



UNILABS

Environmental

Characterisation and Estimation
of Dioxin and Furan Emissions from
Waste Incineration Facilities

Prepared for:
Environment Australia

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EXECUTIVE SUMMARY

Unilabs Environmental was commissioned by Environment Australia to report on the characterisation and estimation of dioxin and furan emissions from waste incineration facilities in Australia.

In 1997 the Governing Council of the United Nations Environment Programme (UNEP) made a decision to phase out certain persistent organic pollutants (POPs) including dioxins and furans. This report is part of ongoing international work aimed at identifying, quantifying and recommending technologies and strategies for the reduction of risk to human health and the environment arising from the environmental release of the twelve key POPs.

Throughout this report, the term “dioxins” is taken to mean the family of compounds comprising polychlorinated dibenzo-*p*-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs). If both PCDDs and PCDFs are present, they are referred to as PCDD/Fs. The summation of PCDDs and PCDFs is given in the form of International Toxic Equivalents, abbreviated to I-TEQ, a scheme in which the toxicity of the mixture is related to the most toxic compound in the family, 2,3,7,8-TCDD.

The North Atlantic Treaty Organisation’s (NATO) Committee on Challenges of Modern Society developed a procedure for assessing the total toxicity of a mixture of CDDs and CDFs, such that consistency could be achieved in reporting of results. This procedure rated the toxicity of individual CDDs and CDFs relative to 2,3,7,8-TCDD, the most toxic and widely studied congener.

The laboratory responsible for the majority of Australian dioxin analyses is the Institute of Environmental Science & Research (ESR) Limited in New Zealand. The ESR laboratory currently uses the NATO ’89 I-TEF scheme to determine I-TEQs.

LIMITATIONS

This report is a compilation of data supplied voluntarily to UniLabs Environmental from waste incinerator operators and the crematoria industry within Australia. The authors found during

the compilation that the information on dioxins and furans is limited. Some incineration facilities have actual test data, particularly on air emissions, but lack test data on incineration waste streams such as the bottom ash, scrubber sludge, fly ash material and wet scrubber effluent discharged to sewer.

The analytical costs for dioxins are high, so most incinerator operators would only conduct dioxin testing where it is a regulatory requirement.

The total number of incinerators operating in Australia is unknown, particularly the smaller batch type units (approximate capacity of 90 kgs) usually found in hospitals. These small incinerators would have a high emission factor but low activity data, so their annual dioxin emissions would be low and would not greatly affect the overall total annual dioxin emissions to air.

This dioxin report focuses on air emissions and releases to land from waste incinerators and crematoria.

RESULTS

A summary of air emission estimates for each waste incineration category and crematoria is given below in Table 1. These are largely based on international data, which are subject to considerable uncertainty.

Table 1. Dioxin Air Emission Estimates for Australian Waste Incineration Facilities and Crematoria

Source	Emission (g I-TEQ/yr)
Biomedical waste incineration	2.5 – 9.7 ¹
Sewage sludge incineration	0.09 – 0.77
Hazardous waste incineration	0.005
Crematoria	0.14 – 4.8
Total	2.7 – 15.3

Note:

1. This range is a refinement of that in the PAE report, 1997 of 0.9-19.

NOMENCLATURE

1. Nomenclature for dioxin-like compounds (USEPA, 1989, Swedish EPA, 1998)

Term/Symbol	Definition
CDD	Symbol for chlorinated dibenzo- <i>p</i> -dioxins, with halogens substituted in any position.
CDF	Symbol for chlorinated dibenzofurans, with halogens substituted in any position.
Congener	Member of a group of compounds with the same basic structure. In the case of CDD/Fs, individual congeners may differ in terms of the degree of chlorination and/or the position of the chlorine atoms. There are 75 CDD and 135 CDF congeners.
Homologue	Group of structurally related chemicals that have the same degree of chlorination, eg, there are 8 homologues of CDDs, monochlorinated through octachlorinated.
Isomer	Substances that belong to the same homologue class, eg, there are 8 isomers that constitute the homologues of TCDDs.
Specific	Denoted by a unique chemical notation, eg, 2,4,8,9-tetrachlorodibenzofuran
Congener	Is referred to as 2,4,8,9-TCDF.
D	Symbol for the dibenzo- <i>p</i> -dioxin homologue class. Also the symbol for di, ie, 2 halogen substitutions.
F	Symbol for the dibenzofuran homologue class.
2,3,7,8	Halogens substituted in the 2,3,7,8 positions.

2. General Terms and Definitions

Term/Symbol	Definition
“M”	means “mono”, ie, 1 halogen substitution.

“Tr”	means “tri”, ie, 3 halogen substitutions.
“T”	means “tetra”, ie, 4 halogen substitutions.
“Pe”	means “penta”, ie, 5 halogen substitutions.
“Hx”	means “hexa”, ie, 6 halogen substitutions.
“Hp”	means “hepta”, ie, 7 halogen substitutions.
“O”	means “octa”, ie, 8 halogen substitutions.
“Am ³ ”	means “actual gas volume in cubic metres as measured”.
“STP”	means “standard temperature and pressure (0°C and 101.325 kPa)”.
“m ³ ”	means “gas volume in dry cubic metres at STP”.
“TE”	means “total toxic equivalents based on the 2,3,7,8-TCDD congener”.
“mg”	means “milligrams” (10 ⁻³ grams).
“µg”	means “micrograms” (10 ⁻⁶ grams).
“ng”	means “nanograms” (10 ⁻⁹ grams).
“pg”	means “picograms” (10 ⁻¹² grams).
“fg”	means “femtograms” (10 ⁻¹⁵ grams).
“N/A”	means “not applicable”.
“I-TEF”	means “international toxic equivalency factor”.
“I-TEQ”	means “international toxic equivalency”.
“Nm ³ ”	means “gas volume in dry cubic metres at STP”.
“Sm ³ ”	means “gas volume in dry cubic metres at STP and 11% O ₂ ”.
“LOD”	means “limit of detection”.

NOMENCLATURE Contd

Term/Symbol	Definition
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“<”	means “less than”. The value stated is the LOD.
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“≤”	means “less than or equal to”. The value stated is the LOD.
“PICs”	means “products of incomplete combustion”.
“PCBs”	means “polychlorinated biphenyl”.
“SCC”	means “specific contaminant concentration”.
“TCLP”	means “toxicity characteristics leachate procedure”.
“VOCs”	means “volatile organic compounds”
“ppb”	means “parts per billion”
“ppt”	means “parts per trillion”

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

In June 1999, Unilabs Environmental (UE) was commissioned by Environment Australia (EA) to undertake a study to build on earlier work prepared for EA by Pacific Air and Environment (PAE) to identify major air emission sources of chlorinated dioxins and furans across Australia. That study identified little data on a number of incineration processes, namely sewage sludge incineration, hazardous waste incineration and crematoria.

1.2 THE OBJECTIVE AND SCOPE OF THIS REPORT

The purpose of this study is to better characterise and describe waste incineration technologies in Australia and to derive estimates of annual releases of dioxins and furans to all environmental media (air as a priority, then soil/land) from the following incineration processes:

- biomedical waste incineration
- sewage sludge incineration
- hazardous waste incineration
- crematoria.

In relation to these processes, the consultancy was to identify and discuss relevant activity data including:

- production/feed rates
- process technologies
- operating conditions
- pollution control equipment.

Unilabs Environmental has identified and discussed:

- the relevant technologies as used in Australia;
- activity data – including information on feed rates, process technologies operating conditions and pollution control equipment utilised; and
- status of regulation – regulations relating to emissions of dioxins and furans to all media-air, land/soil and water in State Territory and local governments.

Unilabs has also provided estimates of emissions for each process identified on the bases of the characterisation and supplied data on emission rates of dioxins and furans.

The consultancy notes that, because of the lack of adequate Australia data for any releases to land or water and crematoria, estimates included in this report have been based on international data.

1.3 THE REPORT

Information about dioxins and furans, including how they are formed, was well covered in the PAE Study (1998). However, it is appropriate to include similar information in the early chapters of this report.

A crucial element to this report has been the cooperation of the waste incineration industry in supplying emission and activity data. A process for introducing the requirements for this report to individual operators was developed with Environment Australia. All information was supplied on a purely voluntary basis.

The main focus of subsequent chapters is the analyses of the data supplied by the waste incineration and crematoria industries.

Derivation of estimates of dioxin and furan emissions is accomplished in chapters 3, 4, 5 and 6.

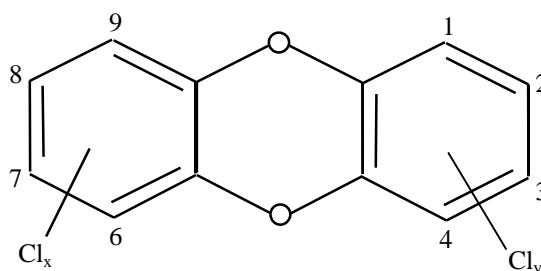
CHAPTER 2

DIOXINS

2.1 DIOXINS

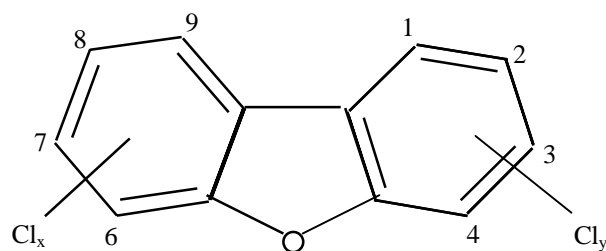
Polychlorinated dibenzo-*p*-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs) are a group of tricyclic aromatic hydrocarbons substituted with one to eight chlorine atoms (Olie et al, 1998). These compounds, commonly known as ‘dioxins’ or ‘dioxins and furans’, are found virtually everywhere on earth, with the main transport mechanism being atmospheric dispersion and deposition (Mukerjee, 1998). As a concession to mainstream terminology, PCDDs and PCDFs are referred to collectively as “dioxins” in this report.

In molecular structure, a dioxin consists of two benzene rings connected by a pair of oxygen atoms and a furan consists of two benzene rings connected by a single oxygen atom and a C-C bond. Each of the eight carbon atoms on the rings that is not bonded to an oxygen atom or another carbon atom can bond with atoms of other elements. By convention these positions are assigned the numbers 1 through 4 and 6 through 9. PCDDs and PCDFs are bonded with 1 - 8 chlorine atoms. Figures 1 and 2 show the molecular structures of PCDDs and PCDFs, respectively.



$X = 0$ to 4, $Y = 0$ to 4, $X + Y \geq 1$

Figure 1 Molecular Structure of Polychlorinated Dibenzop-Dioxins



$$X = 0 \text{ to } 4, Y = 0 \text{ to } 4, X + Y \geq 1$$

Figure 2 Molecular Structure of Polychlorinated Dibenzofurans

There are 75 possible PCDD and 135 possible PCDF congeners, as depicted in Table 2 below.

Table 2. Number of Possible Chlorinated Dibenzo-*p*-Dioxin (CDD) and Chlorinated Dibenzofuran (CDF) Congeners

Level of Chlorine Substitution	Number of Possible CDD Congeners	Number of Possible CDF Congeners
Mono	2	4
Di	10	16
Tri	14	28
Tetra	22	38
Penta	14	28
Hexa	10	16
Hepta	2	4
Octa	1	1

In chemical notation, the site number of the chlorine atom refers to these congeners. For example, 2,3,7,8-tetrachlorodibenzo-*p*-dioxin, or 2,3,7,8-TCDD, is a PCDD congener with chlorine atoms located at the 2,3,7 and 8 positions, as depicted in Figure 3 below (Tchobanoglous et al., 1993).

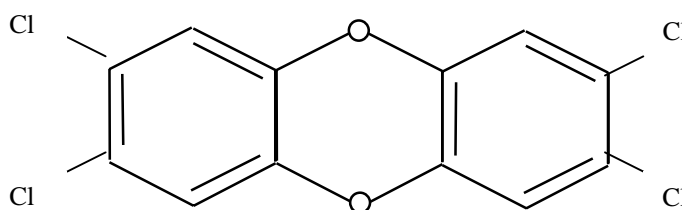


Figure 3. Molecular Structure of 2,3,7,8-TCDD

2.1.1 Occurrence of Dioxins in the Environment

These highly stable compounds are extremely persistent in nature. They are virtually insoluble in water but are soluble in lipids. It is this combination of properties that permits dioxins to enter fatty tissue and accumulate in food chains.

Dioxins are known to be highly toxic to animals and humans, with various studies conducted on laboratory animals reporting teratogenic effects (malformations of the foetus), liver damage, decreased reproduction and growth rates, cancer promotion and behavioural changes. The best-known and most toxic dioxin congener is 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (TCDD).

Even though dioxins can form through natural processes such as bush fires, the presence of the toxic congeners in the environment is predominantly anthropogenic. Dioxins have never been intentionally manufactured, but form as unwanted by-products in the manufacture of organochlorine chemicals (including herbicides and PVC), various combustion and metallurgical processes and chlorine bleaching of paper.

2.1.2 Toxic Equivalency Factors

The toxicity of the 210 individual chlorinated dioxin and furan congeners varies widely. Seventeen of these congeners have chlorine atoms in all of the 2, 3, 7 and 8 positions, and are considered to be the most toxic.

In 1989, the North Atlantic Treaty Organization's (NATO) Committee on Challenges of Modern Society developed a procedure for assessing the total toxicity of a mixture of CDDs and CDFs, such that consistency could be achieved in reporting of results. This procedure rated the toxicity of individual CDDs and CDFs relative to 2,3,7,8-TCDD, the most hazardous and widely studied congener. The I-TEFs/89 scheme, which has been adopted as an interim procedure for assessing dioxin risk by the USEPA and the majority of western countries, assigns a non-zero value to the 17 CDDs and CDFs with chlorine substituted in the 2,3,7,8

positions. A zero value is given to all other congeners, as depicted in Table 3 (USEPA, 1989). This allows the toxicity of various dioxin congeners to be compared and aggregated.

Table 3. International Toxicity Equivalency Factors (I-TEQs) for CDDs and CDFs

CDD and CDF Congeners	1989 NATO scheme I-TEQ	1998 human/mammal I-TEQ	1998 fish I-TEQ	1998 bird I-TEQ
Mono-, Di- and Tri- chlorodibenzofurans	0	0	0	0
Mono-, Di- and Tri- chlorodibenzo- <i>p</i> -dioxins	0	0	0	0
2378 Tetrachlorodibenzofuran	0.1	0.1	0.05	1
Non 2378 Tetrachlorodibenzofurans	0	0	0	0
2378 Tetrachlorodibenzo- <i>p</i> -dioxin	1	1	1	1
Non 2378 Tetrachlorodibenzo- <i>p</i> -dioxins	0	0	0	0
12378 Pentachlorodibenzofuran	0.05	0.05	0.05	0.1
23478 Pentachlorodibenzofuran	0.5	0.5	0.5	1
Non 2378 Pentachlorodibenzofurans	0	0	0	0
12378 Pentachlorodibenzo- <i>p</i> -dioxin	0.5	1	1	1
Non 2378 Pentachlorodibenzo- <i>p</i> -dioxins	0	0	0	0
123478 Hexachlorodibenzofuran	0.1	0.1	0.1	0.1
123678 Hexachlorodibenzofuran	0.1	0.1	0.1	0.1
234678 Hexachlorodibenzofuran	0.1	0.1	0.1	0.1
123789 Hexachlorodibenzofuran	0.1	0.1	0.1	0.1
Non 2378 Hexachlorodibenzofurans	0	0	0	0
123478 Hexachlorodibenzo- <i>p</i> -dioxin	0.1	0.1	0.5	0.05
123678 Hexachlorodibenzo- <i>p</i> -dioxin	0.1	0.1	0.01	0.01
123789 Hexachlorodibenzo- <i>p</i> -dioxin	0.1	0.1	0.01	0.01
Non 2378 Hexachlorodibenzo- <i>p</i> -dioxins	0	0	0	0
1234678 Heptachlorodibenzofuran	0.01	0.01	0.01	0.01
1234789 Heptachlorodibenzofuran	0.01	0.01	0.01	0.01
Non 2378 Heptachlorodibenzofurans	0	0	0	0
1234678 Heptachlorodibenzo- <i>p</i> -dioxin	0.01	0.01	0.001	<0.001
Non 2378 Heptachlorodibenzo- <i>p</i> -dioxins	0	0	0	0
Octachlorodibenzofuran	0.001	0.0001	<0.0001	0.0001
Octachlorodibenzo- <i>p</i> -dioxin	0.001	0.0001	<0.0001	0.0001

2.2 HEALTH IMPACT OF DIOXINS

Dioxins bio-accumulate in the body, which may affect the development of the human foetus/embryo, and cause impairment of the immune system, male reproductive system (for example reduced sperm count) and endometriosis in women over time.

