATOR TYPE	PART	SO2	NOx	CO	HC	HCl (HOSPITAL)	HCl (MUNICIPAL)
Consumat 760 (Municipal)	1.45	(0.75)	(1.6)	(NEG)	(NEG)	--	1.8
Consumat 760 (Hospital)	0.88	(0.75)	(1.6)	(NEG)	(NEG)	8.3	--
Single Chamber	11.9	1.25	0.5	300	15	8.3	(1.8)
Multi Chamber	2.2	1.25	1.1	1.8	1.0	8.3	(1.8)
Pathological	4.0	NEG	1.5	NEG	NEG	(NEG)	--
Controlled Air (Not Consumat 760)	0.9	0.75	1.6	NEG	NEG	8.3	1.4
Fluidized Bed (Air Pollution Controlled)	1.5	0.4	2.5	NEG	0.5	NA	NA
Fluidized Bed (Lulu Island Sewage Sludge)	1.08	1.8	1.04	NEG	0.5	NA	NA
Multiple Hearth Sewage	(1.5)	(0.4)	(2.5)	NEG	(0.5)	NA	NA

( ) = indicates value extrapolated from other incinerator type
NEG = < 0.01
NA = no accurate value available
factors from references: 1; 5; 9; 10; 11; 13; 17; 19

760's was derived from a chlorine material balance (Appendix IV), wherein it was assumed all available chlorine formed HCl. McColgan, 1977 states that on average about 50% of chlorine present in the waste feed would form HCl, hence our factor may overestimate HCl emissions.

The remaining municipal incinerator, which is not a controlled air model, is located at Powell River. It was also manufactured by Consumat, but is of an earlier rudimentary design, being a single chamber, batch loaded, pit type. The emissions estimated from this unit were based on the U.S. EPA's single chamber incinerator emission factors (20).

Total estimated emissions of primary contaminants from municipal incinerators are presented in Table 3, and individual plant emissions are given in Table 4.

TABLE 3 PRIMARY CONTAMINANT EMISSIONS, 1982 (units are tonnes)

SOURCE	PART.	SO_2	NOx	CO	HC	HCl	TOTAL
Hospital (1)	13.5	6.4	6.4	93.1	8.5	45.6	173.5
Municipal (2)	187.3	32.2	21.2	3960.0	198.0	61.1	4459.8
Sewage Sludge (3)	2.7	4.5	2.6	NEG	1.3	N.A.	11.1
TOTALS	203.5	43.1	30.2	4053.1	207.8	106.7	4644.4

NEG - emission factor < 0.01 kg/tonne
N.A. - not available
(1) emissions based on 5,499 tonnes refuse incinerated
(2) emissions based on 33,979 tonnes refuse incinerated
(3) emissions based on 2,525 tonnes sewage sludge incinerated

3.3 Hospital Waste Incinerator Emission Factors

The available data base regarding emissions from this source was not as extensive as was the case with municipal incinerators. Additionally,

many different models, each requiring its own emission factors were encountered during this phase of this study.

For the larger controlled air incinerators, it was prudent to apply the results of studies undertaken by EPS at the Royal Jubilee Hospital (RJH) in Victoria. These reports provided good data on emissions of primary contaminants from hospital waste incineration, and also on hospital waste generation per bed-day. The waste generation data allowed for the estimation of the amount of waste produced and later burned at those hospitals which could not supply an estimation of their waste volume.

A HCl emission factor of 8.3 Kg/tonne was taken from another RJH study (3). Many hospitals sort portions of their waste prior to incineration and therefore may not have the same plastic component as the RJH. Thus it is possible that this HCl factor may overestimate chlorine emissions from some hospital units, but it was assumed to be more representative than the municipal factor.

For hospitals not having a controlled air incinerator similar to the Consumat 760, the U.S. EPA's emission factors for municipal waste incinerators were applied, according to incinerator type. While these values may not be as accurate as those utilized for municipal waste incineration, they do afford good baseline estimates.

Estimated 1982 primary contaminant emissions from hospital units have been compiled and are presented in Table 3. Individual hospital emissions are found in Table 5 which also arranges the hospital units according to B.C. MOE regional boundaries, and gives the regional and provincial totals.

3.4 Sewage Sludge Incinerator Emission Factors

There is currently only one operating sewage sludge incinerator in B.C. It is located at Lulu Island in Richmond, and employs a fluidized bed combustion process. As source testing data was available for this plant no externally generated emission factors were required. Estimated 1982 emissions from this source are presented in Table 2.

TABLE 4 PRIMARY CONTAMINANT EMISSIONS - INDIVIDUAL MUNICIPAL UNITS, 1982
(units are tonnes)

INCINERATOR-SITE	PART.	SO_2	NOx	CO	HC	HCl	TOTAL
Kent (Agazzis)	2.6	1.4	2.9	NEG	NEG	3.3	10.2
Koksilah (Duncan)	18.8	9.7	2.1	NEG	NEG	2.3	53.6
Meade Creek - 3 units (Cowichan Lake)	3.4	1.8	3.8	NEG	NEG	4.3	13.3
Pearless Road (Ladysmith)	5.2	2.7	5.8	NEG	NEG	6.5	20.3
Powell River	157.2	16.5	6.6	3960	198	24.0	4362.3
TOTALS	187.2	32.1	21.2	3960	198	61.1	4459.7

NEG - emission factor < 0.01 kg/tonne

NOTE: emissions based on 33,979 tonnes refuse incinerated

TABLE 5 PRIMARY CONTAMINANT EMISSIONS - INDIVIDUAL HOSPITAL UNITS, 1982 (1)
(units are tonnes)

