Dioxin Discharges from Waste Incineration

Technical Specifications for a National Environmental Standard

August 2001

SINCLAIR KNIGHT MERZ

Dioxin Discharges from Waste Incineration

Technical Specifications for a National Environmental Standard

August 2001

SINCLAIR KNIGHT MERZ

Sinclair Knight Merz Limited
Level 12, Mayfair House
54 The Terrace
PO Box 10-283
Wellington
New Zealand
Telephone: +64 4 473 4265
Facsimile: +64 4 473 3369

Contents

Authors iv

Executive Summary and Recommendations v

1. Introduction 1

2. Scope of a Dioxin NES 3
2.1 Source discharges that should be included in a dioxin NES 3
2.2 Defining incineration 3
2.3 Defining waste 5
2.4 Discharges from activities that should be excluded 8
2.4.1 Crematoria 9
2.4.2 Combustion of certain non-hazardous wastes 9
2.4.3 Other activities 10
2.5 Size threshold 10
2.6 Dioxin-like PCBs 12

3. Design Criteria and Operating Conditions 14

4. Form, Reference Conditions and TEQ 17
4.1 Concentration or mass standard? 17
4.2 Reference conditions 18
4.3 Toxic equivalents and toxic equivalency factors 21

5. Compliance Monitoring and Reporting 24
5.1 Monitoring methods 24
5.2 Sample ports 25
5.3 Accreditation 26
5.4 Sample times 27
5.5 Assessing compliance 27
5.6 Monitoring frequency 28
5.7 Operating conditions during monitoring 30
5.8 Carbon monoxide monitoring method 30
5.9 Reporting 31

Appendix A Basis for a size threshold 33

Appendix B US EPA Waste Definitions 34

Appendix C Specified Wastes Listed in Regional Plans 36

Appendix D Incinerator Operating Conditions in New Zealand Resource Consents 39

References 40

Authors

This report was prepared for the Ministry for the Environment by:

- Philip Millichamp, Sinclair Knight Merz;
- Craig Stevenson, Air and Environmental Sciences Ltd.; and
- Simon Buckland, Ministry for the Environment.

Executive Summary and Recommendations

This report was prepared to provide recommendations on the technical specifications that should be included in any future national environmental standard (NES) for dioxins, which may be promulgated under the Resource Management Act 1991. The focus of this work is on discharges to air from waste incineration processes, but many of the recommendations made are also applicable to other point source discharges that are controlled by a discharge limit. Recommendations cover how a standard should be expressed, and address questions of scope and detail. Because standards for controlling dioxins emissions from waste incinerators are already well established in Europe and North America, information given in these overseas regulations has been used to provide guidance on the form and coverage of a New Zealand dioxin NES.

The recommendations made in this report can be summarised as follows.

- A dioxin NES should apply to discharges from both the incineration and co-incineration of waste.
- Discharges to air that should be subject to a dioxin NES can be specified by providing a definition of incineration and a general definition of waste. Any ambiguity over the meaning of 'waste' can be avoided by listing specific wastes whose discharges upon combustion need to be covered by the NES. This is consistent with international standards.
- Activities whose discharges should be specifically excluded from the NES should also be listed. This list should include crematoria and the burning of virgin wood waste.
- The NES should not include a size threshold. That is, it should be applicable to any facility that discharges dioxin to air upon the combustion of waste, regardless of size.
- Dioxin-like PCBs should be included within the coverage of the NES.
- Incinerator design and operating conditions should be specified by the NES, and these should be consistent with the latest requirements from overseas. They include minimum combustion temperature and residence time, automatic controls and continuous monitoring of carbon monoxide. An out clause on the design and operating requirements should be provided for non-conventional processes.
- Assuming that a discharge limit is specified within the NES, this limit should be expressed as a concentration. This is consistent with international practice and does not unfairly advantage small facilities.
- The discharge limit should be expressed at reference conditions of $0^{o}C$, 101.3 kPa, dry gas and 11% oxygen. Discharge concentrations should be corrected according to these reference conditions. Again this is consistent with common practice.
- The 1997 World Health Organization toxic equivalency factors for human/mammal exposure should be adopted for the dioxins and dioxin-like PCBs. One half the limit of detection should be included for those congeners below measurement detection limits when calculating a toxic equivalents discharge level for compliance against a limit specified in a dioxin NES.

Recommendations relevant to compliance monitoring are as follows.

- Compliance should be measured by sampling and analysis according to US EPA Method 0023A and other US EPA methods to which Method 0023A refers, with analysis of PCBs by US EPA Method 1668A.
- Monitoring sample ports should comply with US EPA Method 1, but with some discretion allowed for existing incinerators.
- Samples should be collected at a point where temperatures are less than the *de novo* synthesis range.
- Both sampling and analysis should be undertaken by IANZ or NATA accredited organisations (or their ILAC equivalent).
- Individual sample times should be at least three hours.
- A minimum of three samples per compliance test is recommended, and compliance should be measured against the arithmetic mean of these samples.
- Monitoring should be undertaken at least every year, reducing to every two years if discharges are less than half the discharge limit specified within the NES. More frequent monitoring should be undertaken for new incinerators in the first year of operation.
- Compliance monitoring should be undertaken when maximum discharges are likely.
- Carbon monoxide should be measured in accordance with US EPA performance specifications.
- Monitoring reports should be submitted within 60 days of testing.
- It is necessary to stipulate minimum requirements for monitoring reports, and the report *Approved Methods for Sampling and Analysis of Air Pollutants* published by the NSW EPA (2000) provides a suitable basis for these requirements.

1. Introduction

A national Organochlorines Programme was commenced by the Ministry for the Environment in 1995 to assess risks to human health and the environment from persistent organochlorine contaminants, including polychlorinated dibenzo-p-dioxins (PCDDs), polychlorinated dibenzofurans (PCDFs)[1] and polychlorinated biphenyls (PCBs). Under the Organochlorines Programme, the Ministry is exploring options for reducing dioxin discharges to air, including establishing a national environmental standard (NES) under the Resource Management Act 1991 in instances where a standard would be efficient and effective in reducing population exposures to dioxins. More detailed information on the Organochlorines Programme is available from the Ministry's web site at: www.mfe.govt.nz/issues/waste/organo.htm.

This report was commissioned by the Ministry for the Environment to progress the development of an NES for dioxin discharges to air. Discharges from industrial combustion sources are identified as one of the major contributors of airborne dioxins to the New Zealand environment (Buckland *et al*., 2000), and the estimated discharges from waste incineration are about 30% of the total from industrial combustion sources. Theoretically, an NES may be established to regulate dioxin discharges at a specified limit, or, in some instances, to prohibit *any* discharge to air. In practice, which of these two approaches is adopted (i.e. limit or prohibit) will vary for each specific source, dependent on a variety of factors including adverse environmental effects, the availability of alternatives and cost considerations.

The brief for this work was to provide recommendations for the *technical specifications* for a discharge standard for *waste incinerators*. That is, the report addresses discharges from a point source for which a *discharge limit* is a regulation within the NES. The report does not address discharges from activities whose discharges have been *prohibited* by the NES.[2] Furthermore, the scope of this work was not to make recommendations on the numerical value of a discharge limit *per se*, although emission limits established in New Zealand by way of resource consent conditions imposed by regional councils are detailed in this report. The rationale for the establishment of an NES for waste incinerators and the justification for the emission limit proposed within that NES are being progressed through other work strands of the Organochlorines Programme.[3] However, in recommending technical specifications, this report assumes that any discharge limit will be consistent with national standards established for waste incinerators in Europe and North America, and also with existing resource consents.

Technical specifications essentially cover how an NES should be expressed, and the discussion within this report addresses questions of scope and detail. These

[1] In this report, 'dioxins' is shorthand for all PCDDs and PCDFs. Dioxins are a family of 210 individual, structurally similar chemicals.

[2] However, aspects of this report, including a definition of waste, will be relevant to discharges that are prohibited by the NES.

[3] See, for example, Wright *et al*., 2001; Stevenson *et al*., 2001.

issues include operating conditions, monitoring methods and measurement reference conditions.

The report is divided into four further sections.

- Section 2 discusses the scope of a dioxin NES, providing definitions of incineration and waste, together with a list of waste materials that should be included and materials that should be excluded from the coverage of the NES.
- Section 3 addresses the need to include design and operating conditions within an NES, and what these should be.
- Section 4 discusses the form of a discharge limit (a mass or concentration limit) and reference conditions.
- Section 5 discusses monitoring and reporting requirements.

The document refers to a number of international standards and guidelines for dioxin discharges from incinerators. The advantages and disadvantages of various approaches are provided. Particular reference is made to the European Commission directive for the incineration of waste (CEC, 2000). These overseas standards form the basis for many of the recommendations made in this report.

2. Scope of a Dioxin NES

2.1 Source discharges that should be included in a dioxin NES

The Ministry has commissioned other work to identify the sources of dioxins in New Zealand (Buckland *et al*., 2000), and to assess whether emission reductions from these sources should be by way of an NES or some other form of policy instrument. The outcome of this work indicates that there is justification for applying regulatory control to the incineration of various wastes, including municipal, clinical, pathological, quarantine, chemical and similar waste materials. Thus the proposed NES will be targeted specifically at discharges to air from waste incineration.

Environmental regulations administered by overseas jurisdictions, such as the United States Environmental Protection Agency (US EPA), have separate standards for specific categories of waste incineration equipment. For example, under US law, municipal waste incinerators (US EPA, 1995b) have to comply with different criteria to hospital/medical/infectious waste incinerators (US EPA, 1997b). The aim of the proposed New Zealand NES is to cover discharges from the incineration of wastes in a range of situations within a single regulatory standard. In the case of waste combusted in purpose-built facilities, this will include pyrolysis incinerators and specialist processes, such as oxygen-enriched systems and plasma processing.[4] Thus, discharges from a large municipal incinerator would be expected to comply with the same requirements of the NES as discharges from a much smaller medical waste incinerator, or from a school boiler in which rubbish is burned. In this respect the approach is similar to the European Commission directive on the incineration of waste (CEC, 2000).

In identifying those activities whose discharges are covered by an NES, a clear definition of both *incineration* and *waste* is required.

2.2 Defining incineration

The European Commission directive (CEC, 2000) defines “incineration plant” as:

> *… any stationary or mobile technical unit and equipment dedicated to the thermal treatment of wastes with or without recovery of the heat generated. This includes the incineration by oxidation of waste as well as other thermal treatment processes such as pyrolysis, gasification or plasma processes in so far as the substances resulting from the treatment are subsequently incinerated…*

[4] Although these technologies may not yet be established in New Zealand, this should not limit the scope of the standard. It is important that dioxin discharges from pyrolysis incinerators, plasma processing etc. are captured and controlled under this NES in the event that such technologies, which are commercially available overseas, are introduced into New Zealand as a means of waste disposal.

This definition goes on to include ancillary equipment, such as waste reception, gas treatment systems, air supply systems etc., but it ignores one aspect. The gases produced from pyrolysis, gasification or plasma processing may well be burned in conventional electricity generation or process equipment, so it might be argued that they are not "incinerated". However, the NES should apply to the combustion of these gases. Substitution of "combusted" would cover this point, and the above definition, amended as suggested, is therefore suitable for inclusion in the NES as part of the glossary or list of definitions.