Various studies conducted on laboratory animals have concluded that dioxins are highly toxic to certain species of animals at very low levels of exposure (Tosine, 1983). Observations included teratogenic effects (malformations of the foetus), liver-damage, decreased reproduction and growth rates, cancer promotion and behavioural changes.

The best-known and most toxic dioxin congener is 2,3,7,8-tetrachlorodibenzo-*p*-dioxin, commonly referred to as TCDD. What toxicity TCDD does possess apparently derives from the chemical's ability to bind very efficiently with a particular type of receptor protein inside the cytoplasm of some cells within the body. This is known as the Ah, or dioxin, receptor (Swedish EPA, 1998).

The resulting TCDD-receptor complex can enter the cell's nucleus and bind with its DNA, thereby disrupting the cell's mechanism for producing proteins. The wide and rather puzzling array of toxic effects induced in animals by TCDD and structurally related compounds are apparently all receptor-mediated responses to these chemicals. It appears to be the differing ability of individual congeners to bind with the Ah receptor that determines how potent a toxic effect they have (Swedish EPA, 1998).

The most noticeable effect of acute exposure to TCDD in humans is chloracne, although epidemiological observations suggest an increased risk of soft-tissue sarcoma and non-Hodgkin's lymphoma. Symptoms including nausea, eye and respiratory tract irritations, dehydration, weight loss and cyanosis have been reported (Hay, 1982), along with altered function of the neuromuscular system, liver, kidneys and pancreas (Crow, 1981).

Chloracne generally takes the form of dermal lesions and in severe cases, pustules on the face and shoulders (Passi et al., 1981). This was first described by Bettmann in 1897 for workers involved in the production of 2,4,5-trichlorophenol and related compounds (Herxheimer, 1899).

Toxicologists initially concluded from such studies that TCDD was one of the most toxic of all man-made substances and recommended that soil levels in excess of one part per billion would constitute an unacceptable health risk to humans. Table 4 below lists recommended levels of TCDD in soils. Indeed, the extrapolation of animal data to humans, itself a contentious exercise, led to dioxins and furans being labelled ‘the most toxic chemical known to man’ (Williams, 1994:40). Subsequent research, however, has discounted most of these inferences, which were based on the effects of very high doses of TCDD on guinea pigs and other peculiarly susceptible animals (Encyclopedia Britannica, 1998).

However, not all authorities agree with this assessment. In February 1997 the International Agency for Research on Cancer (IARC) declared that:

Based on the most recent epidemiological data on exposed human populations, experimental carcinogenicity bioassays in laboratory animals, and supporting evidence on relevant mechanisms of carcinogenesis – 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD) was evaluated as carcinogenic to humans (IARC group 1 classification)”. (McGregor et al., 1998)

Table 4. Government Regulation Limits for TCDD in Soil

Country	Residential (ppb)	Industrial (ppb)	Agricultural (ppt)
Germany	1	10	5 – 40
Netherlands	1	1	1
Canada	1	1	10

(Leathem, S., Institute of Environmental Science & Research Limited, New Zealand)

Indeed, the World Health Organisation (WHO) appears to be placing an increasing emphasis on the toxicity of dioxins. In 1990 the WHO recommended a Tolerable Daily Intake (TDI) for dioxins and furans of 10 picograms TEQ per kg body weight per day (WHO 1998). In 1998 the WHO re-examined new epidemiological data and in particular the effects on neurological development and the endocrine system, and set a new TDI in the range 1 to 4 picograms/kilogram body weight (WHO, 1998a). The WHO media release announcing the decision to lower the ADI gave the following reasons for the reduction:

After ample debate, the specialists agreed on a new tolerable daily intake range 1 to 4 picograms/kilogram body weight. The experts, however, recognise that subtle effects may already occur in the general population in developed countries at the current background levels of 2 to 6 picograms/kilogram body weight. They therefore recommended that every effort should be made to reduce exposure to the lowest possible level. (WHO, 1998b)

The WHO experts also stressed that the upper range of the TDI of 4 pg I-TEQ/kg body weight should be considered a maximal tolerable intake on a provisional basis and that the ultimate goal is to reduce human intake levels below 1 pg I-TEQ/kg body weight/day.

The WHO recommended that

...every effort should be made to limit environmental releases of dioxin and related compounds to the extent feasible in order to reduce their presence in the food chains, thereby resulting in continued reductions in human body burdens. In addition, immediate efforts should be made to specifically target exposure reductions towards more highly exposed sub-populations.

...and thus point to the need for continuing efforts to reduce human exposure to these compounds, by controlling their input to the environment". (WHO 1998a)

According to Grassman et al. (1998),

The adverse effects of dioxins are well established based on studies of experimental animal models and highly exposed human populations. From these investigations, the current view of dioxins as potent toxicants capable of producing a multitude of diverse biologic effects has emerged.

They summarised the relevance of animal models to human health end-points as follows:

- *The reproductive, developmental, immunologic, and carcinogenic responses to dioxins seen in humans also occur in animal models;*
- *The preponderance of biochemical effects induced by dioxins in both animals and humans are mediated by the Ah receptor;*

- *Animal dosing regimens can be varied to examine the range of exposures encountered in human populations;*
- *Dose metrics based on internal dose (tissue dose and body burden) can be used to compare responses across species as these parameters take into account species differences in clearance rates;*
- *The biochemical responses to dioxins in animal models show qualitative and quantitative similarity to those observed in humans;*

and concluded that;

the biologic responses [in human and animals] to dioxins are qualitatively and often quantitatively similar. Exposure to dioxins has been implicated in a wide range of human health effects related to reproduction, immune function, growth and development, and cancer.

In comparing the animal and human responses to dioxins DeVito et al. (1995) observed that:

The present study indicates that in vitro similar responses are seen in human and animal tissues after similar dioxin exposure. Human populations exposed to high concentrations of dioxins exhibit symptoms that are similar to the signs of toxicity seen in some experimental animals exposed to dioxins. These effects are seen at equivalent body burdens, strongly indicating that dioxins are responsible for some of these toxic effects in humans.

and concluded that:

the available data indicate that high-level human exposure to dioxins produce adverse health effects and that humans are sensitive species to the toxic effects of dioxins.

2.3 FORMATION OF DIOXINS IN INCINERATORS

Combustion refers to the rapid oxidation of substances with the evolution of heat. All combustion processes emit certain amounts of air contaminants. In an ideal system, the final products of combustion would be carbon dioxide and water, with diluents such as nitrogen

passing through the system unchanged. However, in a real system, the combustion products are far more varied.

Incomplete combustion of carbon based fuel or waste can lead to the formation of carbon monoxide and other partially oxidised hydrocarbons. Due to the high temperatures in the process (particularly at the flame), a small percentage of the nitrogen will be oxidised to nitric oxide or nitrogen dioxide. Sulphur present in the fuel or waste may be oxidised to form sulphur dioxide or sulphur trioxide, the latter reacting with atmospheric water to form dilute sulphuric acid. In the case of fuels or wastes containing halogens such as chlorine and fluorine, the air emission may contain hydrochloric or hydrofluoric acids, and trace quantities of organohalogens such as dioxins (Buonicore et al., 1992).

The types and concentrations of contaminants in the flue gases of waste incinerators depend on incinerator type, the waste being burned and combustion conditions. Flue gas contaminants can generally be categorised, as follows:

- particulate matter
- acid gases
- heavy metals, and
- products of incomplete combustion.

Particulate matter consists primarily of entrained non-combustible matter in the flue gas, as well as the products of incomplete combustion that exist in solid or aerosol form. The quantity of particulates discharged from the incinerator is dependent on the ash content of the waste, the gas velocities through the incinerator, the type of ash agitation used and the presence or absence of appropriate pollution control equipment (cyclones, baghouse or scrubber).

Acid gases include flue gas constituents which, when combined with water or water vapour, form acids such as nitric acid, sulphuric acid, hydrochloric acid and hydrofluoric acid. Hydrogen chloride can be present in concentrations ranging from a few hundred ppmv to several thousand ppmv for biomedical waste. The main source of acid gases in biomedical waste incinerators is PVC used in disposable equipment. PVC contains approximately 60% w/w chlorine.

Metals such as copper (Cu), iron (Fe), lead (Pb), cadmium (Cd), arsenic (As), nickel (Ni), zinc (Zn) and mercury (Hg) are present in the flue gas primarily as oxides and chloride salts. Most of the metallic compounds are in the vapour phase within the incineration system, since these compounds boil or sublime at temperatures around 1,000°C. The metallic compounds tend to condense as the flue gas is cooled and become adsorbed onto fine particulate matter (generally submicron in size, ie 0.2 - 0.7 micron). It is possible that a portion of the more volatile metals such as mercury and cadmium may remain in the vapour phase, depending upon temperature conditions.

Products of incomplete combustion (PICs) include carbon monoxide and trace organics, including dioxins. This latter group of organic compounds is of special interest because of their health impacts. Levels of PICs in the discharge are generally less dependent on the pollution control equipment and more on the design and operation of the secondary combustion chamber. Provided time, temperature and turbulence (“the three Ts”) are maintained, good combustion is assured. However, dioxins are an indirect result of incomplete combustion, being mainly formed in the post-combustion zone due to the catalytic reaction of chlorine and PICs on the surface of ash in the temperature range of 250 - 400°C.

In incinerators, the PICs that are dioxin precursors are believed to form at a temperature of approximately 500°C. Dioxins are then formed downstream of the combustion chamber, as the precursors are cooled. This occurs in the temperature range 250 to 400°C by reactions between components such as oxygen, water, hydrogen chloride gas and other precursors in a process known as *de novo* synthesis. Any metals present within the gas stream or in the materials of construction may act as a catalyst to dioxin formation.

Full-scale dioxin assessments are severely restricted by the expense and technical difficulties involved with this type of monitoring. Because in incinerator discharges dioxins occur in both the particulate and gas phase, representative samples should only be collected in regions of well developed flow under isokinetic conditions. This is preferable within a stack or long duct.

2.4 CATALYSIS

The catalytic properties of fly ash may be responsible for both the Cl_2 production and the biaryl synthesis (Raghunathan and Gullett, 1996). While the exact mechanism of dioxin formation remains unknown, it is understood that dioxins generally form from the thermal breakdown of organic materials in the presence of transition metals and chlorinated compounds. Dioxin formation takes place from *de novo* synthesis as the flue gas from the incineration process cools down from the initial 1000°C down to about 250°C , with peak dioxin formation occurring in the range of 650°C to 250°C (Tuppurainen et al., 1997). Above 350°C , 94% of all dioxin is in the gas phase.

Dioxin formation occurs only in the low temperature zone of the incinerator and only where residual particles (fly ash) are present. The fly ash acts as a catalytic surface during the formation process (Addink et al., 1990) and also possesses all the necessary components for dioxin formation, these being carbon, small organic compounds, metal ions and inorganic chloride. Copper and iron are the best metal catalysts for this reaction. Chlorine may be incorporated into dioxins through elemental Cl_2 or acid (HCl) form.

The formation mechanisms of dioxins in combustion processes are still not well understood because the formation reactions are very complex. To date, three mechanisms have been identified which relate to dioxin formation, these being:

Pyrosynthesis (high temperature gas phase formation)

Formation from macromolecular carbon (*de novo* synthesis)

Through various organic precursors (such as chlorophenols)

The *de novo* synthesis seems to be the dominant mechanism of dioxin formation in actual combustion systems (Huang et al., 1996). This pathway was supported by both theoretical (Shaub and Tsang, 1983) and laboratory (Eiceman and Rghei, 1982; Vogg and Stieglitz, 1986, Vogg et al., 1987; Stieglitz and Vogg, 1987a, 1987b; Dickson and Karasek, 1987; Nestrick et al., 1987; Hagenmaier et al., 1987) studies on the catalytic role of fly ash. The mechanism requires the presence of oxygen and metal ions in the reaction system as well as still not clearly identified organic carbon and chlorine sources. However, the debate over whether *de*

novo or precursor synthesis is the more dominant mechanism is further complicated by the fact that dioxin precursors may be formed through *de novo* synthesis, as shown in Figure 4.

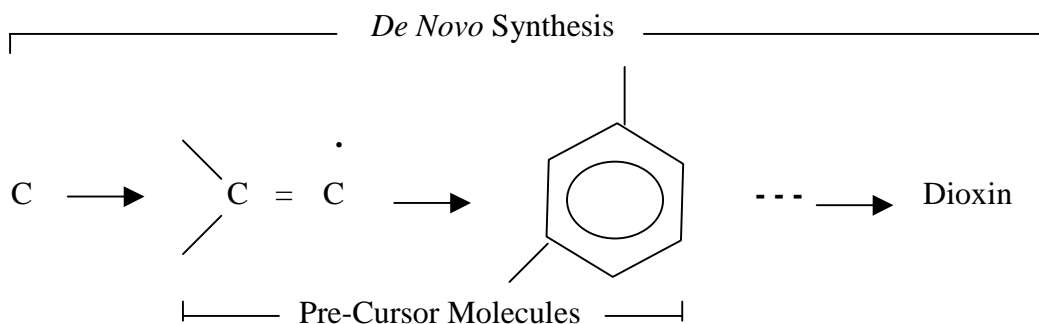


Figure 4. Pre-cursor molecule formation during *De Novo* Synthesis

A fourth pathway to the emission of dioxins following incineration is the direct release from the waste or fuel in an unchanged form. However, in a modern incineration plant, this has been shown to be less significant than post-combustion reformation mechanisms (Taucher et al., 1992).

2.4.1 *De Novo* Synthesis from Carbon

Both Cu and Fe ions have been identified as catalysts in dioxin formation reactions from carbon. Cu ions are 25 times stronger as a catalyst than Fe (Stieglitz et al., 1990). The mechanism of chlorination with Cu has been described above. In this mechanism, the Cu ions are only involved in the chlorination of the macromolecule, not in its oxidative breakdown. If the Cu ion concentration is increased during the *de novo* synthesis, a more than proportional rise in dioxin formation is observed (Stieglitz and Vogg, 1987). Recently, CuCl₂ has also been advanced as a dechlorination catalyst of dioxin already formed (Luijk et al., 1993).