HOSPITAL	Part	SO_2	NOx	CO	HC	HCl	TOTAL
VANCOUVER ISLAND DISTRICT							
Campbell River & District (A)	.52	.06	.02	13.14	.66	.36	14.76
Cowichan District (B)	.08	.05	.04	.07	.04	.3	.58
Nanaimo Regional General (A)	.05	.01	NEG	1.31	.07	.04	1.48
Royal Jubilee (C)	.61	.52	1.1	NEG	NEG	5.72	7.95
St. Joseph's General (B)	NEG	NEG	NEG	NEG	NEG	NEG	.01
Trillium Lodge (A)	NEG	NEG	NEG	.02	NEG	NEG	.03
West Coast General (A)	NEG	NEG	NEG	.01	NEG	NEG.	.02
DISTRICT TOTALS	1.27	.65	1.17	14.56	.78	6.43	24.86
LOWER MAINLAND							
Burnaby General (C)	NEG	NEG	NEG	NEG	NEG	.02	.03
Delta (C)	.01	.01	.02	NEG	NEG	.11	.16
Health Sciences Centre (B)	.22	.12	.11	.18	.10	.82	1.55
Lions Gate (C)	1.37	.79	.68	1.12	.62	5.15	9.73
Louis Brier Home (B)	.05	.03	.02	.04	.02	.17	.33
Richmond General (B)	.03	.02	.02	.03	.01	.12	.23
St. Mary's (Sechelt) (B)	.06	.03	.03	.05	.03	.21	.41
St. Paul's (C)	.01	.01	.02	NEG	NEG	.10	.15
Shaughnessy (C)	.12	.10	.20	NEG	NEG	1.06	1.49
Vancouver General (C)	.08	.07	.15	NEG	NEG	.76	1.06
Chilliwack General (B)	.01	NEG	NEG	.01	NEG	.03	.06
Langley Memorial (B)	NEG	NEG	NEG	NEG	NEG	.01	.02
Maple Ridge (C)	.01	.01	.02	NEG	NEG	.10	.15
M.S.A. General (C)	.02	.02	.05	NEG	NEG	.21	.31
Mission Memorial (A)	.61	.06	.03	15.33	.77	.42	17.22
Peace Arch District (B)	.28	.16	.14	.23	.13	1.06	2.0
Royal Columbian (C)	.04	.03	.07	NEG	NEG	.36	.51
St. Mary's (New West) (B)	.07	.04	.04	.06	.03	.27	.51
Surrey Memorial (B)	NEG	NEG	NEG	NEG	NEG	NEG	.01
Coloney Farm (B)	5.89	3.35	2.94	4.82	2.68	22.21	41.89
DISTRICT TOTALS	8.89	4.85	4.55	21.88	4.4	33.19	77.76

NEG = < .01 Tonne
(1) emissions based on 5,499 tonnes refuse incinerated
NOTE: columns may not add correctly due to rounding
(A) Single Chamber Unit
(B) Multiple Chamber Unit
(C) Controlled Air Unit

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TABLE 5 Continued

HOSPITAL	Part	SO_2	NOx	CO	HC	HCl	TOTAL
KOOTENEY							
Cranbrook and District (B)	.05	.03	.03	.04	.02	.20	.37
Kimberley and District (A)	.31	.03	.01	7.8	.39	.22	8.76
Kootenay Lake District (B)	.20	.11	.1	.16	.09	.76	1.42
Trail Regional (A)	1.72	.18	.07	43.10	2.16	1.21	48.44
DISTRICT TOTALS	2.28	.35	.21	51.1	2.66	2.39	58.99
CARIBOO							
G.R. Baker Memorial (A)	NEG	NEG	NEG	.04	NEG	NEG	.05
Cariboo Memorial (B)	.06	.03	.03	.05	.03	.21	.41
DISTRICT TOTALS	.06	.03	.03	.08	.03	.21	.46
SKEENA							
Bulkley Valley District (B)	.01	NEG	NEG	.01	NEG	.02	.05
Burns Lake and District (C)	.02	.01	.03	NEG	NEG	.15	.21
Mills Memorial (B)	.07	.04	.04	.06	.03	.27	.51
Prince Rupert Regional (B)	.24	.14	.12	.20	.11	.91	1.72
DISTRICT TOTALS	.34	.20	.19	.26	.15	1.36	2.49
OMINECA-PEACE							
Dawson Creek and District (B)	.01	.01	.01	.01	.01	.05	.10
Fort St. John General (A)	.03	NEG	NEG	.77	.04	.02	.86
Pouce Coupe Community (A)	.16	.02	.01	4.11	.21	.11	4.62
Prince George Regional (C)	.04	.03	.07	NEG	NEG	.38	.53
St. John (B)	NEG	NEG	NEG	NEG	NEG	.01	.02
DISTRICT TOTALS	.25	.06	.09	4.89	.26	.57	6.13

NEG - < 0.01 Tonne
(1) - emissions based on 5,499 tonnes refuse incinerated
NOTE: columns may not add correctly due to rounding
(A) Single Chamber Unit
(B) Multiple Chamber Unit
(C) Controlled Air Unit

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TABLE 5 **Continued**

HOSPITAL	Part	SO_2	NOx	CO	HC	HCl	TOTAL
OKANAGAN							
Vernon Jubilee (B)	.04	.02	.02	.03	.02	.15	.29
Kelowna General (B)	.01	.01	.01	.01	.01	.05	.09
Penticton Regional (B)	.33	.19	.17	.27	.15	1.25	2.35
South Okanagan General (B)	.01	NEG	NEG	.01	NEG	.02	.05
DISTRICT TOTALS	.39	.22	.2	.32	.18	1.47	2.78
B.C. TOTALS	13.48	6.36	6.44	93.09	8.46	45.62	173.47

NEG - < 0.01 Tonne
(1) - emissions based on 5,499 tonnes refuse incinerated
NOTE: columns may not add correctly due to rounding
(A) Single Chamber Unit
(B) Multiple Chamber Unit
(C) Controlled Air Unit

4 TOXIC CONTAMINANTS

The toxic contaminants encompassed here are important for their potential or proven detrimental health and environmental effects. For this study selected trace organic compounds and heavy metals were treated as toxic contaminants. There is currently no federal legislation with regard to ambient air concentrations of the organic species dealt with below. However, the B.C. MOE has published Ambient Air Control Objectives for heavy metals, which are presented in Table 6.