- *The dioxin NES should apply to the incineration and co-incineration of waste.*

Co-incineration activities should be covered by the standard, unless specifically excluded as in the case, for example, of particular types of waste. Co-incineration involves the combustion of waste in a process that primarily uses fuels to produce heat or products. As a hypothetical example, part of a large coal-fired power station might blend solid wastes with the coal. Sometimes there is no clear distinction between activities used primarily for energy production and those used for destruction of waste, nor between *waste* and *fuel*. The European Commission directive defines a co-incineration plant as:

> *… any stationary or mobile plant whose main purpose is the generation of energy or production of material products and:*
> - *which uses wastes as a regular additional fuel; or*
> - *in which waste is thermally treated for the purpose of disposal.*
>
> *If co-incineration takes place in such a way that the main purpose of the plant is not the generation of energy or production of material products but rather the thermal treatment of waste, the plant shall be regarded as an incineration plant…*

The phrase "main purpose" is not defined in this definition, but the directive later distinguishes co-incineration from incineration when less than 40% of the resulting heat release comes from burning hazardous waste.[5] This distinction is applied when stipulating different emission criteria for certain contaminants (other than dioxins). Otherwise, the distinction between incineration and co-incineration is as worded above and this applies to different requirements for operating conditions, and a more stringent oxygen reference correction for dioxin emissions from co-incineration plants (CEC, 2000).

Since the NES addresses dioxin only, there is no need to define co-incineration of *hazardous wastes* as in the European Commission directive. Nor should the reference oxygen criteria be substantially different for different incineration activities for the reasons discussed in Section 4.2 of this report. The only differences should be in the operating and oxygen conditions, as described in Section 3. This means that the above extracts from the European Commission directive for incineration and co-incineration should be sufficient for defining the processes whose discharges are to be covered by the standard.

[5] Hazardous waste is also defined by way of European Commission directive 91/689/EEC of 12 December 1991, which provides a comprehensive list of materials.

2.3 Defining waste

Waste could be defined generally, with specified exclusions such as uncontaminated wood waste; or it could be defined specifically, whereby all types of wastes for which dioxin discharges from combustion may be a concern are named. However, the range of waste materials is exceedingly wide and it would be difficult to ensure that all wastes of possible concern are included in any specific definition. In addition, a given waste, which on its own may not be a significant dioxin source when incinerated, could emit comparatively higher levels if incinerated with other waste streams with a higher dioxin discharge potential, such as chlorinated materials. Accordingly, the former approach of a general and inclusive waste definition, with specified exclusions, is the more practical option.

- *Discharges to air from activities that should be subject to a dioxin NES can be specified by providing a general definition of waste.*

This approach is consistent with the European Commission directive, which gives a very general definition of waste when describing the application of its incineration standard. This directive also distinguishes between hazardous wastes and other wastes, as described above, but the principal definition of waste is referred to a separate directive on waste, namely directive 75/442/EEC (EC, 1975). This directive describes waste as “any substance or object which the holder disposes of or is required to dispose of pursuant to the provisions of national law in force”. Directive 75/442/EEC defines disposal as meaning “the collection, sorting, transport and treatment of waste as well as its storage and tipping above or under ground”, and “the transformation operations necessary for its reuse, recovery or recycling”.

In contrast, the US EPA has more specific definitions for waste, which apply to the particular standard regulating emissions. Appendix B gives the definitions for municipal wastes, and hospital, medical and infectious wastes. While providing more comprehensive lists than the definition given in the European Commission directive, they still do not represent a definitive listing of all possible waste streams. Nor can they simply be uplifted directly to a New Zealand NES because they are specific to the particular US standards.

The OECD has also developed a general definition of waste. It is appropriate to look closely at this definition, not least because:

- the OECD is working to harmonise the definition of waste across all member countries
- New Zealand is a member of the OECD.

The OECD definition, as set out in OECD decision C(88)90(FINAL), defines waste as: “Materials other than radioactive materials intended for disposal for reasons specified in Table 1.”

Table 1 consists of 16 reasons why materials are intended for disposal. These are presented in Box 2-1. In view of the comprehensive character of Box 2-1, it appears that any material (other than radioactive material) is a potential waste. Consequently, the definition of the term “waste” in the context of the OECD decision hinges on the definition of disposal, which is set out in Table 2 of OECD decision C(88)90(FINAL). This table consists of two sections: Table 2A (the “D List” – final disposal operations) and Table 2B (the “R List” – recovery operations). In other words, the definition of waste hinges on the intended destination of a material. The R List includes activities such as recycling, recovery, reclamation and reuse. In contrast, the D List includes incineration, release into a water body, deposit to land (for example, landfill), and permanent storage (for example, emplacement of containers in a mine), which reflects the final disposal of a material.

It is evident, therefore, that both the OECD approach as set out in decision C(88)90(FINAL) and the European Commission directive 75/442/EEC are consistent with each other, being based on a general definition of waste that incorporates both final disposal and recycling/ recovery/reuse operations.

■ Box 2-1 Reasons why materials are intended for disposal

The OECD definition of waste, as set out in OECD decision C(88)90(FINAL), gives the following reasons why materials are intended for disposal:

1. production residues not otherwise specified below
2. off-specification products
3. products whose date for appropriate use has expired
4. materials spilled, lost or having undergone other mishap including any materials, equipment, etc. contaminated as a result of the mishap
5. materials contaminated or soiled as a result of planned actions, e.g. residues from cleaning operations, packing materials, containers, etc.
6. unusable parts, e.g. reject batteries, exhausted catalyst, etc.
7. substances which no longer perform satisfactorily, e.g. contaminated acids, contaminated solvents, exhausted tempering salts, etc.
8. residues of industrial processes, e.g. slags, still bottoms, etc.
9. residues from pollution abatement processes, e.g. scrubber sludges, baghouse dusts, spent filters, etc.
10. machining/finishing residues, e.g. lathe turnings, mill scales, etc.
11. residues from raw materials processing, e.g. mining residues, oil field slops, etc.
12. adulterated materials, e.g. oils contaminated with PCBs, etc.
13. any materials, substances or products whose use has been banned by law in the country of exportation
14. products for which there is no further use, e.g. agriculture, household, office, commercial and shop discards, etc.
15. materials, substances or products resulting from remedial actions with respect to contaminated land
16. any materials, substances or products which the generator or exporter declares to be wastes and which are not contained in the above categories.

Two recent publications from the Ministry for the Environment (MfE, 2001a; 2001b) define waste as: “Any material, whether it is a liquid, solid or contained gas, that is unwanted and unvalued and discarded or discharged by its holder”. By using “discarded” and “discharged”, this definition contains elements similar to that of the OECD, reflecting the concept of disposal of waste. It is also slightly more specific by stating that a material may be a liquid, solid or contained gas. A major difference between the Ministry for the Environment and OECD definitions is the words “unwanted” and “unvalued”. For defining waste within a legal framework (such as an NES within RMA regulations), it is prudent to avoid language such as “unwanted” and “unvalued”. These descriptive words are open to differing interpretation; for example, a material that is unwanted and unvalued by one person may be wanted and valued by another.

Because the NES focuses on dioxin discharges to air from waste incineration, it is not necessary that gases (contained or otherwise), be captured by the definition.

There are advantages in excluding gases from the definition, to avoid any ambiguity over, for example, the flaring of landfill gas. A definition of waste should therefore be limited to materials that are either liquid or solid.

In summary, a suitable definition of waste that is established for taking action on dioxin discharges to air, and which draws upon elements of the various approaches discussed above is:

> *Any material, whether it is a liquid or solid, that is discarded or discharged for final disposal by its holder.*

Because "disposal" can be taken to reflect a variety of operations, including recycling, recovery and re-use as per the European Commission and OECD definitions, it is also necessary to clarify "disposal" within the context of the NES. Since the intent of the NES is action on the discharge of dioxin from waste incineration or waste burning, it is appropriate that disposal incorporates aspects of the definition given by the European Commission directive for incineration plants. Thus, for the purpose of a dioxin NES, "disposal" should be defined as:

> *Incineration, co-incineration, burning or any other thermal treatment process, with or without recovery of the heat generated.*

Like "unwanted" and "unvalued", the word "waste" is also problematic and needs to be used with care, particularly if used in a general definition as discussed above. Some materials considered as a waste could also be regarded as a *fuel* or *product*, so there is potential for confusion. However, the loopholes generated by ambiguity over the meaning of "waste" can be avoided by listing specific wastes whose discharges upon combustion clearly need to be covered by the NES. This list need not be exhaustive nor as comprehensive as the US EPA definitions given in Appendix B, since the generality of the principal clause will cover wastes not listed.

- *Any ambiguity over the meaning of "waste" can be avoided by listing specific wastes whose discharges upon combustion need to be covered by the NES.*

Some regional councils provide lists in regional plans of specified materials as parts of rules for discretionary or prohibited burning/incineration activities. Appendix C gives lists of waste materials used for this purpose from the Bay of Plenty, Waikato and Otago plans, and the recent discussion document for the future Auckland plan.

These lists were developed for rules that have different functions to the aims of the dioxin NES. They are also different to each other, and there is no clear reason for the differences. However, they all cover similar materials, broadly what is considered unacceptable to burn without controls, and what upon burning will discharge dioxins. On this basis it is appropriate to take elements from the different plans to form a list suitable for inclusion within the NES. The wording for a definition of "waste" when considering action for dioxin discharge upon waste incineration and a list of waste materials that should be included within this action are provided in Box 2-2.

- *A list of wastes whose discharges upon combustion should be covered by the NES can be developed from waste lists already established within regional air plans.*

This still encompasses a relatively simple list of materials. A more comprehensive list of wastes could be obtained from documents such as the European Council directive on hazardous waste (EC, 1991), or, more appropriately, from the work being undertaken by the Ministry for the Environment on defining hazardous waste.[6] Both the European Council and the New Zealand work define specific materials along with constituents and properties which may make wastes hazardous. However, because the aim of the current work for action on dioxin is to provide a general definition, it is not considered necessary to include a detailed or comprehensive list of wastes.

■ Box 2-2 A definition of waste and a list of waste materials established for the purposes of action on dioxin discharges to air

Proposed definitions: for the purposes of action on dioxin,

Waste means:

Any material, whether it is a liquid or solid, that is discarded or discharged for final disposal by its holder.

Disposal means:

Incineration, co-incineration, burning or any other thermal treatment process, with or without recovery of the heat generated.

Without prejudice to the generality of the above meaning, waste shall include, but is not limited to, the following:

1. refuse, garbage or municipal waste
2. hospital, medical, clinical, pathological or veterinary waste
3. quarantine waste
4. sludge or solids derived from liquid-borne municipal, industrial or trade waste
5. agricultural chemicals or agricultural chemical waste
6. wood preservatives or biocides
7. wood wastes including:
   a) plywood
   b) particle board
   c) wood waste and timber that may contain halogenated organic compounds, including pentachlorophenol (PCP), or heavy metals as a result of treatment with wood preservatives or coatings, or
   d) wood waste originating from construction and demolition waste
8. plastic, rubber, resins or adhesives
9. paints, inks, dyes, pigments, liquors, varnishes, or other surface coatings
10. halogenated solvents or solvent residues
11. waste liquids, including used oil or other waste petroleum products, with a calorific value of 30 MJ/kg or less, or containing 10 mg/kg or more of polychlorinated aromatic compounds, PCP or polychlorinated biphenyls (PCBs), or 1000 mg/kg or more of chlorine
12. unidentified chemicals or laboratory residues
13. waste from contaminated sites or buildings
14. motor vehicles or vehicle parts, or any other combination of metals and combustible material.