2.5 DE NOVO SYNTHESIS

Gaining popularity as the more prominent mechanism of dioxin production, *de novo* synthesis involves the formation of dioxins from macro-molecular carbon structures (Addink and Olie, 1995) and the organic or inorganic chlorine present in the fly-ash matrix (solid phase) at low temperatures (250-300°C) (Tuppurainen et al, 1997).

Influencing factors in the formation of dioxins via *de novo* synthesis include:

- Gas-phase material: O₂ is essential for *de novo* synthesis. Total dioxin formation is approximately half the order with respect to oxygen concentration.
- Solid-phase material: certain forms of carbon (listed below) are necessary for *de novo* synthesis. Carbon that has a graphite structure is unsuitable. Catalysts include Cu²⁺, and to a lesser extent Fe³⁺.
- Chlorine: this is essential for synthesis to occur, as “dioxins” refers to the chlorinated congeners.
- Temperature: the optimum temperature range for dioxin formation is 250 - 400°C, with the maximum formation rate at about 300°C.
- Reaction time: unimportant in the gas phase, reaction time in the solid phase of between 5 and 30 minutes has been shown to produce a near constant rate of dioxin formation.
- Product distribution: the typical product distribution from *de novo* synthesis is as follows: 1 part PCDDs : 1.6 parts PCDFs : 75 parts chlorobenzenes : 6 parts chlorophenols : 0.6 parts PCNP : 0.3 parts polychlorobiphenyls. (Huang and Buekens, 1996).

Various types and forms of carbon have been found to participate in dioxin formation, including bituminous coal (Mahle and Whiting, 1980), soot (Stieglitz et al, 1989), charcoal (Dickson et al, 1989), activated carbon (Addink et al, 1990), the radioisotope ¹³C (Albrecht et al, 1992) and residual carbon (naturally present on fly-ash) (Milligan and Altwicker, 1993). However, graphite, which has a low [aliphatic]:[aromatic] ratio and a crystalline structure, does not give rise to dioxin formation (Addink and Olie, 1995).

These carbon forms/isotopes all have various capabilities in dioxin formation from *de novo* synthesis, which occurs mainly in the downstream areas of incineration systems, that is, as the flue gases are cooled down. Due to a lack of published material on the topic, reasons for these differences remain unanswered. A summary of published results is given in Table 5 below.

Table 5. *De Novo* synthesis of dioxins

Author	Gas Phase Material	Solid Phase Material	Temperature (°C)	Solid Phase Residence Time (min)	Total Dioxin Formation Rate (µg/g-min)	Furan Dioxin Ratio
Luijk et al	Air, H ₂ O, HCl	Active carbon, CuCl ₂	300	60	0.017	0.03-5
Milligan and Altwicker	O ₂ (10%), N ₂	Fly ash	300	30	0.034	4.2
Stieglitz et al	Air	Fly ash	300	120	0.059	1.6
Dickson et al	¹³ C-P ₅ CP, air	Mixture of silica gel, charcoal and CuCl ₂	300	10-60	0.107 (¹² C-PCDDs)	na
Addink et al	O ₂ (10%), N ₂ , HCl (4%)	Mixture of fly ash and carbon	373	60	0.128	5
Hagenmaier	Air	Fly ash	300	120	0.014	2
Stieglitz and Vogg	Air, H ₂ O	Mixture of Mg-Al silicate, charcoal, KCl and CuCl ₂	300	120	0.054	3.3

De novo synthesis occurs mainly in the downstream areas of incineration systems, that is, as the flue gases are cooled down.

2.6 PRECURSOR FORMATION OF DIOXINS

Precursor formation of dioxins involves the reaction at higher temperatures of particles that closely resemble the final dioxin product. Examples include chlorinated aromatic hydrocarbons such as polychlorinated biphenyls, chlorophenols and chlorobenzenes. It is important to reiterate that, while *de novo* and precursor formation are considered to be

different processes, they may operate separately or simultaneously. Indeed, many dioxin precursors are formed from *de novo* synthesis.

Dioxin synthesis from precursors on collected fly ash has been amply studied. However, apart from chlorophenols, which can generate dioxin through direct coupling, no mechanisms can be formulated as the pathways are simply too complicated to allow for an easily obtainable mechanistic insight. The wide range of precursors capable of dioxin formation suggests that any combination of C, H, O, and Cl could generate these toxic compounds. This may be true, but such an observation does not tell what precursors are more reactive than others in dioxin formation. Study of formation rates from chlorobenzenes, chlorophenols, and aliphatic precursors under identical conditions could yield this information. Given these facts, it would be possible to determine the most important precursors in incinerator flue gas.

Temperature and time have a different effect on dioxin formation from precursors than found with carbon, ie, *de novo* synthesis. The optimum temperature window for formation will be different for each precursor and can be well above 500°C. Consequently, as with carbon, formation can occur at the higher temperature side of the post combustion zone. Formation reactions from precursors are possible on a much shorter time scale (seconds-minutes) than with carbon, which, with a continuous supply of reactant adsorbed onto the fly ash from the gas phase, probably continues for hours.

The role of copper compounds both in ring condensation and chlorination appears well established. With a less structurally similar starting material, eg. propene, the role of the catalyst is less clear. Other transition metal ions besides copper can catalyse some of the steps leading to dioxin formation.

2.7 CONTROL OF DIOXINS FROM INCINERATORS

Control of dioxin emissions from incinerators may be undertaken in one of four ways:

- Restricting chlorinated materials
- Combustion control
- Restricting their formation
- Cleansing of flue gases after formation

Modern waste incinerators use a combination of all four approaches. Each is examined in more detail below.

2.7.1 Restricting Chlorinated Materials

As chlorine is the major contributor for dioxin formation, reducing or removing the chlorinated material that enters incinerators may have an effect on the reduction of dioxins.

Substituting chlorinated products with non-chlorinated products is not a simple process, it requires a cradle to grave concept; this concept needs the involvement of government, generators, incinerator operators, transporters, etc.

However, a study conducted by Wilson et al. (1995) revealed that PCDD/PCDF emissions are not directly related to chlorine feed concentrations.

2.7.2 Combustion Control

Combustion control centres on dioxin destruction at high temperatures, typically over 1000°C, and residence times of greater than 2 seconds. While the mechanism remains unknown, it is apparent that the higher the combustion efficiency, the lower the dioxin output in flue gas emissions (Williams, 1994). Others, including Commoner et al. (1987), Hagenmaier et al. (1987 and 1988) and Vogg et al. (1987) disagree, however, finding no direct correlation between furnace temperature, CO concentration, combustion efficiency and dioxin emission, preferring instead *de novo* synthesis as the dominant mechanism.

These conflicting observations can best be explained as follows. Combustion control is necessary for the destruction of dioxins and their precursors in the feedstock, but this does not preclude subsequent *de novo* synthesis in the post-combustion zone.

2.7.3 Restricting Dioxin Formation

Sulphur dioxide (SO₂) is emerging as a significant inhibition mechanism in the control of dioxin formation. According to Raghunathan and Gullett (1996), Griffin (1986) and Ogawa et

al. (1996), sulphur minimises formation of dioxin rather than destroying or capturing it after formation.

The presence of SO₂ depletes molecular chlorine through a gas-phase reaction. In addition, SO₂ has been found to deactivate copper catalysts (Raghunathan and Gullett, 1996). The role of sulphur in reducing the catalytic activity of the fly ash stems from its ability to react with the copper based Deacon catalyst (eg. CuO or Cu₂O) to form CuSO₄

As outlined in Sections 2.4 and 2.5, these two factors are crucial in limiting the formation of dioxins in combustion systems.

The importance of sulphur as a dioxin inhibitor is best demonstrated by comparing combustion systems utilising high sulphur fuels with low sulphur applications. Chlorine and organic ring structures can be found in the fuels of both municipal waste incinerators and coal fired combustors. However, only relatively small amounts of dioxins have been detected in emissions from the coal-fired units. The main difference between the two processes is the level of sulfur present, with the coal-fired system having higher sulfur levels.

Griffin (1986) suggested that the effect of S is to deplete the Cl₂ levels through a gas phase reaction:



According to Raghunathan and Gullett (1996), in municipal waste incinerators and in the presence of HCl, dioxin formation levels were high when no SO₂ was present (S/Cl = 0), but decreased substantially for a S/Cl ratio of 0.64; further increase in the S/Cl made little difference to the reduced levels. It should be noted that reduction due to S is not congener-specific in dioxins and appears to be distributed among all the congener classes; the presence of SO₂ can also convert the Cl₂ back to HCl.

Natural gas provides a cleaner burn than coal, and the higher concentration of organic precursors from coal combustion may offset the inhibitory effect of S. When the S/Cl ratio

was further increased to 0.8 by doping additional SO₂ (coal + Municipal Waste Combustor fly ash + HCl + SO₂) the PCDD and PCDF yield dropped dramatically. As with natural gas tests, the PCDF congeners are in a majority, and the S inhibitory effect is distributed among all the congeners.

Results obtained by Raghunathan and Gullett, (1996) clearly demonstrate the ability of S to inhibit dioxin formation. Frankenhaeuser et al. (1992) also observed a negative effect of SO₂ in the co-combustion of plastics with coal. Lindbauer et al. (1992) added coal to a MSW incinerator and reported a dramatic decrease in yield with SO₂ levels at S/Cl ratios between 1 and 5. However, Gullett has demonstrated that a coal combustion environment, especially when combined with municipal waste combustion conditions, can in fact increase dioxin yields if the S/Cl ratio is not sufficiently high. Therefore the choice of coal and the municipal waste to coal firing ratio may be critical in achieving lower dioxin levels through coal co-firing.

2.7.4 Cleansing of Flue Gases after Dioxin Formation

Traditionally the best available technology for control of dioxins from waste incinerators in Australia was wet scrubbing. This achieved a dioxin emission of 1 - 2 ng/Sm³. Another more recent technology uses activated carbon and calcium oxide (lime) adsorption process for controlling dioxins from waste incinerators to achieve levels well below the strictest international limit of 0.1 ng/Sm³ I-TEQ.

The post-combustion dioxin reduction strategy may be summarised as follows. Firstly, *de novo* synthesis dioxin formation reactions are minimised by using a rapid quench system, whereby gas temperatures are reduced from approximately 550°C down to 200°C in a few milliseconds. The exhaust gases then enter a reactor where they are mixed with hydrated lime and activated carbon, which is subsequently removed in a baghouse. In some facilities, sodium bicarbonate is now being successfully substituted for lime, as this improves acid gas removal.

One problem with the above strategy is that it relies on adsorption rather than suppressive processes; dioxins have not been eliminated from the environment, merely transferred from

one medium (the flue gas) to another (the sorbent, and ultimately landfill). As legislation regarding the landfilling of hazardous waste is being continuously strengthened, it is becoming progressively more difficult and expensive to dispose of this material.

For industry, the possibility of reducing dioxins through catalytic or inhibitive processes is becoming more attractive. As a result, it was decided to also investigate these potential control technologies.

CHAPTER 3

INCINERATORS IDENTIFIED WITHIN AUSTRALIA

3.1 IDENTIFICATION OF INCINERATORS

Crucial to the outcome of this report was the approach to operators in the waste incineration industry and regulatory authorities to provide Unilabs Environmental with emission and activity data. A process for introducing the information requirements for this report to individual incinerator operators was developed with Environment Australia.

Incinerator operators were identified through contact with Federal, State and Territory regulatory authorities and non-government organisations. Operators were advised of the purpose of the report and of the information and data being sought. This was followed up by telephone discussions where possible.

The outcome of the above written requests and research by Unilabs Environmental, identified nineteen waste incinerator operators within Australia. A list of incineration technologies is given in Table 6. A total of five incinerator operators responded to requests for emission and activity data. The Australian Cemeteries and Crematoria Association (ACCA) was very helpful in supplying what available data there was in Australia in regard to crematoria. Table 7 compares numbers and tonnage of Australian incinerators with those of other countries.

3.2 AN INCINERATION PROCESS DEFINITION

There are many definitions for incineration; one that has gained general acceptance is provided by Gill and Quiel, 1993:

Incineration is a combustion process that uses rapid oxidation, excess air and high temperatures to produce conditions whereby hazardous and toxic waste products are thermally broken down and destroyed.

However, this definition does not address the issue of dioxins.

3.3 HOW ARE DIOXINS FORMED?

While the exact mechanism of dioxin formation remains unknown, it is understood that dioxins generally form from the thermal breakdown of organic materials, combined with transition metals and chlorinated compounds.

There are three generally accepted theories on the methods of dioxin formation (discussed more extensively above at section 2.7), as follows:

1. Contaminated feedstock: feed material possibly contains dioxins and some portion of this survives the thermal stress of combustion and is subsequently emitted from the stack.
2. Thermal breakdown of 'precursor' compounds: precursor compounds are chlorinated aromatic hydrocarbons such as PCBs, CPs and CBs (these have a structural resemblance to the dioxin molecule). The formation of dioxins is believed to occur after the precursor molecule has adsorbed onto the surface of the fly ash, the combination of which promotes dioxin formation.
3. *De novo* synthesis: similar to the 'precursor theory': however, instead of dioxin-like compounds reacting to form dioxins, in this case dioxins are formed from completely different molecules reacting to form precursors and, eventually, dioxin-like molecules. Again, like the previous theory, a temperature range of between 250 – 400°C is required for formation to take place.

3.4 OTHER FACILITIES NOT DEFINED AS WASTE INCINERATION

Incineration facilities such as those incinerating (burning) green or wood wastes and quarantine wastes have potential to release dioxin emissions, but are not included in this report. Potential sources such as biomass pyrolysis and municipal waste incineration have also been identified as potential sources of dioxin releases.

Many industrial and manufacturing industries employ afterburners for destruction of gaseous organic contaminants from processes. Afterburners are generally designed to allow a specified retention time for gases and operate at a temperature above 750°C. There is a potential for formation of dioxins in the emission stream from these afterburners. However, these high temperature facilities are not identified in this report.

3.5 WASTE INCINERATION CATEGORIES

Waste incinerators will be categorised into four groups, as follows:

1. Biomedical Waste Incinerators
2. Sewage Sludge Incinerators
3. Hazardous Waste Incinerators
4. Crematoria (approximately 120 in Australia, [ACCA]).

Note: - Crematoria were included as a category for the purpose of this technical report only.