4.1 Organic Compounds

Numerous organic compounds may be formed during incomplete combustion. Chlorine in the refuse may be liberated during combustion and subsequently facilitate the formation of a number of chlorinated organic compounds, some of which are extremely toxic. The chlorinated organic species under consideration here include dioxin and furan, and polychlorinated biphenyls (PCBs).

Unchlorinated organic compounds are also possible products of incomplete combustion. A general group of hydrocarbons, the polycyclic aromatic hydrocarbons (PAHs), will be briefly discussed.

4.1.1 Dioxin and Furan. Dioxin and Furan are the generic terms used when referring to any of the possible 75 species of polychlorinated dibenzo-p-dioxin (PCDD), and 135 species of polychlorinated dibenzofuran (PCDF). Unfortunately the public now frequently associates the term "dioxin" specifically with 2,3,7,8-TCDD, the most toxic PCDD congener. This may raise unwarrented public concern in some instances because while some of these organic compounds have proven to be extremely toxic, others have yet to demonstrate their envirmonmental significance.

Toxicity is dependant upon the location of the bonding sites occupied by chlorine. The PCDD's and PCDF's which have chlorine on three or four of their lateral bonding sites have shown the greatest toxicity (3). Individual toxicities are highly variable amongst closely related isomers. Rappe, 1984 states that LD_{50} results may vary by a factor as large as 10^3 to 10^4 between 2,3,7,8-TCDD and 1,2,3,8-TCDD.

TABLE 6 B.C. MOE HEAVY METAL AMBIENT AIR CONTROL OBJECTIVES (2)

PARAMETER*	RANGE (ug/m^3)	
Antimony (Sb)	0.1	0.5
Arsenic (As)	0.1	1.0
Beryllium (Be)	0.005	0.1
Cadmium (Cd)	0.05	0.3
Chromium (Cr)	0.05	0.1
Copper (Cu)	0.25	2.5
Lead (Pb)	1.0	2.5
Mercury (Hg)	0.1	1.0
Molybdenum (Mo)	0.1	2.5
Nickel (Ni)	0.01	0.1
Selenium (Se)	0.1	0.5
Vanadium (V)	0.05	1.0
Zinc (Zn)	1.0	2.5

* total gaseous and particulate

The most toxic dioxin and furan congeners are given in Table 7.

TABLE 7 MOST TOXIC DIOXIN AND FURAN (3)

Dioxin	Furan
2,3,7,8-tetra-CDD	2,3,7,8-tetra-CDF
1,2,3,7,8-penta-CDD	1,2,3,7,8-penta-CDF
1,2,3,4,7,8-hexa-CDD	2,3,4,7,8-penta CDF
1,2,3,6,7,8-hexa-CDD	2,3,4,6,7,8-hexa-CDF
1,2,3,7,8,9-hexa CDD	1,2,3,4,7,8-hexa CDF

While stack sampling analyses in North America, Europe, and Asia have shown trace amounts of PCDD and PCDF in incinerator emissions, the origin of these compounds remains a somewhat controversial subject. Two main theories have evolved.

The most likely scenario is that PCDD and PCDF are formed from precursor compounds in the waste which become chlorinated during combustion.The other theory is that the dioxin and furan exist in the refuse itself and are simply liberated during combustion. Although dioxin and furan sometimes do exist as impurities in some herbicides, chlorophenols, and other related compounds, it seems unlikely that dioxin in raw refuse are the source of dioxin emissions from solid waste incineration.

4.1.2 Dioxin and Furan Emission Factors. Hart, 1984 suggests that combustion conditions, and not refuse composition (although this may affect combustion dynamics), are the main factors in PCDD and PCDF formation. When waste was spiked with three times the previous amount of PVC, thereby increasing chlorine content, no significant difference in dioxin levels was detected.

Therefore, it may not be erroneous to apply dioxin and furan emission factors developed from EPS tests conducted at the R.J.H. incinerator (3) (Consumat 760) to municipal incinerators, provided that they are of a similar controlled air design. Although the R.J.H. results provide recent stack sampling data, the emission factors derived from this study remain of

limited value because: 1) they are not isomer specific, 2) organic sampling of this nature is still developing, 3) these factors may only be applied to controlled air models and 4) various sampling programs have indicated that while daily emissions may be fairly constant, there is most likely wide monthly and seasonal variation. With this in mind, dioxin and furan emission factors are presented in Table 8, and estimated emissions from the six B.C. municipal Consumat 760 incinerators are given in Table 9. Note that no traces of the dioxin tetra-CD homologue (the most toxic) were detected during the R.J.H. study.

4.1.3 PCDD and PCDF Emission Controls. Hart, 1984 proposes these to be the optimum combustion conditions for the destruction of PCDD and PCDF:

1) minimum of 1 to 2 seconds gas residence time at a temperature of 900° to 1000°C;
2) very turbulent conditions in the high-temperature zone;
3) an air/fuel mixture with a slight excess of oxygen.

Assuming the above to be correct, then all units which are not of a controlled air design are therefore likely to have greater dioxin and furan emission factors than those presented in Table 8. This may be significant with regard to other model sites, which burn large volumes daily (i.e. Powell River Municipal Incinerator).