2.4 Discharges from activities that should be excluded

Having established a general definition of waste and a list of waste materials that should be covered by the NES, it is necessary to define those activities whose discharges should be specifically excluded from the standard. This should address human and pet crematoria, combustion of fuels, and certain wastes that do not contain hazardous substances or materials.

■ *Activities whose discharges should be specifically excluded from the NES should be listed.*

[6] See http://www.mfe.govt.nz/issues/waste/hazwaste.htm, and http://www.environment.govt.nz/NZWLOnline/definition.html.

2.4.1 Crematoria

Human and pet cremation can be considered to be a special case of incineration, usually on a small scale. Unlike medical waste incinerators, for which alternatives are available, either in the form of autoclaves or by transporting waste to a regional facility, no such acceptable alternative may be available for human or pet crematoria. Part of the service provided by cremation is a culturally acceptable means of disposal of final remains in appropriate surroundings that are reasonably accessible for the bereaved. Effectively, burial appears to be the only likely acceptable alternative to cremation for human remains, but this alternative is not acceptable to all people. There are also practical difficulties associated with some technical aspects of an NES, as proposed within this report, if they were to be applied to crematoria.[7]

If crematoria were to be regulated by a national standard at some later date, then a standard for dioxin discharges specific to this activity would be the more appropriate course of action. This has been the approach in Germany and the UK, where specific regulations for crematoria have been established (27.BImSchV, 1997; DoE. 1995).

2.4.2 Combustion of certain non-hazardous wastes

Some materials often considered wastes might be more appropriately termed fuels because they are primarily used to generate energy or material products, and burn with similar discharge characteristics to fuels like coal, oil or gas. These materials include vegetable waste or woodwaste used in thermal plants in the timber processing industry, black liquor in the pulp and paper industry, and certain liquid wastes with a high calorific value (residues from an oil refinery for example, or waste oils).

In the case of vegetable or wood wastes, a distinction must be made between virgin or clean materials and waste that may be contaminated with resins and hardeners etc. (for example, particle board, plywood), or that may have been chemically treated with, for example, halogenated organic compounds (such as chlorothalonil, a chlorinated antisapstain agent) or copper-containing compounds. The latter should be included within the definition of waste, and therefore its use as a fuel would be considered either incineration or co-incineration.

Waste liquids with a high calorific value burn no differently to oil fuels, and therefore, if not contaminated with hazardous substances or materials, they should be treated no differently. Waste oil, for example, is burned in a range of processes such as asphalt plants and a cement kiln. The European Commission directive defines uncontaminated combustible liquid wastes as non-hazardous wastes if the mass of polychlorinated aromatic hydrocarbons or pentachlorophenol amounts to concentrations below those stipulated by member states, and if the calorific value is greater than 30 MJ/kg. A commonly applied limit for the chlorinated compounds and one stipulated in an early German standard, for example, is 10 mg/kg (17.BImSchV, 1990).

---

7 For example, this report will recommend a minimum three-hour sampling time for measurement of chimney discharges (see Section 5.4); a single cremation lasts for considerably less than this.

High levels of elemental chlorine can lead to dioxin emissions if the contaminated oil or liquid is burnt under poor combustion conditions and without emission controls. The US EPA defines waste oil containing more than 1000 ppm chlorine as a hazardous waste, and therefore subject to its regulations governing hazardous waste combustors. This chlorine level has been used as a limit in New Zealand resource consents to define waste oil acceptable for burning in various plants. More recently, the Chief Inspector, Explosive and Dangerous Goods, has set a fuel specification of 1000 ppm for halogens if used oil is to be reprocessed as a fuel oil (MfE, 2000).

2.4.3 Other activities

The European Commission directive excludes two other activities from the scope of the standards: waste from the exploration and exploitation of oil and gas from off-shore installations, and small-scale experimental plants used for research in order to improve incineration technology. There is no need to specify an exclusion in the dioxin NES for discharges from disposal of oil or gas from exploration activity, because these oils can be expected to be covered by the exclusion for liquid wastes with a high calorific value, and gases are not considered within the definition of waste for the NES. However, it does seem sensible to exclude experimental incineration plants from the scope of the NES.

The European Commission also excludes animal carcasses from the scope of its waste incineration directive (CEC, 2000). On the surface, it would appear advisable for the dioxin NES to have a similar exclusion that will allow the burning of animal carcasses to prevent the spread of infectious diseases in the event of a biosecurity risk, such as a foot-and-mouth outbreak. However, there is no need for such an exclusion, because provisions of the Biosecurity Act 1993 will enable the RMA to be overridden in the event of a biosecurity emergency.

A list of materials whose discharges upon combustion should be excluded from the dioxin NES is provided in Box 2-3.

■ Box 2-3 Discharges that should be excluded from the dioxin NES

Discharges that should be excluded from a dioxin NES are those from the following activities:

1. cremation of human beings or pets
2. burning of vegetable wastes from agriculture, forestry or food processing
3. burning of virgin wood and virgin wood wastes
4. burning of waste liquids with a calorific value greater than 30 MJ/kg, containing less than 10 mg/kg of polychlorinated aromatic compounds, PCP or PCBs, and containing less than 1000 mg/kg of chlorine
5. burning of black liquor and fibrous vegetable waste from virgin pulp and paper production
6. incineration plants used for research, development or testing in order to improve the incineration process and which treat less than 50 tonnes of waste per year.

2.5 Size threshold

There is good justification to *include* discharges from very small incinerators in the dioxin NES. This is because the cumulative discharge from small incinerators has the potential to contribute significantly to total dioxin discharges. Unfortunately, it is unlikely to be practicable for small incinerators to operate with acceptable dioxin discharges unless they comply with the same operational requirements (such as temperature, residence time and continuous monitoring for carbon monoxide) as larger units. However, if this measure proved prohibitive to small facilities, reasonable alternatives to small-scale waste incineration are viable. For example, a cost-effectiveness analysis demonstrates that replacement of small medical waste incinerators by autoclaves offers a relatively low-cost means of reducing dioxin discharges (Wright *et al.*, 2001). Transporting such wastes to a regional facility, where available, would be another option.

- *Small incinerators should be covered by the same requirements of the dioxin NES as large incinerators.*

A fundamental problem with specifying a size threshold is that this favours a drive towards the establishment of small incineration facilities. Thus, to avoid compliance with a dioxin NES, a waste operator may prefer to build a number of smaller incinerators with capacity below the threshold, rather than fewer larger plants with capacity above the threshold. This is likely to lead to a relatively adverse environmental outcome: overseas experience has shown that smaller waste incinerators tend to demonstrate poorer performance with respect to dioxin emissions compared to a larger facility, as the latter is more likely to have greater control over combustion conditions and a better level of pollution control equipment.

Several recent overseas standards have no size threshold. The European Commission, for example, has removed the 10 tonnes per year size threshold from the original proposed directive (CEC, 1999), and the final directive (CEC, 2000) covers almost all size ranges. Similarly, while the US EPA's lower size cut-off for the New Source Performance Standards for "small" municipal waste incinerators is 35 tonnes per day (US EPA, 2000c), this is not small by New Zealand standards and there is no such threshold for hospital/medical/infectious waste incineration (US EPA, 1997b).

Likewise, most regional plans in New Zealand have no size threshold for incineration of trade or industrial wastes. The distinction between discretionary, permitted and prohibited activities tends to be related to the type of waste material to be burned, as discussed in Section 2.3 above. In many cases, however, very small-scale *domestic* waste incineration activities are treated differently. While some local authorities have banned or restricted domestic incineration, others make it permitted subject to certain conditions. For those who have restricted domestic burning, it appears the principal issue is the potential to cause nuisance. Cumulative dioxin discharges may not have been taken into account.

Notwithstanding our recommendation that discharges from small incinerators be included within the scope of the dioxin NES, several sources of information provide a potential basis for a size threshold for small incinerators should excluding these incinerators be the preferred option, and these are discussed in Appendix A. This suggests 10 tonnes per year may be suitable, and would exclude little more than domestic-scale incineration activities from the dioxin NES. However, given that dioxin discharges from the domestic (backyard) burning of waste are not insignificant in the context of total dioxin discharges to air in New Zealand (Buckland *et al.*, 2000), excluding this activity from regulatory control of some form is difficult to justify.

2.6 Dioxin-like PCBs

To date, all overseas regulations established for dioxin discharges from waste incinerators do not consider the dioxin-like PCBs. If controls are required for PCB emissions from, for example, hazardous waste incinerators, they are typically set by way of a separate discharge limit, or as requirements for a specified destruction and removal efficiency (DRE) from the waste stream (for example, 'six-nines DRE' or 99.9999% DRE).

PCBs are known to be formed in incinerators and are present in chimney gases released to the atmosphere (Blumenstock *et al.*, 2000; Wilkström *et al.*, 1998; Wilken *et al.*, 1993). Although published data on PCB concentrations in gaseous discharges from waste incinerators are somewhat sparse, studies have shown that emissions vary considerably between incinerators. Concentrations of dioxin-like PCBs are available, and they appear to contribute anywhere from < 1–20% of total dioxin toxic equivalents (TEQ)[8] for discharge samples, with an average of 2–4% (Pernin *et al.*, 1998; Ehrlich *et al.*, 1996; Espourteille *et al.*, 1996; Sakai *et al.*, 1996; Fängmark *et al.*, 1994; Miyata *et al.*, 1994).

There are a number of arguments for and against including the dioxin-like PCBs in a dioxin NES. These are summarised in Box 2-4.

Overall, given the requirements of the Stockholm Convention and recognising that these contaminants are considered to exhibit dioxin-like toxicity and are included within a harmonised toxic equivalents scheme for dioxins and PCBs established by the World Health Organization (WHO), it is recommended that dioxin-like PCBs should be included within the scope of the dioxin NES.

- *Dioxin-like PCBs should be included within the coverage of the NES.*

It should be recognised, however, that the NES is a dioxin standard, and whilst this includes the dioxin-like PCBs, it is not a standard for PCBs universally. If waste with a high PCB content were to be incinerated (such as PCB oils, electrical ballasts and capacitors), it would be appropriate for the regulatory authority to also require monitoring for total PCB discharges and consideration of DRE requirements.

[8] For an explanation of dioxin TEQ, see Section 4.3.