Table 6. List of incinerator technologies used in Australia

Incinerator Description	Number operating in Australia	Written response received
Biomedical Waste Incineration¹		
Controlled Air Incinerator with Wet Scrubbing System	3	2
Controlled Air Incinerator with Dry System	1	1
Rotary Kiln with Wet Scrubbing System	1	0
Excess Air/Batch Type	1	0
Incinerators identified but no information available ³	10	None
Sewage Sludge Incineration²		
Multiple Hearth Incinerator with Wet Scrubbing System	1	1
Incinerators identified but no information available ³	1	None
Hazardous Waste Incineration		
Controlled Air Furnace with Wet Scrubbing System	1	1
Total	19	5

1 From information gathered, a total of 16 biomedical incinerators were identified.

2 From information gathered, a total of 2 sewage sludge incinerators were identified.

3 Of the 11 unknown incinerators it is probable that 50% have ceased operation.

Table 7. Comparison Table of Incinerator Numbers & Activity Data from Australia, UK, USA, Canada and New Zealand

	Australia	UK^a	USA^b	Canada^c	New Zealand^d
Biomedical					
Number of Facilities	16	4,600	6,700	253	>5
Tonnages (per annum)	<30,000	260,000	4,300,000	Unknown	15,900
Hazardous					
Number of Facilities	1	63	190	5	1
Tonnages (per annum)	<2,000	290,000	1,300,000	Unknown	Unknown
Sewage Sludge					
Number of Facilities	2	Unknown	199	Unknown	1
Tonnages (per annum)	23,000	77,000 (dry)	865,000 (dry)		5,200
Municipal					
Number of Facilities	0	30	171	64	0
Tonnages (per annum)	0	2,920,000	29,350,000	Unknown	0
Crematoria					
Number of Facilities	120	700	1,200	Unknown	Unknown
Number of Cremations	60,000	450,000	>1,000,000		21,000

a Source: Her Majesty's Inspectorate of Pollution, 1995.

b Source: USEPA, 1995.

c Source: Environment Canada, 1999.

d Source: New Zealand Inventory of Dioxin Emissions, 1998.

CHAPTER 4

BIOMEDICAL WASTE INCINERATORS

Medical waste incineration was one of the incineration processes mentioned in the PAE Study (1998) as a potentially significant source of dioxins and furans, but was an area that lacked Australian activity data to derive emission estimates. The PAE Study (1998) report briefly described three types of medical waste incinerators without reference to air pollution control equipment.

This chapter will provide necessary information about the waste stream and processing and endeavour to discuss Australian technologies, activity data and air pollution control equipment to derive dioxin emission estimates.

4.1 INTRODUCTION

A biomedical waste incinerator consists of primary and secondary incineration chambers followed by air pollution control equipment, details of which are given later in the chapter. The combustion processes in the primary chamber and secondary chamber are similar; however, the majority of wastes combust in the primary chamber. Pathogens in biomedical clinical wastes are readily destroyed at relatively low temperatures in the primary chamber.

Any products of incomplete combustion (PICs), whether particulate or gaseous forms, are subjected to passage through the secondary combustion chamber at a minimum temperature of 1000°C and a minimum of one second retention time. Air pollution control equipment will be discussed in detail later. Waste streams from the incineration process include:

- biologically inert ash solids from the primary chamber
- baghouse residues, including captured fly ash combined with any adsorbent materials, such as activated carbon and lime (if present);

- settled solids and clarified water from the gas quench and gas scrubbing processes (if present);
- final stack emissions of the incineration process.

4.2 DESCRIPTION OF BIOMEDICAL WASTES

Whilst the main function of a biomedical waste incinerator is for the combustion of clinical wastes, the majority of commercial facilities also dispose of other types of waste materials.

These other wastes often include:

- Quarantine wastes
- Security wastes
- Illicit materials and drugs
- Pharmaceuticals
- Miscellaneous regulated wastes for example non-chlorinated hydrocarbon wastes such as oily rags, solvents, greases, etc.

The properties of these waste materials are described below:

4.2.1 Clinical Wastes

Clinical waste is a heterogeneous mixture of general refuse, laboratory and pharmaceutical chemicals and containers, pathological wastes and cytotoxic wastes. All of these wastes are either infectious or potentially infectious. A brief description of each sub-group is as follows:

General refuse from hospitals is similar to generic wastes from residences and institutions and includes disposable linens, paper, flowers, food, cans, nappies and plastic cups.

Laboratory and pharmaceutical chemicals can include alcohols, disinfectants, cytotoxic agents and heavy metals, some of which (such as cadmium and lead) are found in plastic containers, bags, etc. in the form of colouring agents or plasticisers.

Infectious wastes include isolation wastes (refuse associated with isolation ward patients), cultures and stocks of infectious agents and associated biological products, human blood and blood products, pathological wastes, contaminated sharps and contaminated animal carcasses, body parts and bedding.

Cytotoxic wastes include cytotoxic drugs used for the treatment of cancers and any items contaminated with these drugs. Predominantly the packaging of these items is likely to be plastic or paper based.

The chemical and physical characteristics of the different waste materials vary widely. Clinical wastes can also vary considerably in composition and consequently in heat release, moisture content and bulk density from one container to the next. When waste materials are being processed prior to incineration, they are blended upon waste composition, for example high moisture waste combined with light dry wastes. This promotes stable conditions, good burndown times and possibly reduced contaminant carry-over and/or concentration.

The chemical composition of the waste materials may affect pollutant emissions. Wastes containing metals or plastics are of particular concern. Metals that vaporise at the primary combustion chamber temperature may become metal oxides with particle sizes less than 1 micron. Halogenated plastics, such as polyvinyl chloride, will form acid gases such as hydrogen chloride. The presence of chlorinated wastes could also contribute to the formation of chlorinated organic compounds such as dioxins and furans under poor operating conditions.

A typical composition for clinical wastes as seen in Australia and throughout Asia is as follows (Clunies-Ross and Coccia, 1992):

- 3% PVC
- 5% Pathological
- 30% Plastics other than P.V.C.
- 32% Paper including waxed paper
- 10% Hospital dressings, swabs, etc.
- 10% Miscellaneous wastes (including flowers, rags, etc.)
- 10% Non-combustible including glass, sharps, metal, cans, aerosols.

It is critical to realise that at times the waste stream into the incinerator can consist of virtually pure plastic, pure paper or even glass. The ease of use and the reliability of the incinerator are dependent on its ability to handle the anticipated variations in the waste stream. (Clunies-Ross and Coccia, 1992)

4.2.2 Quarantine Wastes

Like clinical wastes, quarantine wastes can vary significantly in composition, moisture content and calorific value. In general this waste is usually of higher water content and lower calorific value than clinical wastes.

If required to burn large quantities of quarantine wastes, the operation of the incinerator would not suffer but the auxiliary fuel required to maintain the secondary chamber to 1100 degrees Celsius would be likely to increase. Emission levels of particulate and acid gases are dependent on the actual wastes burnt but are likely to be less during the incineration of quarantine wastes.

4.2.3 Security Documents

Incineration is regularly used for the absolute destruction of confidential documents and transparencies by government departments, financial institutions and security agencies. The wastes consist of virtually pure paper or pure plastic or at times a combination of the two.

In small static hearth incinerators the incineration of security documents can present an operational problem. Bundled paper is difficult to burn whereas transparencies, being virtually pure plastic, have a high heat release.

4.2.4 Illicit Materials and Drugs, Pharmaceuticals, and Miscellaneous Regulated Wastes

Quite frequently the operators of commercial clinical waste incinerators are requested to incinerate irregular materials. These can include large quantities of out of date pharmaceuticals and illicit narcotics. In most cases these materials can be classified as clinical waste and can be incinerated without concern. If large quantities of wastes are involved, the incineration of these materials will be spread over a number of days.

Other wastes under this category can be used rags, spent solvents from printing shops or motor garages and greases from mining drag lines, which are contaminated generally with soil material.

4.3 SPECIFIC CHARACTERISTICS OF WASTES

The following properties of wastes all affect the sizing and selection of a suitable incinerator:

- Calorific Value
- Moisture Content
- Glass Content
- Plastic and PVC Content

4.3.1 Calorific Value

An incinerator is predominantly sized on the heat release or calorific value of the wastes to be incinerated. An incinerator designed and sized to burn low calorific wastes can often be significantly smaller than a unit sized to burn the same quantity of high calorific wastes.

The calorific value of clinical wastes has increased significantly within the last 10 years as many of the items in use are now made from plastics and are disposed of after a single use.

4.3.2 Moisture Content

Whilst no special precautions are necessary when burning clinical wastes, care should be taken if the incinerator is also to burn quarantine wastes or sludges as these materials are typically of very high moisture content.

The moisture content of the wastes affects the overall sizing of an incinerator and the layout and the design of the primary chamber. High moisture wastes usually necessitate that the incinerator be equipped with a drying zone prior to the combustion zone.

4.3.3 Glass Content

The glass content of clinical wastes is critical as it can affect the reliability of incineration equipment.

Most types of glass will deform at approximately 600°C and will liquefy at 800-1,000°C. When significant quantities of glass are incinerated, temperature control of the primary chamber is critical, as high temperatures can result in the molten glass pooling to form a solid slab or even a ring in a rotary kiln type incinerator.

In a stepped hearth type incinerator the ash pushers can be used to break up and remove this glass. However, temperature cycling within a rotary kiln can result in a buildup of a glass ring of many layers, which will eventually result in the blockage of the rotary kiln. This necessitates that the incinerator be cooled down and that the glass be removed manually with jackhammers.

4.3.4 Plastic and PVC and Rubber Content

The plastic and rubber content of the waste significantly affects the calorific value and subsequently the capacity of the incinerator. When burning wastes of a higher plastic and/or rubber content than originally designed, the throughput must be reduced to ensure that the overall heat release from the wastes is consistent with the original design.

Combustion of polyvinyl chloride results in the formation of hydrogen chloride acid gas and combustion of rubber results in the formation of sulphur dioxide, sulphur trioxide and subsequently sulphuric acid gas. These wastes are critical in terms of determining the need for an acid gas scrubbing plant, the design of the scrubbing plant and the neutralisation chemical demand of such a plant.

4.4 INCINERATOR EQUIPMENT AND OPERATION

To illustrate the operation of an incinerator we will take one example of a biomedical waste incinerator – Ace Energy Pty Ltd located in Queensland. It is important to note that whilst every medical waste incinerator differs, the basic components of each incinerator are similar in concept and operation. The Ace Energy Biomedical Waste Incinerator and Air Pollution Control System is outlined in Figures 5 and 6, with typical process parameters being shown. As described in the research findings described in chapter 2, it is believed that dioxins are primarily formed in the post combustion zones of the incineration system such as the heat exchanger.

The Ace Energy controlled air incinerator consists of four basic sections, as follows:

- Loader and bin tippler.

- Primary combustion chamber.
- Ash discharge conveyer.
- Secondary combustion chamber.

4.4.1 Loader and Bin Tippler

The function of the incinerator loader is to permit the introduction of waste materials directly into the incinerator primary chamber.

4.4.2 Primary Chamber

The stepped hearth primary chamber consists of 3 stationary hearths on which the waste burns. Each hearth is equipped with an ash pusher for the purposes of pushing the burning materials and ash from the hearth; as this waste is pushed through the incinerator it progressively burns to produce a mixture of volatiles and ash. Each zone of the hearth is equipped with a combustion air supply.

The final stage of the stepped hearth incinerator is the burnout hearth. It is on this hearth, that the carbonaceous matter generated in the controlled air environment is contacted with excess air to burnout the carbon to an acceptable level.

Controlled air biomedical waste incinerators are designed to operate under reducing conditions, conditions that are well suited for combustion of clinical waste due to its volatility and high energy content. Reducing conditions involve using less than the stoichiometric quantity of combustion air necessary for complete combustion in the primary chamber. By starving the process of air the volatile components of the waste are gasified.

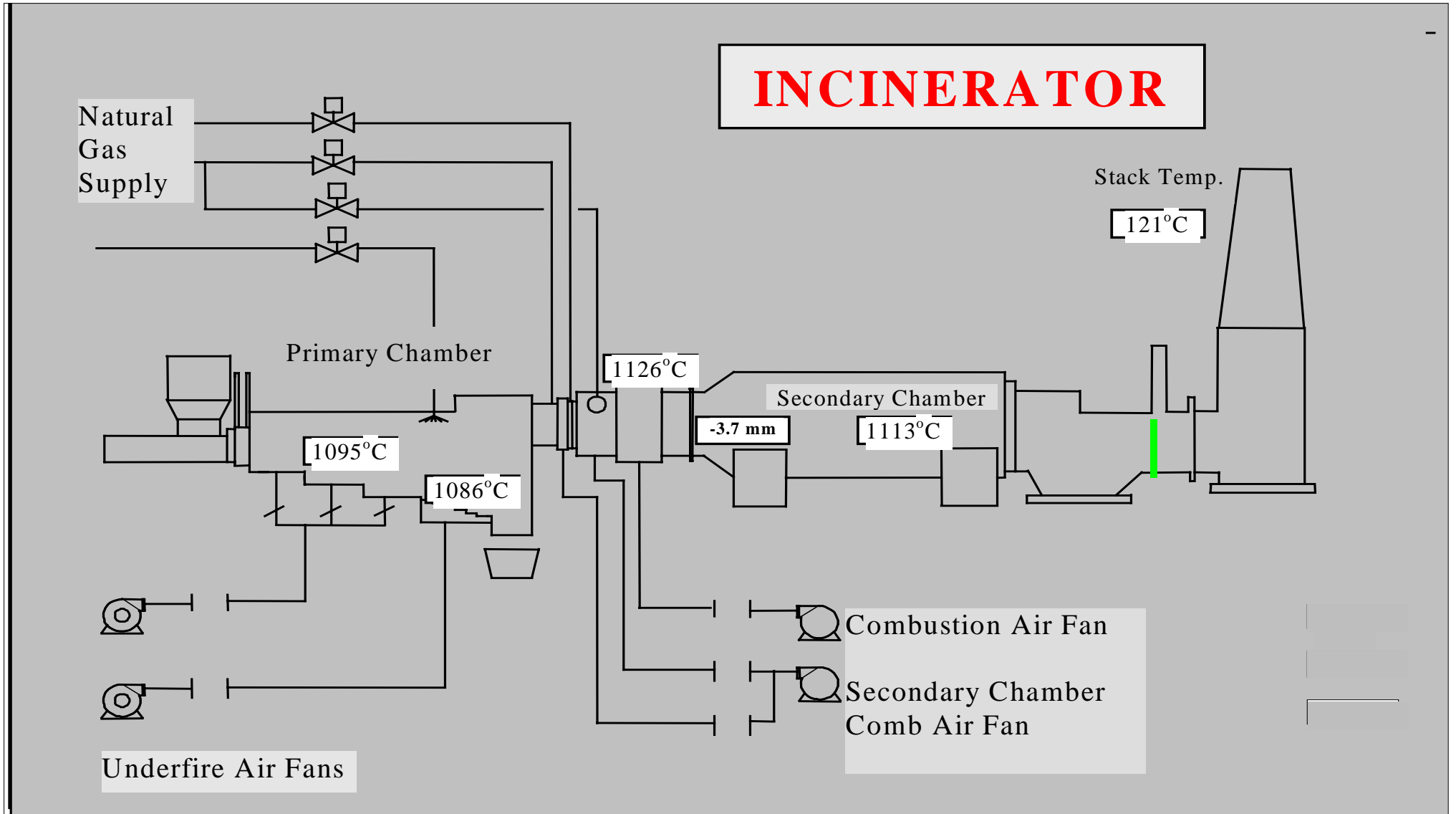
The combustible gases produced can be considered to be a fuel and are mixed with air to be completely combusted in the secondary chamber after ignition by a gas burner in the ignition zone. This process reduces the need for high quantities of auxiliary fuel and minimises the

incombustible particulate carryover from the primary chamber to the secondary chamber and subsequently to atmosphere or the air pollution control plant.

4.4.3 Ash Pushers

The primary combustion chamber is equipped with three hydraulically operated ash pushers, designated 1, 2 and 3, which are used to transfer burning waste through the incinerator. The ash pushers are operated in sequence at the start of every load cycle. The pushers are of a refractory lined steel construction, with de-mountable cast alloy steel nose support plates, and are normally retracted but operate by sliding directly on a cast abrasion resistant section of the hearth.