TABLE 8 DIOXIN AND FURAN EMISSION FACTORS (1)
(from Hospital Incinerator, Controlled Air Unit)

HOMOLOGUE	EMISSION FACTOR (ug/Kg)	
	Dioxin	Furan
Tetra CD	N.D.	0.3
Penta CD	0.2	0.6
Hexa CD	0.2	0.6
Hepta CD	0.2	0.3
Octa CD	0.3	0.2
Total PCD	0.9	2.0

(1) calculated from emission rate (ie. ug/hr), ref. 3
N.D. - < 0.5 ng/hr during source testing

TABLE 9 PCDD AND PCDF EMISSIONS, 1982 (Municipal Controlled Air Incinerators) (units are grams)

HOMOLOGUE	INCINERATOR SITE								TOTAL	
	KOKSILAH		PEERLESS		MEADE CR.		KENT			
	PCDD	PCDF	PCDD	PCDF	PCDD	PCDF	PCDD	PCDF	PCDD	PCDF
Tetra CD	N.A.	3.9	N.A.	1.1	N.A.	0.7	N.A.	0.5	N.A.	6.2
Penta CD	2.6	7.8	0.7	2.2	0.5	1.4	0.4	1.1	4.2	12.5
Hexa CD	2.6	7.8	0.7	2.2	0.5	1.4	0.4	1.1	4.2	12.5
Hepta CD	2.6	3.9	0.7	1.1	0.5	0.7	0.4	0.5	4.2	6.2
Octa CD	3.9	2.6	1.1	0.7	0.7	0.5	0.5	0.4	6.2	4.2
TOTAL	11.7	25.9	3.2	7.2	2.1	4.7	1.6	3.6	18.7	41.5

N.A.- compound not detected (< 0.5 ng/hr) during source testing

NOTE: estimated emissions based on 20,770 tonnes waste incinerated

4.2 Polychlorinated Biphenyls (PCBs)

PCBs have been identified in both municipal and hospital incinerator emissions. O'Connell, 1979 suggests their presence probably results from incomplete combustion of trace PCBs in the waste feed.

While PCBs have not yet been empirically identified as human carcinogens they remain a suspected carcinogenic agent in humans and are controlled under the Environmental Contaminants Act. While considerable stack analysis has been conducted for these types of organics no widely accepted emission factors exist thusfar. Table 10 presents crude PCB emission factors for both hospital and municipal units. Due to the lack of confidence in these figures, no attempt has been made to estimate PCB emissions.

TABLE 10 PCB EMISSION FACTORS

INCINERATOR TYPE	EMISSION FACTOR (mg/Tonne)
Municipal	65.0 (ref. 15)
Hospital (Consumat 760)	29.2 (ref. 3)

4.3 Polynuclear Aromatic Hydrocarbons (PAHs)

Incomplete combustion of carbonaceous fuels (ie. refuse) may also give rise to yet another family of potentially dangerous organics, the unchlorinated aromatic compounds. Those of interest in this report are frequently grouped together as the polynuclear (polycyclic) aromatic hydrocarbons (PAH).

The potential mutagenic and/or carcinogenic qualities of some of these compounds (i.e. Benzo(A)Pyrene) have been recognized for some time, but as is the case with dioxin individual toxicity varies greatly amongst group members.

Although PAHs have been well documented, analytical stack sampling procedures are still evolving. As with most other "toxic" contaminants, quantitative analysis is not yet perfected due to the extremely minute amounts being tested for, commonly sub ppb (parts per billion).

The amount of conclusive data on PAH emissions from waste burning is very limited and most likely does not represent the actual situation accurately. Emission factors based on preliminary EPS and EPA reports are presented in Table 11. Again, as not much confidence may be placed in these factors, no attempt has been made to estimate actual PAH emissions.

4.4 Heavy Metals

Heavy metals (ie. lead, cadmium, mercury) pose significant health hazards when their environmental presence rises above natural background levels. Their extreme toxicity has been well documented for some time. Atmospheric lead concentration is presently a high priority topic for both the Canadian and American governments, resulting in the somewhat controversial lead in gasoline phase-down programs currently being pursued by both countries.

Emission factors for 14 heavy metals are reported in Table 12. These are based on results of EPS stack sampling of the sewage sludge incinerator at Lulu Island and of the incinerator at the Royal Jubilee Hospital. Municipal waste factors are supplied from EPA studies.

TABLE 11 PAH - EMISSION FACTORS

COMPOUND	MUNICIPAL (1) (multi-chamber) ug/Kg	HOSPITAL (2) (Consumat 760) ug/Kg
Benzo(A)Anthracene & Chrysene	3.1	N.A.
Chrysene & Tripheylene	N.A.	9.1
Benzo(A)Fluoranthene & B(J)F & B(K)F	1.4	N.A.
Benzo(B)Fluoranthene & B(K)F	N.A.	7.3
Benzo(A)Fluorine	N.A.	5.8
Benzo(G,H,I)Perylene	1.6	N.D.
Benzo(A)Pyrene & B(E)P	0.8	5.0
Benzo(A)Pyrene	N.A.	N.D.
Benzo(E)Pyrene	N.A.	5.0
Fluoranthene	4.9	5.0
Perylene	0.8	8.6
Pyrene	5.7	2.0
Phenanthrene	N.A.	1.7
2-Me-Benzo(A)Anthracene	N.A.	1.2

N.A. - value not available
N.D. - not detected (< 0.2 ug) during source testing
(1) ref. 19, samples taken downstream from pollution control device
(2) ref. 3