■ Box 2-4 Including dioxin-like PCBs in an NES: reasons for and against

For inclusion	Against inclusion
1. PCBs, including the dioxin-like PCBs, are emitted from incinerators when waste is combusted.	1. Typically, the concentrations of dioxin-like PCBs emitted are low compared to dioxin, and therefore they contribute only a small fraction to the dioxin TEQ of a discharge.
2. The dioxin-like PCBs are part of the harmonised dioxin TEQ scheme established by the WHO. The argument that they contribute only a small fraction of a discharge TEQ compared to dioxin is immaterial.[9]	2. No other jurisdiction includes the dioxin-like PCBs in their emission standards for waste incinerators. A dioxin NES that includes PCBs will be inconsistent with current international practice.
3. When dioxins are collected from a chimney discharge, PCBs can be collected concurrently; there is no extra sampling cost involved. The increased cost for PCB analysis is only a small fraction (10–15%) of the total costs for a compliance measurement.	3. There are increased analytical costs incurred for the PCB determinations.
4. The collection of PCBs from chimney discharges does not present additional sampling difficulties – US EPA Method 0023A allows for their collection.[10] The additional analytical work is routine, established and verified. EPA methods are available. In summary, there are no technical reasons, either sampling or analytical, for exclusion of the dioxin-like PCBs.	4. There are additional analytical steps involved to determine dioxin-like PCB concentrations, allowing for increased experimental error and reduced analytical precision.
5. The Stockholm Convention on persistent organic pollutants clearly identifies waste incinerators as a source of PCBs. Therefore, by inference, these should be addressed as part of any dioxin action.[11]	
6. Compliance reporting of PCB discharge concentrations will contribute additional data to develop and maintain emission inventories.[12]	
7. The WHO and the European Commission (EC) both include the dioxin-like PCBs in their tolerable intake value for dioxin risk assessment. It is likely other agencies and jurisdictions will progressively incorporate dioxin-like PCBs in environmental and human health criteria (e.g. the EC has signalled its intention to revise the proposed limits for dioxins in food with a view to the inclusion of dioxin-like PCBs).	
8. Including the PCBs in a discharge limit will avoid the need to monitor an incinerator's waste feed for PCBs. Such monitoring is likely to be more expensive than the extra analytical costs of determining dioxin-like PCBs in the discharge.	

9 If this argument were taken to its extreme, analysis would also not be undertaken for any dioxin congener not frequently detected in incinerator discharges. Clearly this is nonsensical; being present at low concentrations is not a justification for exclusion.

10 Method 0023A is the recommended method for the collection of chimney discharge samples for dioxins (see Section 5).

11 In May 2001 New Zealand signed the Stockholm Convention, indicating its intention for ratification. The Convention requires that each signatory develop an action plan for dioxin.

12 An obligation of the Stockholm Convention is the development and maintenance of a source inventory and release estimate for unintentionally produced persistent organic pollutants, which includes the PCBs.

3. Design Criteria and Operating Conditions

A key approach to minimising dioxin emissions from conventional waste incineration is to maintain good combustion conditions, and ensure that the exhaust gas treatment systems operate effectively. Good combustion centres on achieving sufficient temperature and residence time in the presence of excess oxygen to destroy dioxins. Similarly, gas treatment systems rely on careful maintenance at optimal conditions to avoid dioxin reformation via *de novo* synthesis and to capture any dioxins in the gas stream. In particular, the rate of cooling of the gas stream, the feed rate of absorbents (such as activated carbon) and the temperature of the particulate control equipment are all critical.

Operating conditions in many incinerators can vary considerably from day to day. A well-designed standard should therefore aim to ensure consistent operation at optimal conditions. A simple discharge limit, on its own, may not be sufficient because, unfortunately, continuous dioxin monitoring techniques are not yet available. Current monitoring methods can only provide intermittent or spot checks on the discharge. There is therefore a strong case for including suitable limits on relevant parameters that can be continuously monitored, and that would indicate good combustion conditions were being achieved and maintained.

Many overseas waste incinerator standards follow this practice, and include combustion specifications in addition to a discharge limit, although the specific conditions differ among international jurisdictions. For example, the Western Australia guideline for biomedical waste specifies a final chamber temperature and residence time of 1100°C for one second, or 1000°C for two seconds, in the presence of at least 6% oxygen (WA EPA, 1998). The European Commission directive on the incineration of waste stipulates 1100°C for two seconds for hazardous wastes with more than 1% halogenated organic substances, and 850°C for two seconds for other wastes (CEC, 2000). Interestingly, the final wording of the European Commission directive does not specify an oxygen limit. A minimum oxygen level of at least 6% was stipulated in the European Commission waste incineration directive during its development (CEC, 1999). However, this proposal was rejected since it was noted that this would hinder the development of new incineration techniques (CEC, 1999).

- *Incinerator design and operating requirements should be specified by the NES. These requirements should ensure efficient combustion of the waste and minimise the discharge of dioxin.*

The latest European Commission directive also has a clause that allows for different conditions to be specified by member states to account for certain categories of waste or thermal processes where the above conditions do not apply (CEC, 2000). A similar out clause for non-conventional processes should be provided in the New Zealand NES. However, it is important that any alternative conditions that are stipulated are sufficient to ensure dioxin discharges remain consistently below the discharge limit.

- *An out clause on the design and operating requirements should be provided for non-conventional processes.*

The combustion requirements frequently coincide with other specifications. The Western Australia guideline stipulates temperature interlock requirements and control equipment temperature limits. The European Commission directive limits carbon monoxide concentrations, and requires interlocks to prevent waste combustion whenever the required conditions are not met (CEC, 2000). Carbon monoxide is a commonly used indicator of good combustion. It is relatively easy to measure continuously and is used in many combustion devices for combustion control. Concentrations of this parameter above certain levels indicate inefficient combustion and potential for higher discharges of dioxin. Limits imposed by the European Commission directive for carbon monoxide include 10-minute averages, 30-minute averages and daily average values, so the potential for poor combustion conditions is well controlled. These limits are recommended for the NES and are listed in Box 3-1.

For some of its waste incineration standards, the US EPA also limits carbon monoxide concentrations in the flue gas and requires monitoring of activated carbon feed and temperature of the particulate control device (US EPA, 1995b). They do not, however, specify minimum temperature or residence time requirements. In this regard, the EPA standards have a slightly greater focus on the pollution control equipment than on combustion conditions. In addition, the US EPA standards include requirements for state-approved operator training and certification.

- *Operating conditions should be consistent with the latest requirements from overseas.*

Resource consent conditions in New Zealand follow broadly similar approaches to the European Commission directive, with combustion temperature and carbon monoxide monitoring requirements. Those waste incinerators that have a dioxin discharge limit on their resource consent are listed in Appendix D, together with the operational requirements specified in the consent. It is appropriate to adopt operating conditions that are consistent with the latest requirements from overseas. On this basis, it is recommended that the conditions imposed by the European Commission directive on waste incineration are adopted for a dioxin NES. These include the above temperature and residence times, automatic start-up criteria, carbon monoxide limits and general requirements for control and monitoring. The full wording for these requirements adapted for a dioxin NES is given in Box 3-1. It includes some modifications to the carbon monoxide limits specified in the European Commission directive to overcome some potential ambiguities.

Many will argue against including design and operating requirements as part of a dioxin NES. Strictly, an NES should only be concerned with limiting dioxin discharges to air, while allowing the industry to determine how it can comply. Furthermore, if the discharge is within acceptable limits, then incinerator operating conditions or other factors are irrelevant. It is conceivable, for argument's sake, that advanced flue gas control equipment could be capable of minimising dioxin discharges even from a very badly controlled combustion process. This argument is attractive because it advocates a relatively simple, non-prescriptive standard. However, current emission control technology relies heavily on the performance of *both* the combustion systems *and* equipment operating conditions, and it is unlikely that significantly more advanced technologies will be available in the near future. At this stage it is therefore important to specify both process conditions and other continuous monitoring systems, which should ensure dioxin discharges consistently remain below the discharge limit specified within the NES.

■ Box 3-1 Suggested design and operating requirements

Facilities subject to this standard shall meet the following design and operating requirements.

1. Incineration plants shall be designed, equipped, built and operated in such a way that the gas resulting from the process is raised, after the last injection of combustion air, in a controlled and homogeneous fashion and even under the most unfavourable conditions, to a temperature of 850°C, as measured near the inner wall or at another representative point of the combustion chamber as authorised by the competent authority, for two seconds. If waste with a content of more than 1% of chlorinated organic substances by weight, expressed as chlorine, is incinerated, the temperature has to be raised to 1100°C for at least two seconds.
2. Each line of the incineration plant shall be equipped with at least one auxiliary burner. This burner must be switched on automatically when the temperature of the combustion gases after the last injection of combustion air falls below 850°C or 1100°C as the case may be. It shall also be used during plant start-up and shut-down operations in order to ensure that the temperature of 850°C or 1100°C as the case may be is maintained at all times during these operations and as long as unburned waste is in the combustion chamber.
3. During start-up and shut-down or when the temperature of the combustion gas falls below 850°C or 1100°C as the case may be, the auxiliary burner shall not be fed with fuels which can cause higher emissions than those resulting from the burning of natural gas, liquefied gas or oil fuels.
4. Co-incineration plants shall be designed, equipped, built and operated in such a way that the gas resulting from the co-incineration of waste is raised in a controlled and homogeneous fashion and, even under the most unfavourable conditions, to a temperature of 850°C for two seconds. If waste with a content of more than 1% of chlorinated organic substances by weight, expressed as chlorine, is co-incinerated, the temperature has to be raised to 1100°C.
5. Incineration and co-incineration plants shall have and operate an automatic system to prevent waste feed:
   (a) at start-up, until the temperature of 850°C or 1100°C as the case may be or the temperature specified according to paragraph 4 has been reached
   (b) whenever the temperature of 850°C or 1100°C as the case may be or the temperature specified according to paragraph 4 is not maintained
   (c) whenever there is a disturbance or failure of the plant operation, including emission control equipment, likely to result in any exceedence of a dioxin discharge limit.
6. The following discharge limits for carbon monoxide concentration, corrected to 11% oxygen, 0°C, 101.3 kPa and dry gas basis, shall not be exceeded (excluding start-up and shut-down):
   (a) 50 mg/m^3 of combustion gas determined as a 24-hour or daily average;
   (b) 150 mg/m^3 of combustion gas determined as a 10-minute average for more than 5% of all measurements over a 12-month period; or
   (c) 100 mg/m^3 of combustion gas as a 30-minute average for more than 5% of all measurements over a 12-month period.
7. Conditions different from those above may be authorised by the enforcement authority, in the event of certain wastes being incinerated or co-incinerated, and/or certain processes for which these conditions are not appropriate, provided it can be demonstrated that the discharge of dioxins will consistently comply with the limit imposed by this standard.

4. Form, Reference Conditions and TEQ

Assuming that a discharge limit is specified within the dioxin NES, it is necessary to consider the form this may take, whether it is expressed as a concentration or mass limit, and the conditions to which the limit should be referenced.

4.1 Concentration or mass standard?

When regulating discharges to air, there has been a general tendency by regional councils to impose mass discharge limits for various contaminants on resource consents. Many such limits are expressed as kilograms per hour or grams per second. The mass discharge is directly related to adverse effects because, in general, downwind concentrations are proportional to the mass discharge rate.[13] Consequently such limits are useful for effects-based management. A limit on the mass discharge rate, however, is not appropriate for a dioxin NES.

If imposed, a mass-discharge limit may encourage the use of small, poorly performing incinerators. By virtue of their size, small incinerators will be able to comply with such criteria much more easily than a larger unit, despite discharging comparatively larger quantities of dioxin per volume of waste burnt. Thus, it is possible that a dioxin NES incorporating a mass emission limit could allow for an overall increase in national discharges to air.