Figure 5. Ace Waste Biomedical Waste Incinerator Combustion Zones – Primary and Secondary (Afterburner) Stages



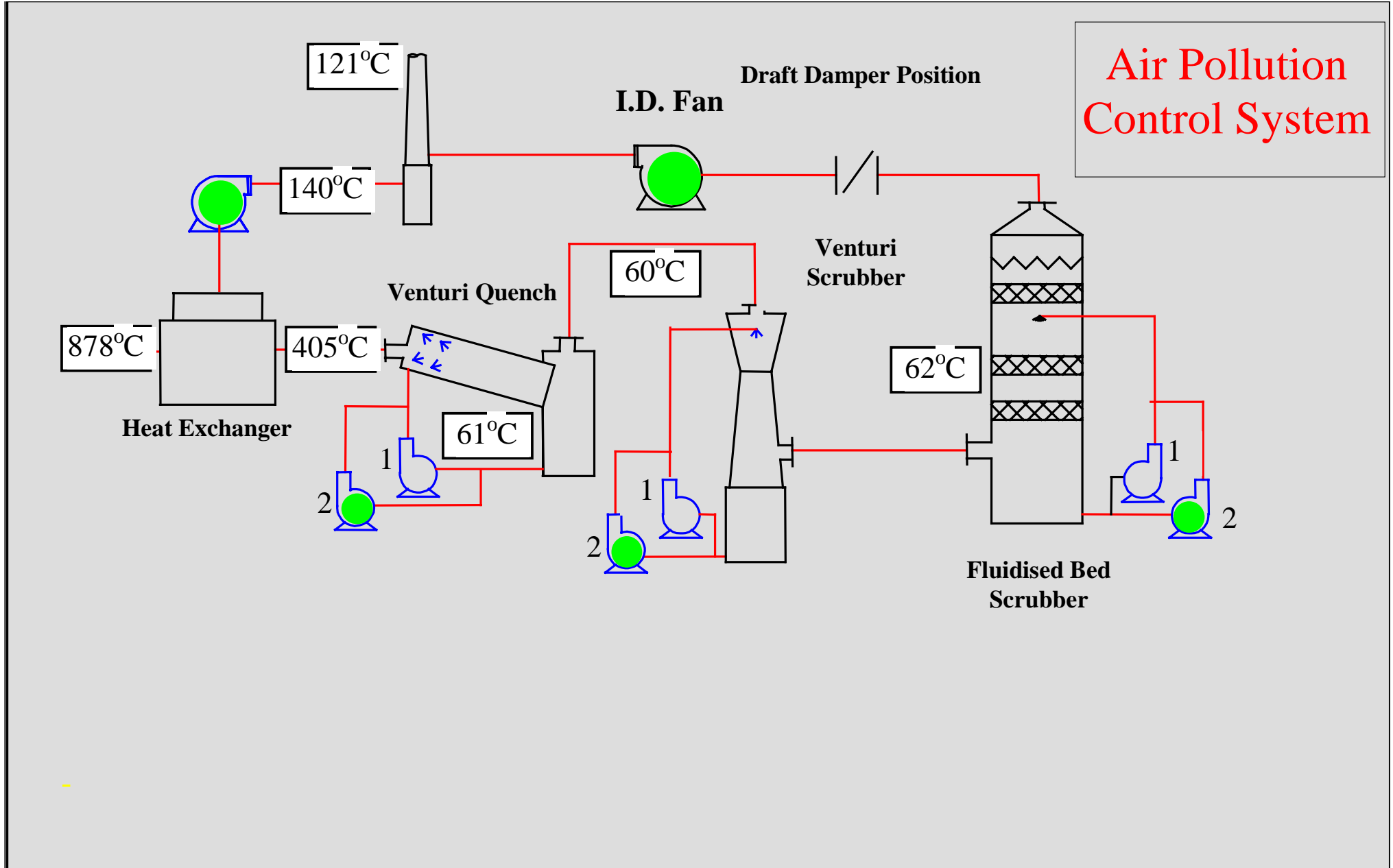


Figure 6. Ace Waste Post Combustion Zones – Wet Scrubber Air Pollution Control System

4.4.4 Ash Discharge Conveyor

This unit is a heavy-duty mild steel construction and is equipped with a heavy loose-link drag conveyor chain, to which a series of mild steel flights are attached at regular intervals. The chain is supported on sprockets and a series of troughs attached to the main incinerator casing. These troughs are fitted with bottom wear plates and drain back to a water bath.

The chain runs through a water bath, which is used to cool the hot ash, prior to it being discharged into an ashbin.

4.4.5 Secondary Chamber

The function of the secondary chamber is to ensure virtually complete breakdown of all combustible gases generated in the incinerator primary chamber. This is achieved by maintaining the secondary chamber at a temperature of over 1000°C whilst ensuring an adequate supply of combustion air. An efficient secondary chamber is essential to minimise emissions of dioxins and other products of incomplete combustion.

The critical parameters when determining the efficiency of an incinerator secondary chamber are the combustion temperature, the combustion chamber retention time and the turbulence (the three Ts). It is necessary to ensure that sufficient combustion air is available to complete the combustion process.

Before the primary chamber off-gases enter the secondary chamber they pass through an ignition zone. This zone is equipped with a natural gas ring burner at its entrance, which ignites the combustible products from the primary chamber and provides excess air. Additional combustion air is mechanically induced under high pressure through a series of tangential ducts located along the chamber of the ignition zone. This high velocity combustion air is used to provide counter-rotation mixing of the high temperature gas stream.

The secondary chamber is typically designed to provide a secondary chamber retention time of 2.0 seconds at a temperature of 1,100°C.

4.5 AIR POLLUTION CONTROL SYSTEMS

The types and concentrations of contaminants in the flue gases of clinical and other waste incinerators depend on incinerator design, the waste being burned and combustion conditions. Flue gas contaminants can generally be categorised as follows:

- Particulate matter
- Acid gases
- Heavy metals
- Products of incomplete combustion.

Air pollution control systems for biomedical waste incinerators have traditionally been characterised as either wet or dry systems. Wet systems consist of a venturi scrubber for particulate removal and fluidised bed scrubbers for acid gas control.

Dry systems generally utilise either fabric filters or electrostatic precipitators for particulate control and spray drier reactors or dry sorbent injection systems for acid gas control.

Recently, dry-wet or wet-dry systems (hybrid) have been used with a goal of achieving the highest possible acid gas removal efficiency with the lowest possible particulate and dioxin emission rates.

Wet type air pollution control systems have traditionally been used to meet the requirements of the Australian pollution control authorities. Whilst these are used by virtually every commercial incineration facility in Australia and will readily achieve the required particulate, acid gas and heavy metals emission standards, they cannot consistently achieve the international dioxin emission standard of 0.1 ng/Sm³ I-TEQ (Clunies-Ross, 1999).

The use of a wet scrubbing plant to achieve 0.1 ng/Sm^3 I-TEQ necessitates the use of extremely high-energy consumption scrubbers with additional filtration. The fans necessary to overcome the resultant pressure drops would consume approximately twice the electric power required for the dry-wet system. Such fans would be extremely noisy and would require extensive maintenance to overcome typical vibration and corrosion problems.

The second type of air pollution control plant, which would be suitable for the incineration of clinical wastes, is the dry system. When combined with activated carbon injection, this system will readily achieve the specified dioxin and particulate emission standards. However, the efficiency of dry systems for acid gas removal is limited.

Nevertheless, the more stringent emission standards, in particular 0.1 ng/Nm^3 for dioxins now being requested by emission control authorities worldwide, necessitate that dry type scrubbing systems complete with activated carbon injection would have to be used.

4.6 WET TYPE AIR POLLUTION CONTROL PLANT

To illustrate the wet type air pollution control system, we have again used the Ace Energy biomedical waste incinerator primarily because there is currently only one other incinerator in Australia using different technology.

Once discharged from the incinerator heat exchanger, the exhaust gases need to be cooled down from 500°C to saturation temperature prior to entry into the scrubbers. This is achieved by adiabatic cooling through the addition of water in the venturi quench/scrubbers to achieve a saturation temperature of approximately 80°C .

Clean exhaust gases are then discharged from the scrubbers to atmosphere through the stack.

There are six fundamental parts to the wet type:

- Heat exchanger
- Venturi quench
- Venturi scrubber
- Fluidised bed scrubber
- Mist eliminator
- Induced draft fan

4.6.1 Heat Exchanger

All pollution control systems are equipped with a heat exchanger located immediately downstream of the secondary chamber. The function of this heat exchanger is to cool the exhaust gases from a temperature of approximately 1,100 – 1,200°C to 550 - 650°C, and to provide hot air for exhaust stack gas reheat.

Heat exchanger contents are a combination of stainless steel and ceramic tubes, which accumulate particulate matter that over time reduces the efficiency of the heat exchanger and then has to be removed, usually by vacuum process. This material is then disposed of to landfill or by blasting high-pressure air to remove the build up of deposits on the tubes, with the deposits being captured by the scrubbing system.

This material tends to have a high concentration of dioxins. This is hardly surprising for the following reasons:

- An accumulation of particulate matter and heavy metals provides a number of active sites and catalysts for dioxin formation.
- A build up of salts provides chlorine for the necessary dioxin synthesis.
- The operating temperatures of the heat exchanger would fall within the *de novo* synthesis zone (200°C to 450°C).

There are no regulations pertaining to the disposal of this material and no analytical data are available.

4.6.2 Venturi Quench

The venturi quench provides gas-liquid contact in a confined area so that the hot incinerator gases are rapidly cooled down to a point approaching saturation temperature. Cooling liquids are introduced by two means: a single high-pressure fresh water mist spray and recirculated liquor. All liquids are introduced counter-current to the exhaust gas flow. The function of the fresh water is for cooling of the gas stream and this liquid is therefore evaporated upon contact with the hot gases.

4.6.3 Venturi Scrubber

The function of the venturi scrubber is to remove dust and particulate matter from the incinerator exhaust gas stream. The venturi is an impingement type device that utilises a small throat area to accelerate the unscrubbed gas stream. The venturi scrubber throat area is fitted with an internal 'bullet' which can be adjusted to achieve the required system pressure drop (the greater the pressure drop, the greater the removal efficiency).

4.6.4 Fluidised Bed Scrubber

The most effective plant for acid gas removal is the wet scrubber. The acid contaminated exhaust air enters at the bottom of the scrubber and is contacted with the alkali-based liquor over the tower packing material. The resultant chemical reaction of the alkali and the acid results in the neutralisation of the acids to produce water and salt.

Process effluent is manually removed to a sump by opening a dump valve fitted on the lowest point of the fluidised bed scrubber holding tank. This process effluent contains particulates and salts removed from the gas stream, which is manually bled from the scrubber to prevent the build up. The alkalinity of the fluidised bed scrubber liquor is monitored using a pH sensor and is controlled by the addition of caustic soda.

4.6.5 Waste Removal from the 'Wet Type' System

The function of the wet scrubbing system is to neutralise and remove pollutants from the incinerator exhaust gases prior to discharge to atmosphere. Many of these pollutants are collected in the scrubber effluent and therefore must be removed to prevent fouling of the system and a subsequent degradation of performance. This is achieved by pumping effluent from the venturi quench/scrubber and fluidised bed to a settling tank with the aim of settling out the solid materials. After the solids have settled, the liquid waste is decanted into a second tank for discharge to sewer.

Solid materials will concentrate at the base of the settling tank as sludge. As the solids reach a pre-determined level, the sludge material is removed by vacuum tanker and treated by immobilisation for landfill disposal.

4.6.6 Mist Eliminator

The function of the scrubbers is to remove pollutants from the incinerator exhaust gases. To minimise the emissions of pollutants to atmosphere, the quantity of water vapour discharged must be reduced. This is achieved by passing the scrubber exhaust gases through a high efficiency mist eliminator.

4.6.7 Induced Draft Fan

The induced draft fan is used to provide the energy necessary to overcome the considerable resistance to gas flow in the air pollution control plant.

4.6.8 Stack with Exhaust Gas Reheat

The cleaned incinerator exhaust gases enter the base of the stack where they are mixed with hot air (at approximately 140 to 160°C) from the heat exchanger. This ensures that gases are discharged at a temperature exceeding dew point, so that no plume is visible. The stack is of

adequate height to ensure that the ground level concentration of contaminants does not exceed regulatory guidelines. Furthermore, the stack is equipped with a test port and an access platform to permit emission testing of the incinerator exhaust gases.

4.7 DRY TYPE AIR POLLUTION CONTROL SYSTEM

4.7.1 Introduction

This type of air pollution control system is only used at one biomedical waste incinerator in Australia. To illustrate this example we will use the Stephenson and Ward (Medicollect) incinerator in Perth, which was retrofitted with a dry type air pollution control system. The dry system utilises a high efficiency fabric filter with lime and activated carbon injection for efficient particulate, acid gas, heavy metal and dioxin removal.

4.7.2 Process Description

The post-combustion treatment process may be summarised as follows:

- Incinerator exhaust gases discharged from incinerator secondary chamber at 1200°C. The exhaust gases need to be cooled down to approximately 135°C prior to entry into the fabric filter.
- Heat exchange cooling of exhaust gases in the ceramic tube heat exchanger from approximately 1200°C to 650°C whilst generating hot air for use as stack reheat air.
- Adiabatic cooling by the addition of water in the gas quench chamber to a temperature of 150°C.
- Injection of activated carbon and lime into the exhaust gas stream and subsequent contact in a rotary contactor.
- Filtration with activated carbon and lime for particulate, acid gas, heavy metal and dioxin control.
- Final acid gas control in a high efficiency fluidised bed scrubber.

- Free water and mist elimination using a high efficiency mist eliminator.
- Exhaust gas reheat to 130°C using reheat air.
- Discharge to atmosphere from stack of 20 meters in height.

4.7.3 Equipment Description

There are six fundamental parts to this post-combustion system:

- Heat Exchanger.
- Adiabatic Gas Quench.
- Activated Carbon and Lime Rotary Contactor.
- Fabric Filter with Precyclone.
- Induced Draft (ID) Fan.
- Exhaust Stack.

4.7.3.1 Heat Exchanger

The function of this heat exchanger is to cool the exhaust gases from a temperature of approximately 1,100 – 1,200°C to 550 - 650°C, and to provide hot air for exhaust stack gas reheat.

4.7.3.2 Adiabatic Gas Quench

The function of the adiabatic gas quench is to cool the incinerator exhaust gases that exit the heat exchanger to a temperature acceptable for entry into the fabric filter. This is achieved in a downflow co-current reaction vessel into which the exhaust gases are contacted with finely atomised water droplets.

The orientation and dimensions of the gas quench are designed to ensure that all cooling water is evaporated prior to discharge. The gas cooler is equipped with a 180 degree inverted discharge to prevent fouling and minimise carryover of particulate matter from the quench.

4.7.3.3 Rotary Lime and Activated Carbon Contactor

Lime and activated carbon reactants are reacted with the adiabatic quench outlet gases in a rotary contactor.

The rotary contactor, which is similar to a rotary ball mill in operation, consists of a rotating drum containing numerous cast iron or ceramic balls. The hydrated lime and activated carbon are pneumatically conveyed directly into this drum where they are contacted with the incinerator exhaust gases, where the fine particles are entrained in the gas stream whilst the larger particles are retained within the rotating ball mill. These larger particles of lime are readily reduced in size by the cast iron or ceramic balls. The ball mill type rotary contactor results in a high level of absorbent and exhaust gas contact, ensuring an efficient utilisation of the lime and activated carbon.