TABLE 12 HEAVY METAL EMISSION FACTORS

INCINERATOR	UNIT	Ag	As	Be	Cd	Cr	Cu	Fe	Hg	Mn	Ni	Pb	Se	V	Zn
Consumat 760 (1) (Hospital)	mg/kg waste	0.154	N.D.	N.D.	1.31	0.80	2.77	10.1	0.013	0.545	0.238	23.1	0.033	0.002	56.2
Multichamber (2) (Municipal)	g/kg waste	0.017	.005	N.A.	0.024	0.016	0.066	0.17	N.A.	0.05	0.004	1.75	0.001	N.A.	2.45
Fluidized Bed (Sewage Sludge)	mg/kg waste	N.A.	N.A.	N.A.	0.33	1.15	4.23	N.A.	4.09	N.A.	0.53	6.54	0.13	N.A.	10.83

N.A. - not available

N.D. - not detected (< 0.2 ug/hr) during source testing

(1) - factor is average of two runs; factor is derived from emission rate, i.e. mg/hr

(2) - factor is for controlled emissions, i.e. downstream of pollution control device

factors from reference: 1; 3; 7

RECOMMENDATIONS

1. Investigations be undertaken into the quantities, characteristics and methods of disposal of hospital radioactive wastes, especially at the Vancouver General Hospital.

2. Studies be conducted into the quantities and characteristics of the organic and especially the chlorinated organic solvents being incinerated at U.B.C.

3. The consequences of the incineration of small quantities of neoplastic drugs at small poorly controlled incinerators be investigated.

4. The results of this survey including the emission factors be incorporated into a computer data base management system that would allow the easy retrieval of data and updating of waste quantities and emission factors.

5. Studies be undertaken on hospital ash samples to ascertain that bulk batch type incinerators are operating at sufficient bed temperatures to assure complete destruction of pathogens, chlorinated organics and neoplastics.

6. The operating conditions and emissions of the Powell River incinerator be more thoroughly investigated.

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APPENDIX I

INCINERATOR MODELS

1 SINGLE CHAMBER INCINERATOR

These units represent the first generation of incinerators, and as such they are of a very basic design. These incinerators consist of a single chamber into which refuse is loaded and lit. They may or may not have a metal grate upon which the waste is loaded. Incomplete combustion and high emission rates are characteristic of these models. Flue glasses are not treated and are emitted directly into the atmosphere from the stack. Air pollution control strategy was not incorporated into the design of these models.

2 MULTIPLE CHAMBER INCINERATOR

Multiple chamber incinerators became prominent in the mid-nineteen fifties and are composed of three independent chambers (see fig. 1). Waste is charged intermittently into the ignition chamber either manually or with a mechanized loader. Each new charge is dried and ignited by the previous one and is sometimes assisted by an auxiliary burner. Underfire combustion air is supplied through a fixed grate (upon which the refuse lies) while overfire air enters through ports usually located in the charging door.

Combustion gases flow through the flame port into the mixing chamber where an auxiliary burner is provided to maintain high combustion gas temperatures. This chamber has been sized to create a high gas velocity to induce mixing of the combustion gas with the secondary air.

From the mixing chamber the gases pass under a curtain wall into the secondary combustion chamber. This chamber is sized for low gas velocity, and attempts to provide sufficient residence time to allow for complete combustion of gaseous pollutants and particular matter. The low velocity in this chamber allows for the settling out of the larger particules. The combustion products then pass through the stack.