An alternative approach is to apply an NES that limits the mass discharge per feed, or some other unit measure of plant size. For example, the US EPA's New Source Performance Standards for secondary aluminium production limit dioxin emissions from "group 1 furnaces" to 15 μg of TEQ per tonne of feed (US EPA, 2000b). This form has universal applicability and has the advantage of being a mass-based limit. Disadvantages include difficulties with the definition and measurement of feed rate or charge. This can be particularly difficult with variable-feed streams or batch systems, or where multiple operations are involved. Despite these difficulties, a mass-per-feed-rate limit should be considered if a future NES is promulgated for non-incineration activities such as metallurgical foundries, where such limits are especially relevant. In these activities the discharges may include a high component of dilution or ventilation air and so it is very difficult to apply a concentration limit.

It may be desirable to apply the same form to an NES for incinerators to ensure consistency of expression. This is not critical, however, and, even if the expression is in a similar form, it may still be necessary to develop different standards for different activities. Furthermore, there is a strong argument for developing an NES for dioxins that is consistent with international standards, even if on the basis of comparability alone. The most common form of dioxin emission standards for waste incinerators overseas is a concentration limit, usually expressed as nanograms of TEQ per standard cubic metre of flue gas (ng TEQ/Sm^3). This is also the way that resource consent conditions have been applied to waste incinerators in New Zealand (see Appendix D).

[13] For the same chimney height and plume rise (as determined by flue gas flow temperature and chimney diameter).

One problem with a concentration limit is the need to account for dilution air. This is relatively simple for many combustion processes where dilution is controlled by the amount of excess combustion air and can be measured by flue gas oxygen concentration,[14] but it may not work for some non-incineration processes.[15] Moreover, even some combustion activities pose problems. Pyrolysis incinerators and liquid waste incinerators, for example, operate effectively with significantly lower excess air in the flue gas than other solid waste incinerators. In recognition of this, several authorities use different reference oxygen contents, depending on the type of equipment. For example, the European Commission directive for waste incineration uses, amongst others, values of 3%, 6%, 10% and 11% oxygen depending on the waste, the facility and the process (CEC, 2000). Thus a concentration standard can be complex and confusing. It will be discussed in more detail in Section 4.2 below.

Another limitation with concentration limits is the potential to unfairly regulate activities with low mass-emission rates and high concentrations in comparison to those with high emission rates and low concentrations. This issue was identified as an area for future regulation in a report for the European Commission and the UK Department of the Environment, Transport and the Regions (Petersen, 1999). However, it is not likely to be a significant concern for waste incineration processes, and is not considered further in this report.

In summary, there are two options: a concentration limit measured at standard or reference conditions, or a mass-per-feed-rate limit with a suitable measurement regime. Both options have advantages and disadvantages. On balance it is recommended that the discharge limit specified within a dioxin NES should be expressed as a concentration limit, which will allow ease of comparison with international standards for waste incinerators.

- *A discharge limit should be expressed as a concentration.*

In any case, a suitable concentration limit will have the same effect as limiting the mass discharge per mass of waste burnt. This is because, for most waste incinerators, there is an approximate correlation between the volume of flue gas discharged (when expressed at reference conditions) and the amount of material burnt.

4.2 Reference conditions

There is some variability amongst international practice with regard to measured reference conditions for concentration limits. Most European standards set reference conditions to 0^{o}C, 101.3kPa, dry gas and 11% oxygen, although the recent European Commission directive for waste incineration (CEC, 2000) and at least one older standard from a member state (Germany; 17.BImSchV, 1990) allows for several reference oxygen contents.

---

[14] In such instances, the flue gas oxygen concentration is corrected back to the reference oxygen content specified, and the concentration of the target analyte adjusted accordingly.

[15] For example, the flue gas from a furnace in a foundry may be diluted considerably by ambient air from within the building. In this case the oxygen concentration will be so close to the ambient air level that any measurement will not provide a reliable indication of dilution.

The European Commission directive specifies reference oxygen contents of:

- 11% for incineration plants;
- 3% for incineration of waste oil;
- 10% for co-incineration in cement kilns;
- 6% for co-incineration in combustion plants (presumably coal boilers, etc.);
- the measured oxygen content when it is less than the relevant reference content for incineration or co-incineration of hazardous waste and when emissions are reduced by exhaust gas treatment.

It is notable that the last requirement would apply to hospital and medical waste incineration (being defined as hazardous waste) but not to municipal solid waste, which does not appear to be defined as a hazardous waste.

In contrast, the US EPA uses one oxygen reference in its various standards for different types of waste incineration, but uses a value of 7% and a different temperature (20°C) (US EPA, 1995b, 1997b and 1999).

The oxygen content is a measure of flue gas dilution from excess combustion air, as discussed earlier. Measured contaminant concentrations are calculated to a reference value according to equation (1) below.

$$C_{ref} = C_{meas}(20.9 - \%O_{2\ ref})/(20.9 - \%O_{2\ meas}) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where:

C_{ref}	is the dioxin concentration expressed at the reference oxygen concentration
C_{meas}	is the dioxin concentration at the oxygen concentration in the emission, expressed on a dry gas basis
$\%O_{2\ ref}$	is the reference oxygen concentration
$\%O_{2\ meas}$	is the measured oxygen concentration in the emission, expressed on a dry gas basis.

There is no need for the NES to specify the procedures to be followed to correct for temperature or pressure, as these procedures are detailed in the US EPA monitoring methods that it is recommended should be used for compliance purposes (see Section 5).

Variable reference conditions make comparisons difficult and give rise to potential confusion. The general European Commission directive conditions of 0°C, 101.3 kPa, dry gas and 11% oxygen for incineration are already commonly applied to most New Zealand resource consents, although without the requirement that correction be done only for emission concentrations exceeding 11% oxygen (Appendix D).

The rationale for the European Commission directive using various reference oxygen concentrations is unclear. Some, such as for combustion of waste oil (3%) and co-incineration of wastes (10% and 6%) may rely mostly on the typical oxygen concentrations at which those processes operate rather than any more general rationale for establishing emission limits. It should also be remembered that the directive covers contaminants other than dioxins and the reference oxygen applies generally. Thus the issue may be complicated by the need to maintain a degree of consistency with other standards, such as particulate discharge limits applied to boilers or cement kilns.

It is questionable whether it is necessary to correct to 11% oxygen at all when discharges are below this level. The effect of lower reference oxygen concentrations, or of not correcting to 11% for oxygen concentrations when less than 11%, is to apply a more stringent limit to the dioxin emission rate. For example, requiring compliance with 0.1 ng TEQ/m^3 at 3% oxygen allows only 55% of the dioxin mass emission rate for 0.1 ng TEQ/m^3 expressed at 11% oxygen.

However, it is recommended that 11% oxygen be adopted as the reference condition for dioxin emissions from any waste incineration process. This practice has the advantage of simplicity and is followed by regional councils to date in consent conditions relating to dioxins. Such an approach is also consistent with the US EPA, albeit using a different value for the oxygen content.

A general 11% oxygen reference could allow larger emissions from co-incineration on a mass-per-feed-rate basis when compared to a dedicated incineration plant. This is because relatively clean combustion gases from the fuel firing will dilute the emissions and make it easier to meet the 11% criterion. However, this is only true if the fuel component of the emissions from the co-incineration plant contains very low concentrations of dioxins, and to some degree this situation also applies to existing waste incinerators, which use supplementary fuel, for example, in the secondary combustion chamber.

Moreover, the higher discharge per feed is not as significant from an effects perspective in these circumstances. The dilution effect from co-incineration may help disperse the discharges, principally because they are likely to be from a larger plant with a higher chimney and more plume rise. Thus the dioxins from relatively small amounts of waste burnt in a co-incineration unit will generally disperse more rapidly than a slightly smaller discharge resulting from the same amount of waste burnt in a dedicated incinerator.

The lower reference oxygen concentrations set by the European Commission for co-incineration processes address the issue of potentially high dioxin emissions on a mass-per-feed-rate-of-waste-combusted basis to only a small degree. For example, decreasing the reference oxygen concentration from 11% to 10% in cement kilns only decreases the dioxin emission allowed by 9%; and decreasing the reference oxygen concentration to 6% decreases the emission allowed by about 45%. These are limited decreases compared with the possible increases in mass-per-feed for small proportions of waste with much larger quantities of conventional fuel. If the possibility of relatively high dioxin emission rates on a mass-per-feed basis in co-incineration plants is a significant concern, adoption of reference oxygen concentrations below 11% does not offer an effective means of limiting such emissions.

It appears that only relatively minor quantities of particular types of waste are likely to be burned in co-incineration plants. It is unlikely that significant quantities of wastes such as municipal solid waste, quarantine or medical wastes would be incinerated in industrial plants other than dedicated waste incinerators, because of the requirements for specialised feed facilities, emission controls for contaminants other than dioxins, and ash handling facilities.

Therefore, taking into account the desirability of a simple and consistent approach and other issues discussed above, it is recommended that the reference conditions for an NES for all incineration and co-incineration facilities should be 0^oC, 101.3 kPa, 11% oxygen and dry gas.

■ *A discharge limit should be expressed at reference conditions of 0 °C, 101.3 kPa, 11% oxygen and dry gas.*

Equation (1) is not appropriate for incineration in oxygen-enriched atmospheres, because oxygen cannot then be used as a reliable measure of dilution. For such situations, the most appropriate approach is for the enforcement authority to establish reference conditions taking account of the process involved. The suggested wording for the reference conditions for the discharge limit within an NES is given in Box 4-1.

■ Box 4-1 Reference conditions

Discharge concentrations shall be referenced to 0^oC, 101.3 kPa, dry gas, 11% oxygen by volume, except when wastes are incinerated or co-incinerated in an oxygen-enriched atmosphere, in which case compliance shall be measured at a reference oxygen content determined by the relevant enforcement authority.

Application of an 11% oxygen reference concentration to combustion products from pyrolysis processes is appropriate, as in the EC directive. Waste processing by pyrolysis or plasma before combustion of the gases produced in air does not significantly affect the ultimate composition of emissions, except to the extent that some of the combustible material (particularly carbon) may not be converted to gaseous form. When this happens, compliance with an emission standard with a reference concentration of 11% oxygen will effectively impose a slightly more stringent limit on a mass-per-feed basis.

4.3 Toxic equivalents and toxic equivalency factors

Toxic equivalents (TEQ) is a common method for expressing the concentration of dioxins. Toxic equivalency factors (TEFs) are used to assess complex mixtures of dioxins and dioxin-like PCB congeners in relation to the most toxic dioxin congener, namely 2,3,7,8 tetrachlorodibenzo-p-dioxin (TCDD). Thus dioxin discharges are normally expressed as the total TCDD TEQ, which is calculated by applying the TEFs to concentrations of individual congeners as follows:[16]

$$TEQ = \sum(PCDD_a \times TEF_a) + \sum(PCDF_b \times TEF_b) + \sum(PCB_c \times TEF_c) \quad \ldots\ldots\ldots\ldots(2)$$

The most common TEF values used throughout the 1990s were the International factors (I-TEF) (Kutz *et al*., 1990). All dioxin emission limits applied to New Zealand incinerators in the past have been expressed as I-TEQ.