The rotary contactor also has the significant advantage of breaking away any lime build-up that can occur near the injection point in a dry scrubbing system. This greatly minimises the risk of blockage, which can occur in some systems due to water carryover from the adiabatic quench into the fabric filter.

4.7.3.4 Fabric Filter with Pre Cyclone

The exhaust gases are discharged from the rotary contactor and are first passed through a preliminary cyclone prior to entry into the fabric filter. This cyclone ensures that only small particles of dust or lime can come into contact with the fabric filter, minimising the abrasion on the fabric filter bags. The reactants injected into the fabric filter will form a coating on all surfaces, and the subsequent additional contact of the exhaust gases through the reactants embedded on the fabric filter bags completes the reaction process.

A critical factor in the operation of a cyclone and the fabric filter is the elimination of cold spots or wet spots on the fabric filter casing. Cold spots can result in the condensation of acid gases, which would result in severe corrosion of the cyclone or fabric filter structure.

The cyclone and fabric filters are equipped with a heat-traced hopper, which is well insulated and lined to prevent the formation of cold spots. To prevent cold spots on the top of the fabric filter and to prevent the pooling of water during periods of rain, the fabric filter is equipped with a penthouse cover, which sits over the top of the fabric filter and is of sufficient height to allow all maintenance, including the replacement of bags, to occur within an enclosed and covered environment. The fabric filter is equipped with bypass ductwork and controls to ensure that the incinerator exhaust gases only enter the fabric filter when they are in the appropriate temperature range.

4.7.3.5 Induced Draft Fan

The induced draft fan is used to provide the energy necessary to overcome the considerable resistance to gas flow in the air pollution control plant.

4.7.3.6 Stack with Exhaust Gas Reheat

The cleaned incinerator exhaust gases enter the base of the stack where they are mixed with hot air (at approximately 200°C) from the heat exchange. This ensures that gases are discharged at a temperature exceeding dew point, so that no plume is visible. The stack is of adequate height to ensure that the ground level concentration of contaminants does not exceed regulatory guidelines and is equipped with a test port and an access platform to permit emission testing of the incinerator exhaust gases.

4.7.4 Overview of the Major Australian Biomedical Waste Incinerators

The largest biomedical waste incinerators in use in Australia consist of seven main items; the waste loader, the primary chamber, the ignition zone, the secondary chamber, the heat exchanger, the air pollution control system (APCS) and the stack. This is represented diagrammatically in Figure 7 below.

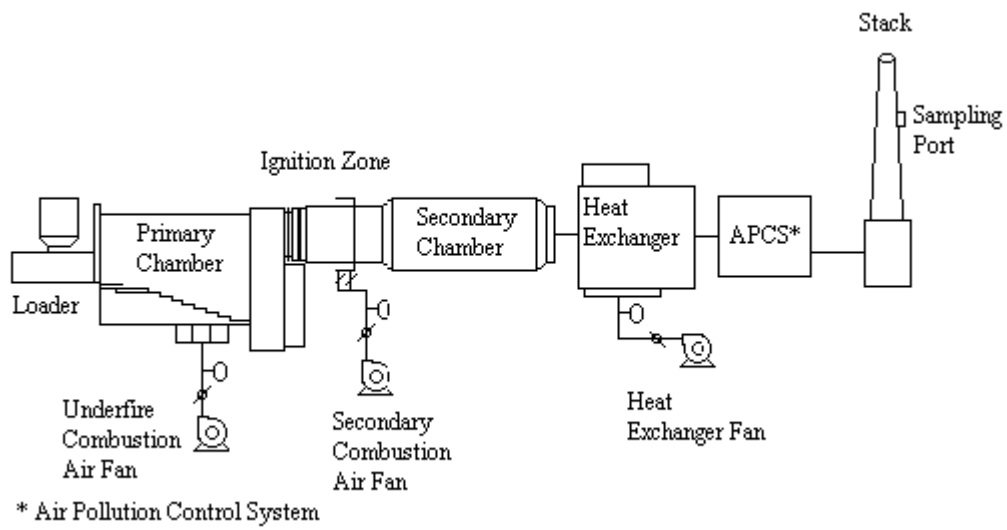


Figure 7. Basic Design of Major Australian Biomedical Waste Incinerators

4.8 COMPARISON OF AIR POLLUTION SYSTEMS

A summary of the capabilities and comparative cost of each type of system is given in Table 8 below:

Table 8. Comparison of Air Pollution Control Systems

Pollutant	Air Pollution Control Plant		
	Wet System	Dry System	Dry-Wet System
Acid Gases	Best Available	Adequate	Best Available
Particulate	Moderate	Best Available	Best Available
Heavy Metals	Very Good	Good	Best Available
Dioxins	Moderate	Very Good	Best Available
Operations Skill	Low	Moderate	High
Operating Costs	Moderate	Low	Moderate
Capital Cost	Low	Moderate	High

(Clunies-Ross and Coccia, 1992)

4.9 EMISSION QUANTIFICATION

Chapter 3 identifies fifteen biomedical waste incinerators in Australia; seven represent hospital incinerators and nine are privately operated.

4.9.1 Releases to Air

Emission data were received from three biomedical waste incinerator operators, who supplied the necessary activity data that enabled Unilabs Environmental to determine and quantify annual dioxin emissions to air. Data received represent a total of 20% of biomedical waste incinerators identified in Australia, but the data representation is probably greater due to the likelihood that some biomedical waste incinerator closures have occurred.

To quantify annual emissions of dioxins, it was necessary to develop two categories to distinguish the known activity data received, from unknown activity data.

Dioxin emission factors for the other twelve incinerators were based on international data contained in the report “A Review of Dioxin Emissions in the UK”(Her Majesty’s Inspectorate of Pollution, 1995). The UK report assumes two ranges of emission factors:

Old plant: 120 – 480 µg I-TEQ / tonne

New plant: 20 – 120 µg I-TEQ / tonne

Where annual waste disposal tonnages were not provided by incinerator operators, disposal tonnages were calculated from the incinerator capacities assuming 85% incinerator availability (approximately 7450 hours).

Australian information used in this report is a good representation of identified waste incinerators. For this report emission ranges have been used to account for

- incinerator operators who had not supplied the relevant information;
- the possible uncertainty when applying the international data to Australia; and
- the variation of different furnace and air pollution control systems used.

It is important to note that the original international emission factors are also subject to uncertainty.

4.9.1.1 Methodology

The annual discharges were calculated by determining the following:

Emission factors to determine the rate of discharge for an activity. Emission factors are expressed as micrograms (µg) I-TEQ per tonne of waste for a process. Where available, results from emission sampling were used to characterise a process. Otherwise internationally accepted emission factors were substituted. The internationally accepted emission factors are often expressed as a range to reflect the expected variability in the processes.

Measuring or estimating the frequency of an activity. Activity was reported as tonnes per annum for a process.

Multiplication of an emission factor by an activity gave an estimate of the mass of the discharge of dioxin, expressed as I-TEQ.

4.9.1.2 Australian Emission Estimates

The estimated air emissions from biomedical waste incinerators in Australia are presented in Table 9. A comparison of the estimated emissions for all waste incineration processes for a range of nations is presented in Table 16.

Table 9. Annual Dioxin Air Emission Estimates for Biomedical Waste Incinerators

Incinerator Description	Emission Factor ($\mu\text{g I-TEQ/tonne}$)	Activity Data (estimated tonnes incinerated/year)	Annual Dioxin Emissions (g I-TEQ/year)
Controlled Air Incinerator with Wet Scrubbing System ¹	4.62	4,800	0.022
	46.8	1,500	0.070
Controlled Air Incinerator with Dry System ¹	0.426	936	0.0004
Unknown technology but source identified	120 – 480	21,000 (Approximate)	2.41 – 9.60
Total:		28,236 ²	2.5 – 9.7

Note:

1. The estimates presented above are principally calculated from data presented to Unilabs Environmental, where it is assumed that the results are most recent (1998/99), unless certificate of analysis is supplied to indicate differently.
2. An estimation of total waste incinerated only, as a certain amount of medical waste is treated and disposed of by other technologies.

In Australia, as in the United States, biomedical waste incineration is the predominant source of dioxin emissions from incinerators. In both these countries biomedical waste incineration is estimated to contribute about two thirds of the total dioxin emissions to air for waste incineration processes (Clunies-Ross and Brash, 1999; USEPA, 1998). In Canada, as with the United Kingdom and many other European countries, the emission of dioxins from municipal

waste incineration predominates (Her Majesty's Inspectorate of Pollution, 1995; Environment Canada, 1999).

4.9.2 Releases to Land and Water

Solid and liquid wastes are the by-products of the incineration of biomedical wastes, which include:

- biologically inert ash/solids from the primary chamber;
- ash deposits collected in the heat exchanger;
- settled solids and clarified water from the gas quench and gas scrubbing processes (if present);
- baghouse residues including captured fly ash combined with any absorbent materials, such as activated carbon and lime (if present).

The above waste streams are likely to contain quantities of dioxins which are primarily disposed of at lined or equivalent landfills, except for the settled solids from the gas scrubbing process, which are treated before disposal. Solids that are entrained with the effluent discharged to sewer would be captured within the treatment facilities and most likely disposed over agricultural land.

Only one incinerator in Australia has a dry type air pollution control system; the remainder are of a wet scrubbing type or have no gas cleaning system at all (hospital incinerators).

No data were available on releases to land and water, so again estimates have to be derived from international data to quantify possible dioxin levels released to land and water.

4.9.2.1 Determining Activity Data

Bottom ash generation for biomedical waste incinerators in the UK was estimated to be 12 to 28% of the waste feed (Her Majesty's Inspectorate of Pollution, 1995). This range would be equivalent to Australian incinerators except for one incinerator operator who is able to achieve a bottom ash generation of approximately 8 to 9% of the waste feed.

Heat exchanger ash deposits as mentioned earlier in this chapter are most likely to contain the highest level of dioxins as this area creates the right conditions for the *de novo* synthesis to occur. The amount of ash generated in this area is unknown.

Wet scrubbing systems remove solid contaminants from the gas stream. These solid contaminants are likely to have dioxins adsorbed onto them, as the scrubbing system is directly after the heat exchanger and dioxins are primarily formed in the post combustion zones of an incineration system. The quantity of solids removed by this system is unknown.

Dry systems also remove solid contaminants using lime and activated carbon; the contaminant is captured on filter bags that are automatically cleaned on a regular basis. The residue that is removed from the filter bags is collected in skips or sealed bags. The quantity of solids removed by this system is unknown.

Wet scrubbing systems use water to remove contaminants from the gas stream. Contaminant-laden effluent is regularly removed from the scrubbers and the solids are usually settled out in settling tanks/ponds (scrubber sludge), then the effluent is discharged to sewer. No further treatment is performed so solids would find their way into the sewer system with the effluent.

4.9.2.2 Probable Australian Dioxin Emission Estimates for Solid/Liquid Wastes

As no data are available, all PCDD/F concentrations for solid and liquid wastes were based on international data contained in the report “A Review of Dioxin Releases to Land and Water in the UK” (Her Majesty’s Inspectorate of Pollution, 1995). The UK report assumes the following ranges of concentration data:

- bottom ash (all plants) 15 - 300 ng I-TEQ / kg (ash)
- gas cleaning (dry) 1,800 – 4,500 ng I-TEQ / kg (residue)
- wet scrubber residue 680 ng I-TEQ / kg (residue)

Releases to land are bottom ash and gas cleaning residues. These releases from biomedical waste incinerators are presented in Table 10. Other releases to land are the heat exchanger ash deposits and liquid from the wet scrubbing process. These have not been quantified, as no data is available internationally or locally, but dioxins are surely present.

Table 10. PCDD/F Releases from Solid & Liquid Wastes from Biomedical Waste Incineration

	Bottom ash (g I-TEQ/yr)	Gas Cleaning Residues (g I-TEQ/yr)
Wet Gas Cleaning System	0.012 - 0.24	0.15
Dry Gas Cleaning System	0.002 - 0.04	0.13 - 0.37
Other*	0.05 - 0.95	0.58
Total	0.053 - 1.2	0.86 - 1.1

Note:

This table does not include PCDD/Fs released through heat exchanger ash and clarified water from wet gas cleaning systems due to a lack of data.

* Batch type incinerators.

CHAPTER 5

SEWAGE SLUDGE INCINERATORS

Sewage sludge incineration was one of the incineration processes mentioned in the PAE Study (1998) as a potentially significant source of dioxins and furans, but lacked current Australian activity data to derive emission estimates. The PAE Study (1998) report briefly described six types of sewage sludge incinerators without reference to air pollution control equipment.

This chapter will provide necessary information about the waste stream and processing and endeavour to discuss Australian technologies, activity data and air pollution control equipment to derive dioxin emission estimate.

5.1 INTRODUCTION

Two sewage sludge incinerators have been identified in Australia; one operates in the ACT and the other in the Northern Territory. A written response was received from Australian Capital Territory Electricity and Water Corporation (ACTEW) but information on the Northern Territory was unavailable.

To illustrate a sewage sludge incinerator we will use the multiple hearth incinerator operated by the ACTEW. This facility incinerates 1.5 tonnes/hour of sludge cake generated from the Lower Molonglo Water Quality Control Centre (LMWQCC), which is the main sewage treatment facility for the Canberra area.

5.2 PROCESS DESCRIPTION

Prior to incineration of the sludge, it is typically dewatered until it is about 15 to 30 percent solids, at which point it will burn without supplemental fuel. Unburnt residual ash is removed

from the incinerator, usually on a continuous basis, and landfilled. A portion of the non-combustible waste, as well as unburnt VOCs, is carried out of the combustor through entrainment in the exhaust gas stream. These gases are then treated by a wet scrubbing process.

5.2.1 Multiple-Hearth Incinerator

The basic MHF is cylindrical in shape and is oriented vertically. The outer shell is constructed of steel and lined with refractory material and surrounds a series of horizontal refractory hearths, while a hollow, rotating shaft runs through the centre of the hearths. Attached to the central shaft are the rabble arms, which extend above the hearths. Each rabble arm is equipped with a number of teeth and, as the central shaft rotates, the teeth on the rabble arms rake through the sludge and break up the solid material in order to increase the surface area exposed to heat and oxygen. The teeth are arranged on the arms to rake the sludge in a spiral motion, alternating in direction from the outside in and from the inside out between hearths. Burners located in the sidewalls of the hearths provide supplemental heat when necessary.

Partially dewatered sludge is fed onto the perimeter of the top hearth by conveyors or pumps. The motion of the rabble arms rakes the sludge toward the centre shaft, where it drops through holes onto the next hearth below and is raked in the opposite direction.

This process is repeated on all of the subsequent hearths. Scum (material that floats on wastewater and is generally composed of vegetable and mineral oils, grease, hair, waxes, fats, and other materials that will float) may also be fed to one or more hearths. Scum may form in many treatment units, including the preparation tanks, the skimming tanks, and the sedimentation tanks. Quantities of scum are generally small compared to other wastewater solids.

Most of the moisture in the sludge is evaporated in the drying zone, which comprises the upper hearths of an MHF. The temperature in the drying zone is typically between 425 and 760°C. Sludge combustion occurs in the middle hearths as the temperature is increased to

between 800 and 1000°C. The cooling zone comprises the lowermost hearth(s), where the ash is cooled by the incoming combustion air.