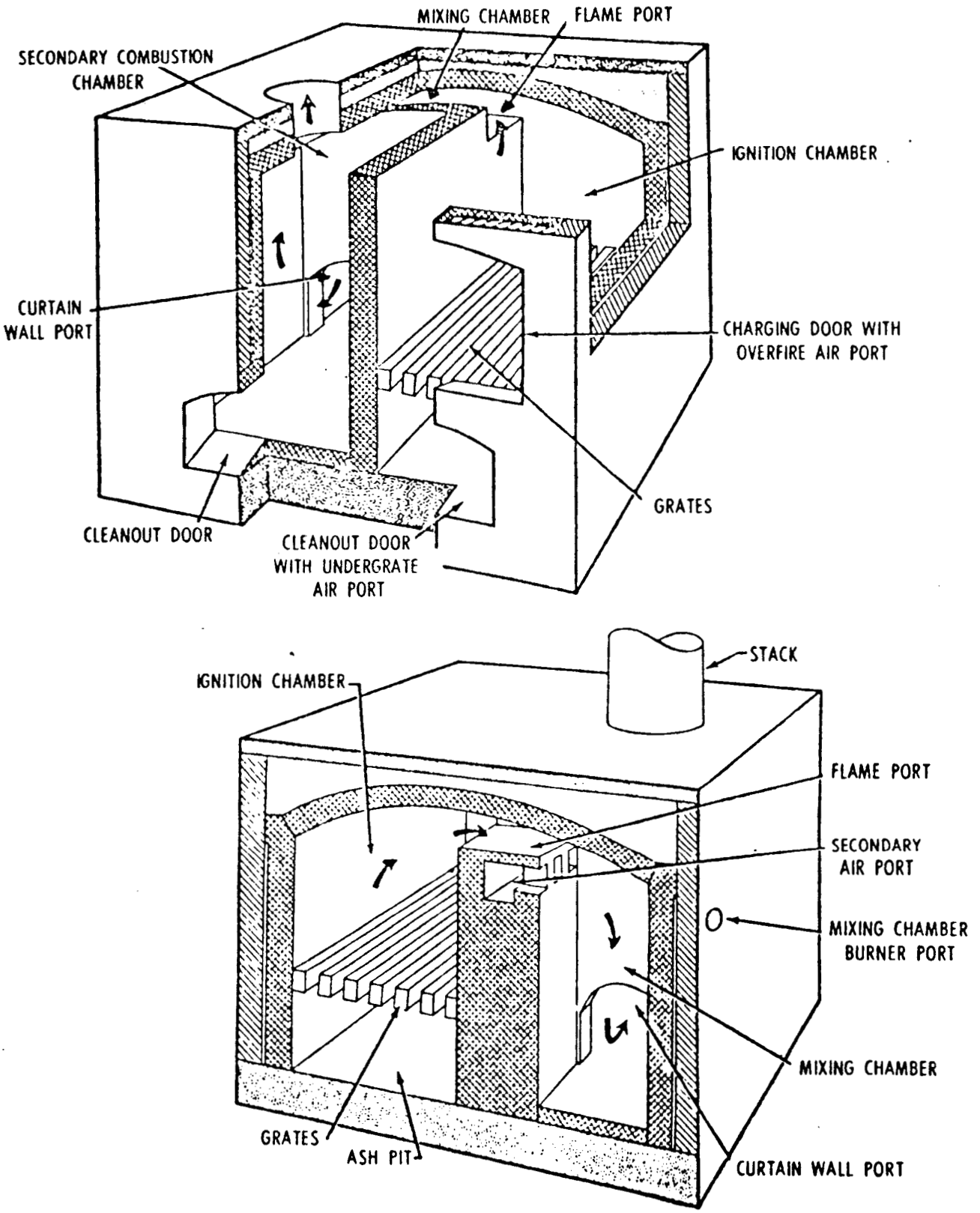

FIGURE 1 MULTIPLE-CHAMBER INCINERATOR

(ref 9.)

3 CONTROLLED AIR INCINERATOR

Controlled air incinerators were introduced commercially in the late nineteen sixties. They are characterized by an airtight ignition chamber, compact afterburner and forced combustion air supply (Figure 2). As such they utilize a two stage incineration process.

During the first stage waste is heated in the primary (lower) chamber. Here the available air is held to less than stochiometric requirements, thereby limiting combustion and heat released and inducing pyrolysis. This destructive distillation results in low gas velocities and turbulence so that inorganic particulates are not entrained with the gas flow and carried to the upper chamber. Only volatile gases, and very small particles pass into the upper chamber.

In the upper (secondary) chamber the combustible smoke and gases are mixed with excess air and burned at about 800°C. After this burn, additional air is introduced in the stack to reduce the temperature of flue gases before discharge to the atmosphere.

4 FLUIDIZED BED INCINERATORS

The fluidized bed incinerator became commercially popular in the early nineteen-sixties. It is quite versatile and is presently used in petroleum and paper industries, processing of nuclear wastes, and in sewage sludge disposal.

The basic fluidized bed combustor is shown in figure 3. The bed is essentially a vessel containing inert granular particles, such as sand (as in the case at Lulu Isl.). Blower driven air enters at the bottom and proceeds vertically through the bed, agitating or "fluidizing" it and causing it to circulate in a manner similar to that of a dense liquid mass. Wastes are injected by various means (pneumatically, mechanically, gravity), and are "auger" fed at Lulu Isl. Rapid and uniform mixing of wastes and bed material occurs.