16 For a more detailed discussion of the derivation, application and applicability of TEFs, see Smith and Lopipero (2001) or US EPA (2000a).

Although TEFs have been available for the dioxin-like PCBs for a number of years (Ahlborg *et al*., 1994), to date PCBs have not been incorporated into discharge limits for incinerator discharges, either in New Zealand or overseas. Even the recent European Commission directive for the incineration of waste does not include the dioxin-like PCBs (CEC, 2000). However, for the reasons outlined in Section 2.6, it is recommended that a dioxin NES should include the dioxin-like PCBs.

In 1997 an expert group from the WHO reassessed the TEFs for dioxins and PCBs by re-evaluating toxicological effects data on a range of species, and *in vivo* biological data (Van den Berg *et al*., 1998). This resulted in revised human-based TEFs and new TEFs for fish and birds for application in risk assessment studies. These can also be adopted for regulatory purposes. The new TEFs for human/mammal health are the same as the I-TEFs for most dioxin congeners but include a higher value for 1,2,3,7,8-pentachlorodibenzo-p-dioxin and lower values for octachlorodibenzo-p-dioxin and octachlorodibenzofuran.

The 1997 WHO-TEFs produce a more conservative TEQ result from the analysis of samples: it has been suggested that their use will result in an approximate 10% increase in TEQ calculations for body burden exposures compared to the use of I-TEFs for dioxins and the 1994 WHO-TEFs for PCBs (van Leeuwen and Younes, 2000). An assessment of congener profiles from a range of measurements from New Zealand incinerators suggests the 1997 WHO-TEFs will produce a 4 to 14% increase in the TEQ for dioxin discharges (PCBs ignored). Congener profiles from US EPA emission factors for several combustion processes also suggest the increase in TEQ levels will fall within this range.

While many overseas standards and guidelines currently specify older TEF schemes (such as the I-TEFs) and do not include the dioxin-like PCBs, it is reasonable to assume that over time the 1997 WHO-TEFs will become the benchmark for future environmental and human health guidelines and regulations.[17] For example, the recently revised WHO tolerable daily intake for dioxin (van Leeuwen and Younes, 2000) is based on the latest WHO-TEFs, as are the Agency for Toxic Substances and Disease Registry's minimal risk level and dioxin soil criteria (ATSDR, 1998). The recently completed Stockholm Convention on persistent organic pollutants specifies the use of the 1997 WHO-TEFs for the purposes of action on dioxins taken within the framework of this convention. It is also sensible to adopt factors that are based on the most recent research and understanding of dioxin toxicity, and that relate to effects on a wider range of species.

Therefore, it is recommended that New Zealand adopt the 1997 WHO-TEF values from the outset within any new dioxin regulation, including a dioxin NES for discharges to air from waste incinerators. The 1997 WHO-TEFs are presented in Box 4-2.

- *WHO (1997) toxic equivalency factors for human/mammal exposure should be adopted.*

[17] However, the European Commission directive specified use of the I-TEF values, even though the 1997 WHO TEFs were published several years before this directive came into force.

■ Box 4-2 Recommended toxic equivalency factors

Congener	Toxic Equivalency Factor
2,3,7,8-Tetrachlorodibenzo-p-dioxin	1
1,2,3,7,8-Pentachlorodibenzo-p-dioxin	1
1,2,3,4,7,8-Hexachlorodibenzo-p-dioxin	0.1
1,2,3,6,7,8-Hexachlorodibenzo-p-dioxin	0.1
1,2,3,7,8,9-Hexachlorodibenzo-p-dioxin	0.1
1,2,3,4,6,7,8-Heptachlorodibenzo-p-dioxin	0.01
Octoachlorodibenzo-p-dioxin	0.0001
2,3,7,8-Tetrachlorodibenzofuran	0.1
1,2,3,7,8-Pentachlorodibenzofuran	0.05
2,3,4,7,8-Pentachlorodibenzofuran	0.5
1,2,3,4,7,8-Hexachlorodibenzofuran	0.1
1,2,3,6,7,8-Hexachlorodibenzofuran	0.1
1,2,3,7,8,9-Hexachlorodibenzofuran	0.1
2,3,4,6,7,8-Hexachlorodibenzofuran	0.1
1,2,3,4,6,7,8-Heptachlorodibenzofuran	0.01
1,2,3,4,7,8,9-Heptachlorodibenzofuran	0.01
Octachlorodibenzofuran	0.0001
3,3',4,4'-Tetrachlorinated biphenyl (PCB #77)[18]	0.0001
3,4,4',5-Tetrachlorinated biphenyl (PCB #81)	0.0001
3,3',4,4',5-Pentachlorinated biphenyl (PCB #126)	0.1
3,3',4,4',5,5'-Hexachlorinated biphenyl (PCB #169)	0.01
2,3,3',4,4'-Pentachlorinated biphenyl (PCB #105)	0.0001
2,3,4,4',5-Pentachlorinated biphenyl (PCB #114)	0.0005
2,3',4,4',5-Pentachlorinated biphenyl (PCB #118)	0.0001
2',3,4,4',5-Pentachlorinated biphenyl (PCB #123)	0.0001
2,3,3',4,4',5-Hexachlorinated biphenyl (PCB #156)	0.0005
2,3,3',4,4',5'-Hexachlorinated biphenyl (PCB #157)	0.0005
2,3',4,4',5,5'-Hexachlorinated biphenyl (PCB #167)	0.00001
2,3,3',4,4',5,5'-Heptachlorinated biphenyl (PCB #189)	0.0001

When measurements of individual dioxin congeners are below the limit of detection (LOD), it is justified to include these congeners in the TEQ calculation. Several methods may be used, but few discharge standards or guidelines specify a particular approach. The common method in New Zealand is to include half of the LOD as the "measured" concentration. Whilst this is also a common approach overseas, some countries when assessing compliance against guideline or regulatory criteria use the full LOD value. An advantage in including LOD values in calculating discharge TEQ concentrations is that it ensures satisfactory analytical detection limits are achieved using the methods employed. Sampling and analytical procedures commonly used for measuring dioxin discharges to air from point sources (see Section 5) are routinely able to achieve very low detection limits (at the pg/Sm^3 level). Consequently, when assessed against discharge limits, such as the European Commission directive or resource consent limits established by regional councils, the contribution of LOD values to such limits would be expected to be very small even if no dioxin congeners were actually quantified. In conclusion, it is recommended that half LOD values should be included in determining a TEQ discharge level for the purposes of compliance against a discharge limit specified in a dioxin NES.

- *One half the LOD should be included in the TEQ calculations for those congeners below measurement detection limits.*

18 PCB numbering is according to Ballschmiter and Zell (1980).

5. Compliance Monitoring and Reporting

5.1 Monitoring methods

Regardless of the target analyte, when monitoring chimney emissions there is considerable potential for different monitoring methods to produce different results, even when the most rigorous quality assurance procedures are followed. In the case of dioxins, the ultra-trace level at which monitoring is required to be undertaken makes the potential for variability in the results even greater. Compliance with a dioxin NES should therefore be determined using well-established and verified methods. Although several potentially suitable methods are available, it is preferable to limit the monitoring (including analytical) requirements to as few methods as possible. This will help to achieve national consistency, and should contribute to the long-term accuracy and reliability in the application of these methods.

US EPA Method 23 (US EPA, 1995a) or Method 0023A (US EPA, 1996), the revised sampling method, have been used almost exclusively for dioxin discharge measurements in New Zealand. This country also has a good level of experience with measuring dioxins using this method. Other US EPA methods are already commonly used in New Zealand and the Ministry for the Environment's compliance monitoring guidelines recommend a number of US EPA methods for determining key air contaminants (MfE, 1998). It is therefore a logical extension that US EPA methods be adopted as the reference monitoring methods for a dioxin NES.

Methods 23 and 0023A are batch-sampling procedures, where exhaust gas samples are manually extracted from a chimney using isokinetic sampling techniques and taken to a laboratory for sample recovery and analysis. Method 23 is required by other overseas jurisdictions for dioxin measurements, including the New South Wales Environment Protection Authority. One of the differences with the revised Method 0023A is that it allows for modification to provide simultaneous sampling and analysis of PCBs, and is therefore preferred over the older method.

- *Compliance should be measured by sampling and analysis according to US EPA Method 0023A and other US EPA methods to which this refers, with analysis of PCBs by US EPA Method 1668A.*

Method 0023A only provides comprehensive procedures for chimney sampling, but it makes reference to a number of other US EPA methods, which collectively include requirements for sampling, sample recovery and analysis. Reference is made to the relevant sections of US EPA Methods 1, 2 and 5. For analysis, reference is made to Methods 8290 and 8280. Method 8280 covers the quantitation of dioxins by low-resolution mass spectrometry. As such, it is considered to be unsuitable for the quantitation of dioxins at low concentrations, and is therefore not considered appropriate for a dioxin NES.

The analysis of PCBs uses techniques described by US EPA Method 1668A. It is not referred to in Method 0023A and therefore must be specifically listed in the NES.

The recommended EPA methods to be incorporated within the dioxin NES are summarised in Box 5-1.

■ **Box 5-1 US EPA sampling and analytical methods for a dioxin NES**

US EPA method	Application
Method 0023A	Sampling emissions of dioxins from stationary sources. Modified versions of this method allow simultaneous sampling and analysis for PCBs and other semi-volatile organic compounds.
Method 1	Selection of sampling ports and traverse points.
Method 2	Determination of the average velocity and the volumetric flow rate (selection of pitot tube).
Method 5	Isokinetic sampling (for determination of emissions of particulate matter).
Method 8290	Analytical method for the detection and quantitation of dioxins by high-resolution gas chromatography and high-resolution mass spectrometry (HRGC/HRMS).
Method 1668A	Analytical method for the detection and quantitation of PCBs by HRGC/HRMS.

Procedures for all sampling and analytical steps described in these methods require specialist expertise. They are complex, technically demanding and expensive. Such techniques are essential, however, since the levels that dioxins may be present in chimney discharges are such that measurement methods require a capability to detect and accurately quantify ultra-trace concentrations.

5.2 Sample ports

US EPA Method 1 prescribes sample port specifications in detail. These include a minimum distance of eight duct diameters downstream and two duct diameters upstream from any flow disturbance. Unfortunately, it is not always possible to meet these requirements, particularly for existing incinerators, where chimney and duct layout may have been built without considering the requirements of this method. Where these requirements are not met, in many cases existing sampling ports can be covered and new ports installed to meet EPA Method 1 specifications, often at little additional cost. This should always be the preferred option. Even this may not be practical in some instances, however, and some flexibility is therefore necessary to give the enforcement authority some discretion to judge the suitability of sampling ports for existing facilities.

■ *Sample ports should comply with US EPA Method 1, with some discretion allowed for existing incinerators.*

While US EPA Method 1 gives procedures for determining the acceptability of sample locations, and allows for a sample port at least two diameters downstream and 0.5 diameters upstream of a disturbance, this may not eliminate the need for judgement in some cases. The Australian standard method for selection of sampling ports (AS 4323.1-1995) is similar, but arguably less comprehensive than US EPA Method 1. In any case, if US EPA Method 0023A is adopted for sampling and analysis, it is preferable to comply with the corresponding US EPA method for sample port requirements.