5.3 AIR POLLUTION CONTROL SYSTEM

This process utilises a wet scrubbing process to clean exhaust gases.

5.4 EMISSION QUANTIFICATION

Emission and activity data received from one of the two sewage sludge incinerator operators identified by this consultancy enabled Unilabs Environmental to determine and quantify annual dioxin emissions to air in Australia.

To quantify annual emissions of dioxins, it is necessary to develop two categories to distinguish the known activity data that have been received from unknown activity data.

To quantify for the unknown emission factor and activity data, international data were used. The UK report “A Review of Dioxin Emissions in the UK”(Her Majesty’s Inspectorate of Pollution, 1995) identifies emission factors used for the sewage sludge incineration. The UK report assumes the following range of emission factors:

9 - 77 µg I-TEQ/tonne

For the activity data required for sewage sludge incinerators to obtain annual dioxin emission estimates, several assumptions had to be made from available data researched on identified incinerator capacities. Where annual waste disposal tonnages were not provided by the incinerator operators, these were calculated from the incinerator capacities assuming 85% incinerator availability (approximately 7450 hours).

Australian information used in this report is a good representation of identified waste incinerators. For this report emission ranges have been used to account for (1) incinerator

operators who had not supplied the relevant information; (2) the possible uncertainty when applying the international data to Australia; and (3) the variation of different furnace and air pollution control systems used. It is important to note that the original international emission factors are also subject to uncertainty.

5.4.1 Methodology

The methodology used to quantify emissions is very simple. The emission factors are multiplied by the relevant 'activity data' to determine annual dioxin emission estimates. For example, the waste incineration emission factors are typically in units of 'micrograms per tonne waste incinerated', multiplied by the activity data, which is the annual quantity of waste incinerated.

5.4.2 Australian Emission Estimates

The emissions for each of the dioxin sources covered by this report are quantified in Table 11 below. The final emission estimate is determined by multiplying the first column by the second and gives a result in grams per year.

Table 11. Annual Dioxin Emission Estimates for Sewage Incineration

Incinerator Description	Number of Incinerators Identified	Emission Factor (µg I-TEQ/tonne)	Activity Data (tonnes incinerated/yr)	Annual Dioxin Emissions (g I-TEQ/yr)
Multiple Hearth Incinerator with Wet Scrubbing Process	1	0.135	13,000	0.002
Unknown technology but source identified	1	9 - 77	10,000	0.09 – 0.77
Total	2		23,000	0.09 – 0.77

CHAPTER 6

HAZARDOUS WASTE INCINERATION

Hazardous waste incineration was one of the incineration processes mentioned in the PAE Study (1998) as a potentially significant source of dioxins and furans, but lacked current Australian activity data to derive emission estimates. The PAE Study (1998) report briefly described five types of hazardous waste incinerators without reference to air pollution control equipment.

This chapter will provide necessary information about the waste stream and processing and endeavour to discuss Australian technologies, activity data and air pollution control equipment to derive annual dioxin emission estimate.

6.1 INTRODUCTION

Hazardous waste incinerators generally dispose of chlorinated hydrocarbon wastes. Other technologies have almost eliminated the requirement for high temperature incineration disposal of hazardous waste, primarily because of public concern (Environment Australia, 1997).

Waste Service NSW, Homebush Bay, is the only incinerator identified in this classification.

6.2 WASTE SERVICES NSW – LIDCOMBE LIQUID WASTE PLANT

6.2.1 Process Description

The Lidcombe Liquid Waste plant receives approximately 100,000 tonnes per annum of industrial waste, from over 5,000 individual companies within NSW. The plant operates on a continuous basis, seven days a week.

The incoming wastes are blended accordingly to calorific value and stored within one of the six 500 m³ tanks located on site. The blended wastes in the storage tanks are processed as a batch, with each batch then processed continuously.

The first main process step is centrifuge separation; this separates the water from the oily sludge. The water is subjected to a number of treatment steps before being discharged to sewer.

The oily sludge is then partially dried in three banks of hollow screw sludge driers, which are heated by a circulating thermal oil stream. The evaporated water and volatile hydrocarbons are condensed and phase separated, with the hydrocarbon phase being used as recovered fuel for the thermal oil heater which, in turn, heats the circulating thermal oil stream.

The solid residue produced by the hollow screw driers is physically and chemically stabilised on site, within a newly commissioned residue processing plant. This stabilised material meets the toxicity characteristic leachate procedure (TCLP) and the specific contaminant concentration (SCC) criteria for waste destined for a conventional landfill.

The main thermal oil heater is a vertical, cylindrical, down-fired furnace, burning natural gas and/or recovered fuel. The process may be summarised as follows:

- A nominal capacity of 3.5 MW firing rate
- A combustion air flow of 6000 Nm³/hour, and operates at
- A combustion zone temperature of 1200°C, with

- A target flue gas oxygen content of 6% v/v and
- A combustion zone residence time of > 2 seconds.

The above conditions are necessary to achieve complete combustion of the recovered fuel, which can contain up to 5% chlorinated hydrocarbons.

Flue gas leaves the radiant combustion zone at around 1000°C and is cooled to 500°C as it passes through the convection bank heat exchanger, preheating the incoming thermal oil stream before it passes through spiral tubing in the radiant zone of the furnace.

Flue gas leaves the convection bank at 500°C and passes through the tube side of a gas/gas heat exchanger, the air heater, where it is cooled to about 250°C. Ambient fresh air is blown, via a fan, through the shell side of the air heater, where its temperature rises to about 250°C. Finally, it is discharged into the base of the flue gas stack to elevate the discharging flue gas to above its dew point and suppress any visible plume.

Because the recovered fuel contains small amounts of chlorinated hydrocarbon, sulphur compounds and silicone oils, the flue gas from the furnace and after the air heater is subjected to caustic scrubbing, to remove acid gases and particulates before discharge to atmosphere. The scrubber is a down flow, co-current venturi scrubber, irrigated with dilute caustic soda (at pH above 8.5).

The scrubbed flue gas, with the particulates and acid gases removed, is now cooled to about 80°C, passes via an induced draft fan to the base of the stack, where it mixes with heated air from the air heater, to give a stack discharge temperature of approximately 120°C. Table 12 represents design emission limits that will be achieved following the installation of a new caustic scrubber in August 1999.

Table 12. Improved Operating Parameters post-installation.

Pollutant	Limit
PCDDs and PCDFs	0.1ng/m ³
Particulate matter	50 mg/m ³
Smoke, Ringelmann shade	1
Soot, Bacharach shade	3
SO _x as SO ₂	50 mg/m ³
NO _x as NO ₂	350 mg/m ³
Sb, As, Pb, Cr, Co, Cu, Mn, Ni, V, Sn	0.5 mg/m ³
Fluorine	1 mg/m ³
Hydrogen sulphide	0.1 mg/m ³
Chlorine	2 mg/m ³
Acid gases as HCl	10 mg/m ³
Sulphuric acid and sulphur trioxide	10 mg/m ³
Hg and compounds	0.05 mg/m ³
Cd, Tl and compounds	0.05 mg/m ³
Organic substances as total carbon	10 mg/m ³
Carbon monoxide	50 mg/m ³

6.3 EMISSION QUANTIFICATION

Investigation revealed only one hazardous waste incinerator operating in Australia. Emission and activity data received from the operator of the plant enabled UniLabs Environmental to determine and quantify annual dioxin emissions to air.

Australian information used in this report is a good representation of identified hazardous waste incinerators, but other types of high-temperature waste-destruction processes may be included in this category at a later date.

6.3.1 Methodology

The methodology used to quantify emissions is very simple. The emission factors are multiplied by the relevant 'activity data' to determine annual dioxin emission estimates. For example, the waste incineration emission factors are typically in units of 'micrograms per tonne waste incinerated', multiplied by the activity data, which is the annual quantity of waste incinerated.

6.3.2 Australian Emission Estimates

The emissions for each of the dioxin sources covered by this report are quantified in Table 13 below. The final emission estimate is determined by multiplying the first column by the second and gives a resultant in grams per year.

Table 13. Annual Dioxin Emission Estimates for Hazardous Waste Incinerators

Incinerator Description	Number of Incinerators Identified	Emission Factor (µg I-TEQ/tonne)	Activity Data (tonnes incinerated/yr)	Annual Dioxin Emissions (g I-TEQ/yr)
Vertical, cylindrical down fired furnace with wet scrubbing system	1	2.59	1,971	0.005

CHAPTER 7

CREMATORIA

Crematoria were mentioned in the PAE Study (1998) as a possible source of dioxins and furans, but lacked current Australian activity data to derive emission estimates. The PAE Study (1998) report briefly described two types of crematoria.

This chapter will provide necessary information about the waste stream and processing and endeavour to discuss Australian technologies, activity data and air pollution control equipment to derive an annual dioxin emission estimate.

7.1 PROCESS DESCRIPTION

There are two types of crematory furnaces (Bremmer et al, 1994):

- ‘cold types’, in which the coffin is placed inside the furnace at a temperature of approximately 300°C; and
- ‘warm types’, where the coffin is placed inside at a temperature of 800°C or higher

When the crematory reaches the operating temperature the coffin is placed on the combustion chamber grate and the ignition burner is fired to attain a target combustion temperature sufficient for the proper reduction of human remains. The afterburner preheats the chamber to the desired temperature, depending on whether the furnace is a ‘cold’ or ‘warm’ type. When the coffin is introduced into the combustion chamber, the burner is ignited, and cremation begins at about 870 to 980°C (USEPA, 1995).

The gases produced during cremation are passed through the afterburner. The cremation process lasts about 2-2.5 hours in the ‘cold’ type furnaces; while between 1.2-1.5 hours is required for ‘warm’ type furnaces; a cool down then follows for 45 minutes to 1.5 hours.

7.2 EMISSIONS DATA

Emissions data for each of the international studies are presented in Table 14.

Table 14. International Emissions Data for Crematoria

Emission Study	Dioxin Emissions (ng I TEQ/ body burned)
US ^a	
-Emission range	0.097 – 0.776
-Average	0.374
UK ^b	
-Emission range	2400 – 80000
Netherlands ^c	
-Emission range	2400-4900 (28000) ^d
-Average	4000
Australian data	Not Available

a Source: USEPA, 1995.

These emissions data were determined from a speciated profile of the 2,3,7,8-substituted isomers (further discussed below)

b Source: Her Majesty’s Inspectorate of Pollution, 1995.

c Source: Bremmer et al, 1994.

d The principal range from which the representative average was attained is 2400-4900; however, the highest value that was presented in the study was 28000 ng/body (quoted from a (former) West Berlin crematory).

7.2.1 US Emission Data

The US emissions factors were determined based on speciated CDD/CDF profiles developed during the testing of two propane-fired crematories over a two-week period. It is unclear as to

whether these crematories were designed to state of the art standards; however, their emissions levels are orders of magnitude below those determined by both of the other studies. The US emissions data are questionable due to the enormous difference between them and the UK and Netherlands data, and the similarity in emissions data between the latter two studies. It is noted that the US crematories tested used afterburners; however, all crematories considered in the Netherlands study also used afterburners.

7.2.2 UK Emission Data

The emission factors presented in Table 14 are based on UK source test data, as well as data presented in the Netherlands study. It was noted that emissions might be high from the UK cremation facilities tested, as the plants were not state of the art. This certainly appears to hold true when the emissions are compared to the US data.

7.2.3 Netherlands Emission Data

The Netherlands study was the only study which defined emissions according to the two furnace types. The following emission rates of dioxins were determined from two sources tested:

- Cold type: 2.4 µg I-TEQ/body; and
- Warm type: 4.9 µg I-TEQ/body.

These emissions from these two furnace types produce the range presented in Table 14. Note, however, that the higher emissions from the warm type crematory furnace were partly attributed to the fact that it utilises flue gas cooling, which results in the formation of a proportion of the CDD/CDF compounds. The maximum emission rate presented in the study was 28 µg I-TEQ/body for a crematory in (former) West Berlin. However, this does not seem to be included in determining the final average emission rate presented above.

7.3 AUSTRALIAN ACTIVITY DATA

Due to the lack of source test data for crematoria in Australia, reliance on international data is required to estimate emissions. The Australian Cemeteries & Crematoria Association supplied activity data on the number of cremations annually. This figure has remained static for 10 years. The UK emission factors were used to form the basis of emissions estimates, as they are very comparable. The UK emission range of 2.4-80 µg I-TEQ/tonne will be used to represent Australian sources.

7.4 EMISSION QUANTIFICATION

Research in this study identified approximately 120 crematories operating throughout Australia (see Chapter 3). Emission data were received from the Australian Cemeteries and Crematoria Association, who supplied the necessary activity data that enabled Unilabs Environmental to determine and quantify annual dioxin emissions to air.

No data locally or internationally were available on residues from cremation.

7.4.1 Methodology

The methodology used to quantify emissions is very simple. The emission factors are multiplied by the relevant 'activity data' to determine annual dioxin emission estimates. For example, the crematoria emission factors are typically in units of 'micrograms per body incinerated', multiplied by the activity data, which is the number of cremations annually.

7.4.2 Australian Emission Estimates

The emissions for each of the dioxin sources covered by this report are quantified in Table 15 below. The final emission estimate is determined by multiplying the first column by the second and gives a result in grams per year.

Table 15. Annual Dioxin Emission Estimates for Crematoria in Australia

Incinerator Description	Number of Types Reported	Emission Factor (µg I-TEQ/tonne)	Activity Data (cremations/yr)	Annual Dioxin Emissions (g I-TEQ/yr)
All	120	2.4 - 80	60,000	0.14 – 4.8

Note:

Emission factors used for crematoria are from the UK report “A review of dioxin emissions in the UK” (Her Majesty’s Inspectorate of Pollution, 1995).

CHAPTER 8

LIMITATIONS OF THIS STUDY

The key problems that Unilabs Environmental faced in carrying out this study were:

1. The apparent unwillingness of some facilities to support the production of this report by supplying the necessary information.

2. Unilabs Environmental made every effort to contact the incinerator operators to determine why they had not responded to the written request for information. The reasons provided may be summarised as follows:
 - EA made no preliminary preparation to strategically involve the waste incineration industry in the whole process. As incinerators are the primary information holders, earlier contact may have improved the provision of information and explained the purpose of the consultancy. As a result, insufficient time was provided to gain the support of board members and other interested parties (including legal representatives) to release the requested information.
 - Concern that information requested may identify the operator and result in unwanted attention.
 - Operators state that some information requested is not required by their regulatory authority and therefore they either do not possess the information required or are unwilling to divulge the information they do have to the consultant.

The consultant's approaches with the support of Environment Australia to State regulatory authorities for relevant information about waste incineration data were partially successful. The authorities preferred the consultant to apply for information under the "Freedom of Information Legislation" which is not an unreasonable request in itself. However, the time constraints for this report did not permit this course of action.

CHAPTER 9

CONCLUSIONS

On an international basis there is low level of incineration activity in Australia, as can be seen in Table 7. This is largely the result of the availability and cost effectiveness of landfill, coupled with a negative public perception of this disposal technique. This is best highlighted by the fact that Australia does not have a municipal waste incinerator, even though this technology is common place in most western countries.

Table 16 summarises the dioxin emissions information gathered by this study and compares it to emissions of other countries.