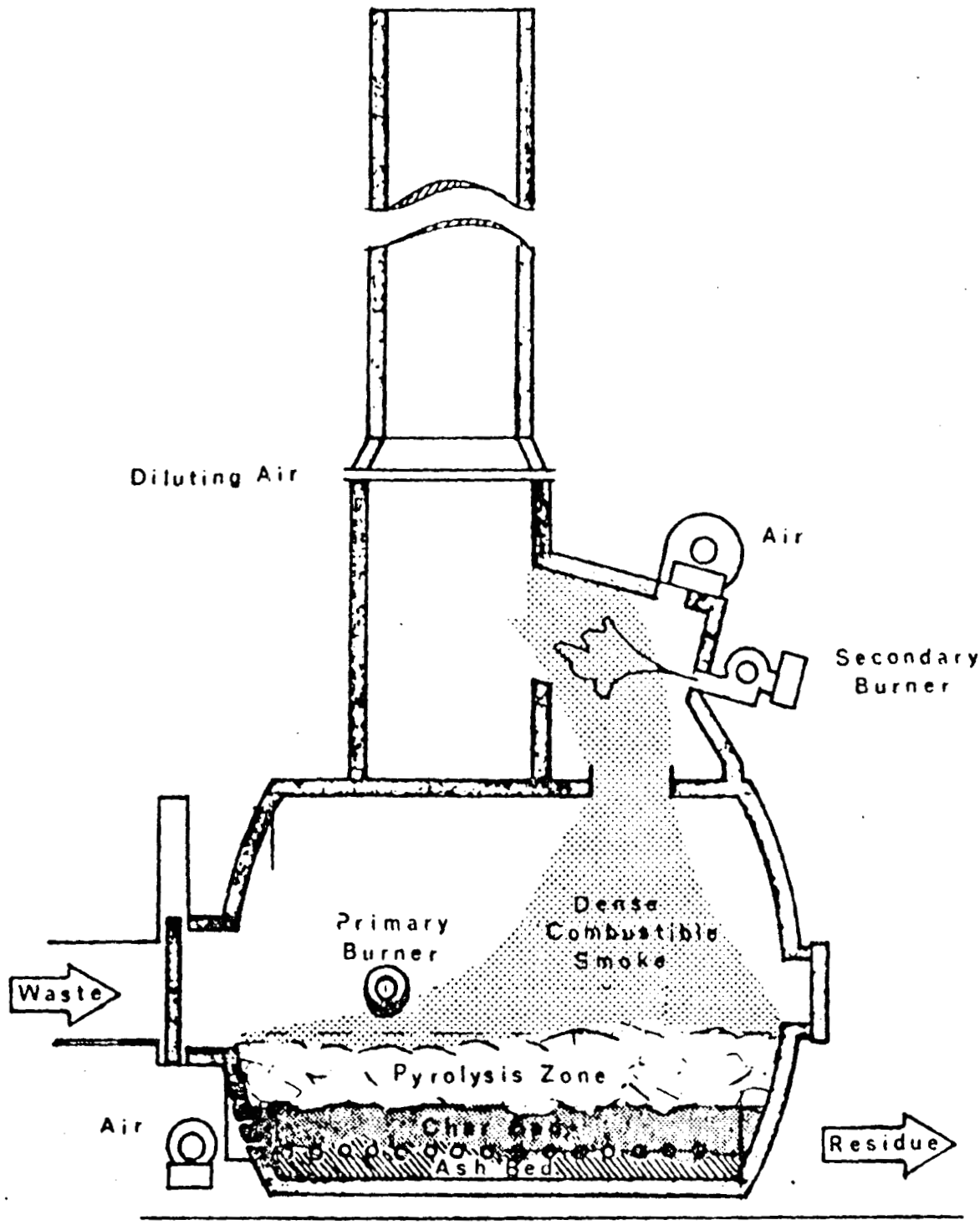

Fig.2 CONTROLLED AIR INCINERATION PROCESS
(ref. 10)

In the combustion process, heat transfer occurs between the bed materical and the injected waste. Typical bed temperatures are in the range of 760° - 870°C. Heat from combustion is transferred back to the bed material. Solids remain in the bed until they have become small and light enough to be carried off with the flue gas as particulates, and should be removed from the flue gas stream by a cyclone or other particulate collection device before release to the atmosphere.

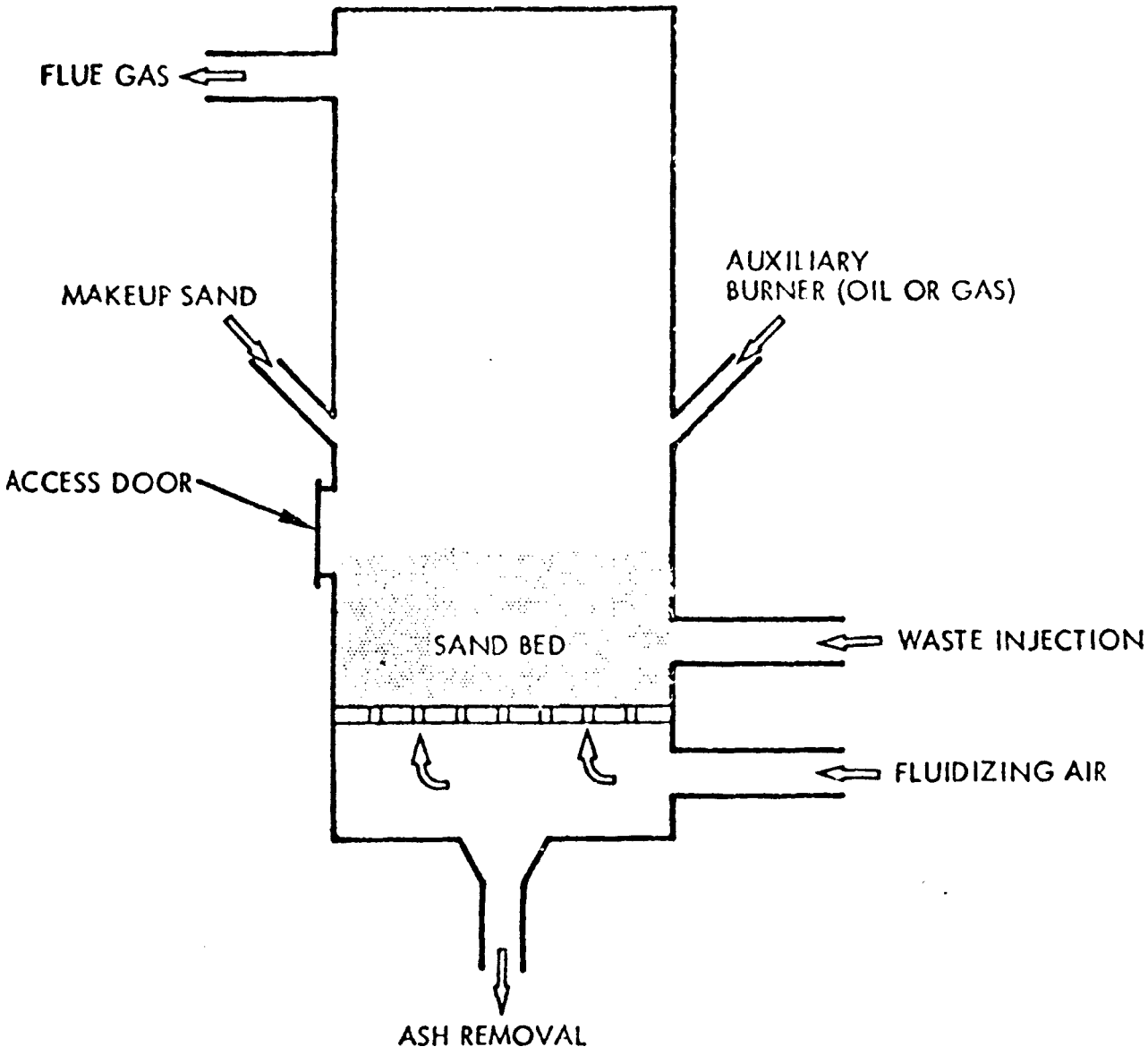

FIGURE 3 Schematic of a Fluidized Bed Combustor

APPENDIX II

INCINERATOR QUESTIONNAIRE

ENVIRONMENT CANADA
Environmental Protection Service - Pacific Region
Air Programs Group
Kapilano 100 - Park Royal, West Vancouver, V7T-1A2

I N C I N E R A T O R Q U E S T I O N N A I R E

Please note:

1) Units: We have employed metric units. Feel free to respond in whatever units you are most comfortable with but clearly indicate what they are (e.g., B.T.U.'s, tons, pounds, F°, etc.).