It is important that the temperature of the sample port be below the *de novo* synthesis range (approximately 200–450°C) where precursors cool and interact with particulate and ducting surfaces, etc. This is a particular consideration for those incinerators with no control equipment. Measurements above 200°C could give unrealistic results, since dioxin reformation via *de novo* synthesis may be

■ *Samples should be collected at a point where temperatures are below 200°C, which is the lower temperature threshold for de novo synthesis.*

incomplete at this point. In some cases this may not be intentional, but result from a very short discharge chimney that does not provide for flue gases to cool before discharge to atmosphere. In these cases, it could be argued that dioxin formation could be suppressed at the discharge point due to rapid cooling and dilution as exhaust gases mix with ambient air. Unfortunately, the extent of this suppression is not certain and there may be a higher discharge than that measured at elevated temperatures. There are also difficulties associated with sampling hot gases due to the potential for breakthrough from the absorbent media used in the sampling equipment described in Method 0023A, or the possibility of *de novo* synthesis occurring in the sample probe. This can result in measurement of dioxin levels that are not representative of actual levels in the discharge. Consequently it is recommended that sample ports be at locations where the temperature is less than 200^{o}C.

5.3 Accreditation

Any compliance monitoring for a regulatory standard should be undertaken using appropriate quality assurance procedures. Such procedures are particularly important in the case of dioxins, where measurement and quantitation will be required at the ultra-trace level (at or below the pg/Sm^3 level in air discharges) for compliance monitoring. The above US EPA methods incorporate specific quality assurance/quality control procedures and there is a strict regulatory environment in the United States, which has additional requirements on conformity accreditation and operator training. Unfortunately, the US regulatory environment is different and consequently the quality assurance approach of the EPA methods cannot simply be transported to New Zealand. It is necessary, therefore, to ensure that the monitoring is independently accredited for conformity to the particular methods used, and subject to a suitable New Zealand quality assurance system. International Accreditation New Zealand (IANZ) is responsible for such conformity accreditation, and is the New Zealand representative of the International Laboratory Accreditation Cooperation (ILAC).

- *Both sampling and analysis should be undertaken by IANZ or NATA accredited organisations (or their ILAC equivalent).*

At the time of writing there is one New Zealand laboratory accredited for ultra-trace analysis of dioxin samples, but IANZ has not accredited any New Zealand organisation for sampling dioxin emissions (or any other air emissions for that matter). However, several Australian consultants are accredited for sampling by the equivalent National Association of Testing Authorities (NATA). While sampling costs would be higher when using organisations from overseas, Australian consultants have been used in New Zealand in the past for dioxin emission sampling, as well as for other contaminants. Furthermore, it is likely that New Zealand organisations will seek IANZ accreditation within the next few years, particularly in response to the promulgation of a dioxin NES.[19] It has also not been uncommon for environmental samples from New Zealand to be sent to the US for dioxin analysis. Whilst it is more complicated to send air emission samples overseas, it is not impossible by any means, requiring only good co-ordination between the sampling agency in New Zealand and the overseas laboratory.

[19] At least one sampling organisation has already discussed with regulatory agencies the need and requirements for sampling accreditation.

In conclusion, sufficient services are available to recommend that IANZ or NATA accreditation for both sampling and analysis is required for compliance monitoring of a dioxin NES.

5.4 Sample times

Method 0023A specifies how to calculate the minimum sample time necessary to achieve a desired detection limit. This depends on the sensitivity of the analysis and the sample flow rate (which is relatively constrained by the method due to the need for isokinetic sampling). Detection limits for individual congeners should preferably be well below the discharge standard recognising the TEQ calculation protocols. As discussed in Section 4.3, the inclusion of half LOD values in calculating the discharge TEQ concentration should dictate that adequate detection sensitivity is obtained. Nevertheless, to achieve the necessary detection limits will require that sampling be undertaken for a period of several hours per sample.

As well as being important for achieving detection limit sensitivity, sample times must be of a length that will ensure a reasonable representation of incinerator operation. Many incinerators operate with continuously varying conditions, particularly with respect to waste feed. It is therefore necessary to ensure that the sampling time is of sufficient duration to avoid potentially anomalous results.

Some overseas discharge standards stipulate minimum sample times. For example, the US EPA standard for hospital/medical/infectious waste incineration requires a minimum sample time of four hours (US EPA, 1997b). Similarly, the European Commission directive stipulates a minimum of six hours and a maximum of eight (CEC, 2000), whilst the older German standard for waste incinerators stipulates 6 to 16 hours (17.BImSchV, 1990). This longer sampling time of the German standard is likely to reflect, in part, the less sensitive analytical methodologies that were available at the time the standard was promulgated and the need, therefore, for larger sample volumes.

- *Individual sample times should be at least three hours.*

Dioxin sampling of New Zealand waste incinerators has typically been approximately three hours per sample, and this is appropriate for the detection limits that can be achieved using current analytical methodologies (including that specified by US EPA Method 0023A). It has also been the norm for three samples to be collected per test (see Section 5.5), giving a total sample time of nine hours or more. However, these samples may not always have been collected continuously, and indeed may have been collected over a period of days. Nonetheless, there is no need for unnecessarily long sample times, and a minimum of three hours per sample is sufficient to represent incinerator operation.

5.5 Assessing compliance

One compliance measurement should consist of at least three separate samples. This is consistent with US EPA requirements (for example, US EPA, 1995b) and reflects common New Zealand practice. Three samples per compliance measurement will effectively cover a minimum total monitoring period of nine hours if each sample is for the recommended minimum of three hours.

- *A minimum of three samples per test is recommended and compliance should be measured against the arithmetic mean of these samples.*

Compliance should be measured against the arithmetic mean of the three results. This is also consistent with the US EPA requirements (US EPA, 1995b) and this should be included if US EPA monitoring methods are employed. It also provides a greater level of statistical robustness when compared to a one-off sample testing regime.

It may be necessary to consider the situation where one individual sample is over the discharge limit specified in the NES, while the arithmetic mean is not, or when the mean of three results is close to the limit (within sampling and analytical error, for example[20]). While still in compliance, it is possible that such results would serve as a warning, and it would be advisable for the enforcement authority to undertake further investigations, particularly if emissions are trending upwards. Any NES should therefore provide for the possibility for the relevant enforcement authority to require additional testing to be undertaken.

The NES should clearly state that no dioxin monitoring result should exceed the standard. In other words, if the mean of *one* series of three samples is above the limit, then the standard is not being complied with and the enforcement authority will need to respond accordingly, including the possibility of taking enforcement action. While many standards allow other contaminants to exceed the limit for a small percentage of time, such as carbon monoxide, this approach is usually only applied to contaminants where continuous monitoring is undertaken. For dioxins however, where a limited number of measurements is taken, it is advisable not to allow any result to exceed the limit. This is consistent with the European Commission, the US EPA and other international dioxin standards.

5.6 Monitoring frequency

Dioxin discharge measurements are very expensive and monitoring can form a significant portion of the total business costs for some incinerator operations. Reliable monitoring needs to be balanced against imposing costly requirements, recognising that discharges can change over time, particularly as equipment ages and if operation practice and waste components or composition vary.

In recognition of the high costs of dioxin monitoring, the US EPA standard for hospital/medical/infectious waste incinerators requires only an initial performance test for dioxins (US EPA, 1997b). For other contaminants, this standard requires monitoring for the first three years of operation and, if tests show compliance, then subsequent monitoring should be done every third year. US EPA standards for municipal waste incinerators require annual dioxin monitoring for units that burn more than 225 tonnes per day and three-yearly monitoring for units that burn less than this but more than 35 tonnes per day (US EPA, 1995b). There are also provisions for reduced frequency if emissions are well below the emission standard. These standards also require regular monitoring of a number of other parameters, some on a continuous basis, which provide a means to maintain the overall performance of the incinerator and give an indication of dioxin discharge potential.

[20] Bearing in mind that the US EPA indicates that inter-laboratory testing of Method 0023 and Method 8290 to establish method accuracy and precision for sampling has not been performed (US EPA, 1996)

The European Commission directive for waste incineration requires dioxin monitoring at least every three months for the first year of operation, with at least two further "measurements" per year thereafter (CEC, 2000). The number of samples per measurement is not specified, which implies that one sample is likely to be the requirement. The directive also provides a provision for a reduction in the frequency of dioxin measurements from twice a year to once a year provided that the emissions are below 50% of the limit specified in the directive.

Dioxin monitoring frequency required in New Zealand resource consents varies between six-monthly and three-yearly (Appendix D), but the most common requirement is for annual measurements. The reasons for the differences are not clear, but it is likely that the variations are due principally to different regional council approaches or community pressures, since the resource consent process allows for particular circumstances to be taken into account. Whatever the case, the requirements appear to be generally more demanding than the US EPA's waste incinerator standards but less demanding than the European Commission directive.

The proposed dioxin NES will apply to various incinerator types and sizes. With this in mind, the minimum monitoring frequency should provide a balance between the proportionally high costs for smaller incinerators and the need to regularly monitor very large sources. It is also sensible to encourage operators to achieve lower discharges. Finally, it must be recognised that regional councils should be given powers to require more frequent monitoring than that specified by the standard, should specific circumstances require this (see Section 5.5).

Giving consideration to the above factors and recognising that existing New Zealand incinerators are relatively small, monitoring should be undertaken at least once per year for both existing and new sources alike. New sources should measure[21] the discharge on at least two separate occasions (separated by at least two months) within the first year, with the first measurement no later than six months after commissioning. To reduce costs and encourage lower discharges, the monitoring frequency for both new and existing sources could reduce to once every two years if the discharge proves to be less than half the discharge limit specified in the dioxin NES for at least two consecutive compliance measurements, and all other parameters are in compliance, including temperature and carbon monoxide. This option of reduced monitoring frequency should only apply to new sources after they have demonstrated compliance with the NES for a period of two years.

- *Monitoring should be undertaken at least every year, reducing to every two years if emissions are less than half the standard. More frequent monitoring should be undertaken for new incinerators in their first year of operation.*

In the event that an incinerator that has been successfully operating at half the discharge limit under the provisions of reduced monitoring frequency, fails to meet the 50% discharge limit requirement in its most recent compliance measurement, the incinerator should be required to undertake annual compliance measurements until it can again demonstrate compliance at half the discharge limit.

In addition to the annual monitoring requirements, it would be important to provide powers to the enforcement authority to require further testing in the event

[21] Each compliance measurement should consist of three tests, as discussed in Section 5.5.

that the routine monitoring shows non-compliance, or results are within experimental error of the limit. This could serve a number of needs, including a check to confirm the accuracy and reliability of the results, an ability to promptly test the effect of any subsequent process changes undertaken in response to a high result, or simply a means to gather more evidence for an enforcement action.

5.7 Operating conditions during monitoring

The dioxin NES should stipulate that testing must be undertaken when maximum discharges are likely. This means that the incinerator or co-incinerator must be operated as normal with respect to combustion temperatures and control equipment parameters, *but* the waste feed must correspond to the worst case. The procedure for identifying the worst-case feed conditions should be subject to approval by the relevant enforcement authority. Establishing worst-case feed conditions will be a difficult task, but consideration should at least be given to the composition of the waste and the feed rates. The processing of wet waste with low calorific value and high chlorine contents, for example, may give rise to a high dioxin potential if burnt at maximum rates.