Dioxins are currently effectively controlled from a number of installations around the world using carbon and lime adsorption processes. Although such technology has been shown to effectively reduce the concentration of dioxins in a gas stream to a level well below the international limit of 0.1 ng/Nm^3 , there are a number of fundamental problems that have limited its use.

Firstly, the installation of such equipment constitutes a major capital expense, typically in the range of 25 - 50% of total capital. Secondly, this technology utilises large quantities of adsorption media, which in turn must be disposed of. With this type of process, dioxins are not eliminated from the environment, merely transferred from one medium (the air) to another (the adsorbent), and ultimately landfill.

Another approach to the problem is the development of an in-situ catalyst to control dioxins. Environmental catalysis now plays a significant role in reducing pollution in our atmosphere. The most common form of this is the catalytic converters on petrol vehicles for reducing NO_x

and VOCs, but considerable progress has also been made in developing catalysts to reduce priority pollutants in emissions from other combustion processes. Some preliminary research conducted during this project indicated that catalysts could be developed to reduce dioxin emissions from waste incineration, and this is now the focus of contemporary research.

A major problem in devising such catalysts is that the dioxin formation mechanisms have only been partially identified. This is despite the expenditure of many hundreds of millions of dollars in research throughout the world over the past three decades. Certain key parameters were deemed to have a significant influence on dioxin formation mechanisms, although insufficient data existed within the operational parameters of particular applications.

Sulphur dioxide (SO₂) is emerging as a significant inhibition mechanism in the control of dioxin formation. According to Raghunathan and Gullett (1996), Griffin (1986) and Ogawa et al. (1996), sulphur minimises dioxin formation rather than destroying or capturing it after formation.

Because of growing public awareness about dioxins and stricter environmental controls being placed upon incineration, many incinerator operators are reviewing the performance of their air pollution control systems at capturing dioxins. Another important area that is currently under reviewed is suppression techniques. These techniques will have enormous benefits if successful, by reducing dioxin formation and thus dioxin emissions to air and particularly to land and water.

Table 16. PCDD and PCDF emissions for Australia, UK, USA, Canada, Netherlands, Austria, Switzerland and West Germany

Incineration Process Category	Australia	UK^a	USA^b	Canada^c	Netherlands^d	Austria^d	Switzerland^d	West Germany^d	New Zealand^e
Biomedical (grams I-TEQ/yr)	2.5 – 9.6	18 – 88	1,600 – 16,000	3.1	2.1	4	2 – 3	5.4	0.26
Hazardous (grams I-TEQ/yr)	<0.5	1.5 – 8.7	11 – 110	1.3	16	6	<1	0.5 – 72	0.001-0.003
Sewage Sludge (grams I-TEQ/yr)	0.09 – 0.77	0.7 – 6	10 – 52	0.3	0.3	<1	Unknown	0.01 – 1.1	0
Municipal (grams I-TEQ/yr)	0	460 – 580	1,300 – 6,700	151.7	382	3	90 – 150	5.4 – 432	0
Crematoria (grams I-TEQ/yr)	0.14 – 4.8	1 – 35	Included in above biomedical	Unknown	*0.2 ^f	*0.1 ^f	*0.42 ^f	*2.1 ^f	0.05-1.68

Note:

- a Source: Her Majesty's Inspectorate of Pollution, 1995.
- b Source: USEPA, 1995.
- c Source: Environment Canada, 1999.
- d Source: PAE Study, 1998
- e Source: New Zealand Inventory of Dioxin Emissions, 1998.
- f Source: Landesumweltamt NRW, (1997).
- * Unified Germany.

CHAPTER 10

RECOMMENDATIONS

We make the following recommendations for further assessment of dioxin emissions into the Australian environment:

There is a need for consistent regulatory requirements for the testing of all incineration processes Australia wide. The testing regime should include the solid and liquid waste streams as well as the air emissions, so as to develop a thorough dioxin inventory.

Waste derived fuel is becoming a favourable method of lowering fuel costs and some industries are now utilising these as supplementary fuels. This report did not include those industries, but because waste derived fuel could possible contain chlorine, there should be a requirement for those industries to report dioxin emissions and be included in the above inventory.

As this report did not review information from all operating incinerator plants, a proper profile of all types could not be established in the Australian context. However it is recommended that the emission factors adopted by Unilabs Environmental be accepted in the interim until more reliable data is available.

Programs should be initiated to investigate the optimisation of incineration processes to reduce emissions of dioxin in the most cost effective and environmentally beneficial way. Further investigation is required into catalytic or inhibitive suppression techniques, for reducing dioxin emissions from combustion processes for potential industry applications such as waste incineration.

Accredited personnel who have the necessary experience and skill should perform the measurement of dioxins in stack gases. A recognised sampling procedure such as USEPA method 23 (modified method 5) should be used as this is the most widely used procedure internationally.

REFERENCES

Addink, R., Van Bevel, B., Visser, R., Wever, H., Slot, P., Olie, K., **1990**, *Chemosphere*, *20* (10-12), 1929.

Addink, R., Olie, K., **1995**, Mechanisms of Formation and Destruction of Polychlorinated Dibenzop-dioxins and Dibenzofurans in Heterogeneous Systems, *Environ. Sci. Technol.*, *29* (6), 1425-1435.

Albrecht, I., Naikwadi, K., Karasek F., **1992**, *Organohalogen Compd.*, *8*, 217.

Bremmer, H.J., Troost, L.M., Kuipers, G., de Koning, J., Sein, A.A., **1994**, 'Emissions of Dioxins in the Neitherlands', Report No. 770501018, RIVM, Bilthoven, TNO, Apeldoorn, Netherlands.

Bumb, R., Crummett, W., Cutie, S., Gledhill, J., Hummel, R., Kagel, R., Lamparski, L., Luoma, E., Miller, D., Nestruck, T., Shadoff, L., Stehl, R., Woods, J., **1980**, *Science*, *210*, 385-390.

Buonicore, A., Davis, W., Pakrasi, A., **1992**, Combustion Sources in *Air Pollution Engineering Manual*, eds. Buonicore, A., Davis, W. Air & Waste Management Association, Van Nostrand Reinhold, 207.

Clunies-Ross, C., Coccia, M., **1992**, *Environment Impact Statement for the Proposed Incineration Facility for the Disposal of Biomedical Waste, Quarantine Waste and Security Documents at Ace Waste Pty Ltd*, Pollution Consulting Services, Kallista, Victoria.

Clunies-Ross, C., Stanmore, B., Millar, G., **1996**, Dioxins in Diesel Exhaust, *Nature*, *381*, 379.

Clunies-Ross, C. **1999**, PhD Thesis “Minimising the Formation of Dioxins in Biomedical Waste Incinerators” Unpublished.

Commoner, B., Shapiro, K., Webster, T., **1987**, *Waste Manage. Res.*, *5*, 327.

Crow, K., **1981**, *Clin. Exp. Dermatol.*, *6*, 243-257.

De Vito, M., Birnbaum, L., Farland, W., Gasiewicz, T., 1995, *Environ Health Perspect* *103*, 820.

Dickson, L., Karasek, F., **1987**, *J. Chromatogr.* *389*, 127-137.

Dickson, L., Lenoir, D., Hutzinger, O., Naikwadi, K., Karasek, F., **1989**, *Chemosphere*, *19*, 1435.

Eiceman, G., Rghei, H. O., **1982**, *Environ. Sci. Technol.*, *16* (1), 53-56.

Encyclopedia Britannica, **1998**, *Britannica CD 98, Multimedia Edition*.

Environment Canada, **1999**, *Dioxins and Furans and Hexachlorobenzene - Inventory of Releases*, January.

Environment Australia, **1997** *Appropriate Technologies for the Treatment of Scheduled Wastes*, Review Report Number 4.

Frankenhaeuser, M., Manninen, H., Virrki, J., Kojo, L., Ruuskanen, J., Vesterinen, R., **1992**, The Effect of the Chlorine/Sulfur Ratio on Organic Emissions from the Combustion of Mixed Fuels, *NESTE Final Report*, Porvoo Finland.

Her Majesty's Inspectorate of Pollution, **1995**, *A Review of Dioxin Emissions in the UK*

Her Majesty's Inspectorate of Pollution, **1997**, *A Review of Dioxin Releases to Land and Water in the UK*.

Gill, J., Quiel, J.M., **1993**, *Incineration of Hazardous, Toxic, and Mixed Wastes, First Edition*.

Grassman, J., Masten, S., Walker, N., Lucier, G., **1998**, *Environ Health Perspect*, 106, Supplement 2.

Greenpeace Australia, **1998**, *Dioxin Hotspots: Known and Potential Sources of Dioxin Pollution in Australia*, prepared by Matt Ruchel and Darryl Luscombe, December.

Griffin, R., **1986**, A New Theory of Dioxin Formation in Municipal Solid Waste Combustion, *Chemosphere*, 15, (9-12), 1987-1990.

Hagenmaier, H., Kraft, M., Brunner, M., Haag, R., **1987**, *Environ. Sci. Technol.*, 21, 1080.

Hagenmaier, H., Kraft, M., Haag, R., Brunner, H., **1988**, *Energy Recovery Through Waste Combustion*, eds. Brown, A., Evemy, P., Ferrero, G., Elsevier Applied Science, Essex.

Hay, A., **1982**, *The Chemical Scythe – Lessons of 2,4,5-T and Dioxin*, Plenum Press, New York.

Herxheimer, K., **1899**, *Münchenere Med. Wochenschr.*, 46, 278.

Huang, H., Beukens, A., **1996**, *Sci. Tot. Environ.*, 193, 121.

Landesumweltamt NRW, **1997**, ‘Identification of Relevant Industrial Sources of Dioxins and Furans in Europe’, LUA Materialien 43, North Rhine-Westphalia State Environment Agency on behalf of the European Commission, DG X1, July.

Lindbauer, R., Wurst, F., Prey, T., **1992**, Combustion Dioxin Suppression in Municipal Solid Waste Incineration with Sulfur Additives, *Chemosphere*, 25, 1409.

Löfroth, G., Zebühr, Y., **1992**, Polychlorinated Dibenzo-*p*-dioxins (PCDDs) and Dibenzofurans (PCDFs) in Mainstream and Sidestream Cigarette Smoke, *Bull. Environ. Contam. Toxicol.*, 48, 789-794.

Luijk, R., Jansen, J., Grovers, H. A., **1992**, *J. Organohalogen Compd.* 8, 99-102.

Mahle, N., Whiting, L., **1980**, *Chemosphere*, 9, 693-699.

McGregor, D., Partensky, C., Wilbourn, J., Rice, J., **1998**, *Environ Health Perspect*, *106* (2), 755.

Milligan, M., Altwicker, E., **1993**, *Environ. Sci. Technol.*, *27*, (8), 1595-1601.

Mukerjee, D., **1998**, Health Impact of Polychlorinated Dibenzo-*p*-dioxins: A Critical Review, *J. Air & Waste Manage. Assoc.*, *48*, 157-165.

Naikwadi, K., Albrecht, I., Karasek, F., **1993**, *Chemosphere*, *27* (1-3), 335-342.

Nestrick, T., Lamparski, L., Crummett, W., **1987**, *Chemosphere*, *16* (4), 777-790.

New Zealand Ministry for the Environment, **1998**, 'New Zealand Inventory of Dioxin Emissions', Phase III Report.

Oehme, M., Larssen, S., Brevik, E., **1991**, Emission Factors of PCDD and PCDF for Road Vehicles obtained by Tunnel Experiments, *Chemosphere*, *23* (11-12), 1699-1708.

Ogawa, H., Orita, N., Horaguchi, M., Suzuki, T., Okada, M., Yasuda, S., **1996**, Dioxin Reduction by Sulfur Component Addition, *Chemosphere*, *32* (1), 151-157.

Olie, K., Addink, R., Schoonenboom, M., **1998**, Metals as Catalysts during the Formation and Decomposition of Chlorinated Dioxins and Furans in Incineration Processes, *J. Air & Waste Manage. Assoc.*, *48*, 101-105.

Pacific Air & Environment (PAE) Study, **1998**, *Sources of Dioxins and Furans in Australia: Air Emissions*.

Passi, S., Nazzaro-Porro, M., Boniforti, L., Gianotti, F., **1981**, *F. Brit. J. Dermatol.*, *105*, 137-143.

Ragunathan, K., Gullett, B., **1996**, Role of Sulfur in Reducing PCDD and PCDF Formation, *Environ. Sci. Technol.*, *30* (6), 1827-1834.

Stieglitz, L., Vogg, H., **1987**, *Chemosphere*, *16*, (8-9), 1917-1922.

Stieglitz, L., Zwick, G., Beck, J., Roth, W., Vogg, H., **1989**, *Chemosphere*, 18 (1-6), 1219-1226.

Stieglitz, L., Vogg, H., Bautz, H., Beck, J., Zwick, G., **1990**, *Organohalogen Compd.*, 3, 175-177.

Swedish Environmental Protection Agency (EPA), **1998**, Monitor 16: Persistent Organic Pollutants - A Swedish View of an International Problem, Stockholm, Sweden.

Taucher, J., Hannah, D., Green, N., Porter, L., Czochanska, Z., Clunies-Ross, C., **1992**, PCDD, PCDF and PCB Emissions under Variable Operating Conditions from a Waste Oil Furnace, *Chemosphere*, 25 (7-10), 1429-1433.

Tchobanoglous, G., Theisen, H., Vigil, S., **1993**, *Integrated Solid Waste Management: Engineering Principles and Management Issues*, McGraw-Hill Series in Water Resources and Environmental Engineering.

Tosine, H., **1983**, in *Chlorinated Dioxins and Dibenzofurans in the Total Environment*, eds. Choudhary, L., Keith, L., Rappe, C., Butterworth, London.

Tupperainen, K., Halonen, I., Ruokojarvi, P., Tarhanen, J., Ruuskanen, J., **1998**, *Chemosphere*, 36 (7), 1493.

US Environmental Protection Agency (USEPA), **1989**, *Exposure Factors Handbook*, Office of Health and Environmental Assessment, July.

USEPA, **1995**, 'Locating and Estimating Air Emission from Sources of Dioxins and Furans', Office of Air Quality Planning and Standards, Research Triangle Park, NC.

US Environmental Protection Agency (USEPA), **1998**, *The Inventory of Sources of Dioxin in the United States, External Review Draft*, EPA/600/P-98/002Aa, April.

Vogg, H., Stieglitz, L., **1986**, *Chemosphere*, 15 (9-12), 1373-1378.

Vogg, H., Metzger, M., Stieglitz, L., **1987**, *Waste Manage. Res.*, 5, 285.

Williams, P., **1994**, Pollutants from Incineration: An Overview in *Waste Incineration and the Environment*, eds. Hester, R., Harrison, R., Royal Society of Chemistry, Letchworth.

Wilson, J.D., Park ,C.N., and Townsend, D.I., **1995**, “Dioxin emissions from full scale hazardous waste combustion units handling variable chlorine feed compositions”, International Incineration Conference, May 8-12, 1995.

World Health Organisation (WHO), **1998a**, *Assessment of the Health Risk of Dioxins: Re-evaluation of the Tolerable Daily Intake (TDI)*, WHO European Centre for Environment and Health, International Programme on Chemical Safety, 25-29 May, Geneva, Switzerland,

World Health Organisation, **1998b**, *Experts Re-Evaluate Health Risks from Dioxins*, *Press Release*, WHO/45, June 3.