2) E.M.: The letters "e.m." beside each of the major headings represent an estimating method. In this space please indicate how you arrived at your answers (e.g., operators records, manufacturers specs., fuel bill, etc.).

3) The A.P.C. Permit is the Air Pollution Control Permit Number. If your incinerator has a permit please fill in the number.

4) Feed Description: The following categories have been prepared to help you describe the type of waste you are incinerating.

Type	Description	Examples
A	Cellulosic solids, up to 15% moisture.	paper, cardboard boxes, wooden pallets
B	Cellulosic solids, 15% - 40% moisture	wet paper, damp rags or clothing
C	Cellulosic solids, over 40% moisture.	fruits & vegetables, kitchen waste
D	Plastics	waxes, polyethylene containers, plastic bags.
E	Pathological materials and remains.	hospital dressings, disposable bedding, parts of humans or animals

Please combine the various categories that best characterize your waste - i.e., 50% A 20% B 10% C 15% D 5% E.

5) If you encounter any difficulties or uncertainties, please contact either Paul Ross or Paul Beauchemin at 666-6711.

6) Please return to Paul Ross at the above address.

B.C. INCINERATOR INVENTORY FOR THE BASE YEAR 1982
****

Date:
File No:

==========

GENERAL INFORMATION

==========

Plant Name: A.P.C.Permit #: and Date:

Address: Permittee:

Location: Lat. ;Long. Address:

Contact: and Phone:

No. of Hospital Beds:

==========

INCINERATOR DESCRIPTION {e.m. }

==========

Manufacturer: Heat Recovery System yes___ no___

Mailing Address: Manufacturer:

Model No: Model No:

Type: Type:

Design Capacity;
Tonnes of Waste/hr:
Tonnes of Waste/day:

Design Capacity;
kJ/hr:

Pollution Control Equip. yes__ no__

Manufacturer:

Model No:

Type:

Temperature Controls yes__ no__

Automatic___ Manual___

Primary Chamber; yes___ no___

Set Points; high_____ low_____

Secondary Chamber; yes___ no___

Set Points; high_____ low_____

Comments:

Stack Details

No. of Stacks:

Height:

Diameter:

Gas Flow Rate:

Gas Temperature:

Sample Ports: yes___ no___

Burner Details

No. of Burners; Primary Chamber:

Secondary Chamber:

FEED DETAILS {e.m. }

Feed Description:

Loading Method:

% of Total Waste Collected Which is Incinerated:

Weight of Average Load: ____kg

Average No. of Loads/Day:

Operating Schedule,1982

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Total
No. of Operating Days:													
Tonnes Incinerated:													

AUXILIARY FUEL {e.m. }

Type:

Consumption Rates

Litres/Tonne of Waste:

Litres/Year {1982}:

Sulphur Content:

COMMENTS

APPENDIX III

AUXILIARY FUEL SULPHUR DIOXIDE EMISSIONS

1 AUXILIARY FUEL CONSUMPTION

(1) Royal Jubilee 131.4 L/Tonne (from Questionnaire)
(2) Lake Cowichan 12.43 L/Tonne (ref. 11)

2 AUXILIARY FUEL CHARACTERISTICS (Diesel Oil No. 2)

Sulphur Content = 0.02%
(ref. 10)
Specific Gravity = 0.82

3 CALCULATION OF SO_2 EMISSION DUE TO FUEL OIL

- assume all sulphur will form SO_2

3.1 R.J.H.

$$= \frac{131.4\,L}{\text{Tonne}} \times \frac{1000\,cc}{L} \times \frac{0.82\,g}{cc} \times \frac{kg}{1000g} \times \frac{0.02\,S}{100} = \frac{0.022\,kg\ of\ S}{\text{Tonne of Waste}}$$

$$= \frac{0.043\,kg\ of\ SO_2}{\text{Tonne of Waste}}$$

3.2 Lake Cowichan

$$= \frac{12.43\,L}{\text{Tonne}} \times \frac{1000\,cc}{L} \times \frac{0.82\,g}{cc} \times \frac{kg}{1000\,g} = \frac{0.02\,S}{100} = \frac{0.002\,kg\ S}{\text{Tonne of Waste}}$$

$$= \frac{0.004\,kg\ of\ SO_2}{\text{Tonne of Waste}}$$

APPENDIX IV

MUNICIPAL WASTE HCl EMISSIONS
(Chlorine Material Balance)

1 CHLORINE IN PLASTIC

- plastics contain average of 6.0% Cl (ref. 14)
- municipal wastes contain 3.0% to 3.5% plastic (ref. 10)
- assume 3.0%

2 CHLORINE CONTENT OF MUNICIPAL WASTE

$$\frac{3 \text{ plastic}}{100 \text{ waste}} \times \frac{6 \text{ chlorine}}{100 \text{ plastic}} = 0.18\% \text{ chlorine in municipal waste}$$

3 CHLORINE EMISSION FACTOR FOR MUNICIPAL WASTE

- assume all chlorine is converted to HCl

$$\frac{0.0018 \text{ chlorine}}{\text{waste}} \times \frac{1000 \text{ kg}}{\text{Tonne}} = \frac{1.8 \text{ kg HCl}}{\text{Tonne of waste}}$$