- *Compliance monitoring should be undertaken when maximum discharges are likely.*

There must also be a requirement to report records of relevant operating conditions as evidence of such operation (see Section 5.9).

5.8 Carbon monoxide monitoring method

Section 3 recommended continuous carbon monoxide monitoring with limits on carbon monoxide concentration. To ensure the plant is operating consistently with good combustion, this parameter must be measured with the appropriate level of precision and reliability.

The European Commission directive provides data recovery requirements and analytical performance criteria for this parameter, and also stipulates that European standard methods or other international methods be followed.

In this case, because US EPA methods are recommended for dioxin measurements, the US EPA criteria should be adopted for the carbon monoxide monitoring. While the US EPA has a *reference standard* for carbon monoxide, which employs non-dispersive infrared technology (US EPA Method 10), this level of monitoring is not necessary. Instead, the specifications set out in the US EPA Performance Specification 4 (US EPA, 1997a) will provide an acceptable level of monitoring. These are general requirements but stipulate criteria zero and span, calibration drift and relative accuracy, which are similar but more complete than the performance criteria listed for carbon monoxide in the European Commission directive.

- *Carbon monoxide should be measured in accordance with the US EPA performance specifications (Specification 4 – Specifications and Test Procedures for CO Continuous Emission Monitoring Systems in Stationary Sources).*

Data recovery should follow the European Commission directive requirements, which means that no more than five half-hourly average measurements shall be discarded due to instrument malfunction or maintenance within a 24-hour operating period. Similarly, no more than 10 daily or 24-hour average measurements should be discarded per 12-month period. Because many smaller incinerators will not operate continuously, and for ease of interpretation and application of these requirements, it is advantageous to turn these absolute values into percentage criteria. This would mean that no more than 10% of all half-hourly average measurements should be discarded within a 24-hour operating period, and no more than 3% of all daily or 24-hour average measurements should be discarded per 12-month period.

5.9 Reporting

Results of dioxin monitoring should be reported to the relevant authority as soon as practicable after completion of each compliance test. Without a report, the monitoring should be deemed incomplete, and therefore non-compliant with the NES. The NES should therefore include a strict reporting time and form. The US EPA requires reports to be submitted within 60 days of a test. This is longer than similar requirements in New Zealand resource consents, but 60 days is probably a fair requirement considering the complexity of dioxin analysis, and allows for the option for samples to be sent overseas for analysis.

- *Reports should be submitted within 60 days of testing.*

The publication *Approved Methods for the Sampling and Analysis of Air Pollutants in New South Wales* (NSW EPA, 2000) has a list of specific requirements for a discharge monitoring report and most of these are considered suitable for New Zealand. With no other forum in New Zealand for stipulating how compliance monitoring should be reported, such a list should be included as part of the dioxin NES. Using the NSW requirements as a basis, Box 5-2 lists the recommended minimum reporting requirements modified for the NES.

- *It is necessary to stipulate minimum requirements for monitoring reports, and the NSW approved methods provide a suitable basis for reporting requirements.*

■ Box 5-2 Minimum reporting requirements for dioxin monitoring

Compliance monitoring reports should detail the following:

1. name and address of owner of facility being monitored
2. name and address of reporting organisation or individual
3. details, including accreditation, of the sampling and analytical personnel and their organisation
4. report date
5. date, start and completion times and place of measurements
6. details of process operating conditions during sampling, including a record of the waste feed rate, combustion chamber temperatures and control equipment operating conditions
7. general description of the waste feed composition, including chlorine content
8. location of the sample plane, with respect to the nearest upstream and downstream flow disturbance
9. number of sampling points (traverses) across the sample plane
10. sampling start and stop times
11. average chimney gas velocity at the point of sampling
12. average chimney gas temperature at the point of sampling
13. water content of chimney gas
14. oxygen content of chimney gas
15. 10-minute average carbon monoxide concentrations during each dioxin test run
16. chimney gas sample volume collected under actual field conditions
17. chimney gas sample volume collected corrected to reference conditions
18. concentration (mass per volume basis) of individual dioxin congeners quantified at reference conditions
19. mass discharge of individual dioxin congeners
20. limit of detection for each congener not detected corrected to reference conditions
21. recovery of isotopically labelled standards used in the sampling and analytical procedures
22. concentration (mass per volume basis) of total toxic equivalents (TEQ) in the discharge corrected to reference conditions
23. dioxin mass discharge of total TEQ
24. any factors that may have affected the monitoring results
25. precision of the results
26. calibration details for each instrument used to take measurements
27. verification of sampling and analytical methodologies used.

A particularly important part of these requirements is the reporting of operating conditions during sampling. Specific conditions relevant to dioxin discharges include the waste feed, combustion chamber temperatures and control equipment operating conditions. For example, if a fabric filter is used, it is important to record the operating temperature; if a carbon adsorption system is used, the carbon feed rate is also a critical parameter that must be reported.

Reporting requirements for carbon monoxide monitoring and combustion temperature (see Box 3-1) could also be stipulated, but this is not considered necessary since this is a continuous monitoring requirement and could result in large amounts of data being sent to the enforcement authority. Rather, it is better to ensure a record of the monitoring is kept for a suitable period (five years). These records can then be made available to the enforcement authority upon request. All carbon monoxide results should be reported for each dioxin sampling period, however, since this forms part of the operating procedures that must be recorded during sampling.

The composition of waste should also be reported, particularly if there is a question over the need for the stricter combustion requirements described in Section 3 for waste with more than 1% halogenated material. However, rather than require all waste materials to be so analysed, it would be more appropriate to give the enforcement authority powers to require this testing in the event that halogenated material is likely to be present in such quantities.

Appendix A Basis for a size threshold

If a size threshold is to be stipulated for a dioxin NES, there are several examples that can be used to provide guidance.

1. The Second Schedule to the Clean Air Act 1972 continues to be used throughout New Zealand, particularly as a starting point for rules in regional plans. The schedule was relatively complicated for incineration activities because it had different requirements for combustion of different wastes. Incineration of pathological wastes, for example, was listed in Part A if the capacity was more than 100 kg/hr, and consequently required licensing by the Department of Health. Smaller pathological incinerators were listed in Part B and required licensing by local authorities. Combustion of other wastes, such as plastics, halogenated material, treated wood, oil sludge and paint residues were listed in Part B if undertaken in excess of 25 kg/hr and Part A if more than 100 kg/hr. Thus most incinerators (greater than 25 kg/hr) required licensing under the Clean Air Act. The distinction between Part A and B processes provides an indication of the relative potential for adverse effects and the difficulty of controlling such activities.

2. Many regional plans distinguish between *domestic* incineration and other waste incineration activities, which suggests a size threshold corresponding to this scale may be appropriate. Also, those regional plans that have adopted a size threshold for *industrial or trade* waste incineration (TRC, 1997; GDC, 2000) have made facilities permitted if they release less than 5 MW of heat. The reasons for this threshold are unclear, but it appears to be based on the fuel burning criteria from the Clean Air Act Schedules. In any case, this is not a suitable threshold for controlling dioxin discharges. If the waste has a calorific value of 15 to 20 MJ/kg, 5 MW corresponds to a waste consumption rate of about 1000 kg/hr, which is a relatively large unit (several thousand tonnes per year). This would encompass nearly all medical, quarantine or general waste incinerators operating in New Zealand.

3. The proposed European Commission directive for waste incineration (CEC, 1999) excluded plants that treat less than 10 tonnes per year of non-municipal waste (equivalent to about 2 to 5 kg/hr).[22]

There appears to be a wide range of precedent size thresholds for the management of incinerator discharges, but if a size threshold was considered appropriate, 10 tonnes per year may be suitable. This would allow little more than domestic-scale incineration activities. However, given that dioxin discharges from the domestic (backyard) burning of waste are not insignificant in the context of total dioxin discharges to air in New Zealand (Buckland *et al*., 2000), excluding this activity from regulatory control of some form is difficult to justify.

- *If a size threshold is to be stipulated in a dioxin NES, the recommended threshold is 10 tonnes of waste per year.*

[22] However, this size threshold did not eventuate in the final directive that came into force (CEC, 2000).

Appendix B US EPA Waste Definitions

B.1 Municipal waste (US EPA, 1995b)

Municipal solid waste or municipal-type solid waste or MSW means household, commercial/retail, and/or institutional waste. Household waste includes material discarded by single and multiple residential dwellings, hotels, motels, and other similar permanent or temporary housing establishment or facilities. Commercial/retail waste includes material discarded by stores, offices, restaurants, warehouses, nonmanufacturing activities at industrial facilities, and other similar establishment or facilities. Institutional waste includes material discarded by schools, nonmedical waste discarded by hospitals, material discarded by nonmanufacturing activities at prisons and government facilities, and material discarded by other similar establishments or facilities. Household, commercial/retail, and institutional waste does not include used oil; sewage sludge; wood pallets; construction, renovation, and demolition wastes (which includes but is not limited to railroad ties and telephone poles); clean wood; industrial process or manufacturing wastes; medical waste; or motor vehicles (including motor vehicle parts or vehicle fluff). Household, commercial/retail, and institutional wastes include:

1. *Yard waste;*
2. *Refuse-derived fuel; and*
3. *Motor vehicle maintenance materials limited to vehicle batteries and tires except as specified in S50.50b(g).*

B.2 Hospital waste (US EPA, 1997b)

Hospital waste means discards generated at a hospital, except unused items returned to the manufacturer. The definition of hospital waste does not include human corpses, remains, and anatomical parts that are intended for interment or cremation.

Infectious agent means any organism (such as a virus or bacteria) that is capable of being communicated by invasion and multiplication in body tissues and capable of causing disease or adverse health impacts in humans.

B.3 Medical/infectious waste (US EPA, 1997b)

Medical/infectious waste means any waste generated in the diagnosis, treatment, or immunisation of human beings or animals, in research pertaining thereto, or in the production or testing of biologicals that is listed in paragraphs (1) through (7) of this definition. The definition of medical/infectious waste does not include hazardous waste identified or listed under the regulations in part 261 of this chapter; household waste, as defined in S261.4(b) (1) of this chapter; ash from incineration of medical/infectious waste, once the incineration process has been completed; human corpses, remains, and anatomical parts that are intended for interment mation; and domestic sewage materials identified in S261.4(a)(1) of this chapter.

(1) Cultures and stocks of infectious agents and associated biologicals, including: cultures from medical and pathological laboratories; cultures and stocks of infectious agents from research and industrial laboratories; wastes from the production of biologicals; discarded live and attenuated vaccines; and culture dishes and devices used to transfer, inoculate, and mix cultures.

(2) Human pathological waste, including tissues, organs, and body parts and body fluids that are removed during surgery or autopsy, or other medical procedures, and specimens of body fluids and their containers.

(3) Human blood and blood products including:
- *(i) Liquid waste human blood;*
- *(ii) Products of blood;*
- *(iii) Items saturated and/or dripping with human blood; or*
- *(iv) Items that were saturated and/or dripping with human blood that are now caked with dried human blood; including serum, plasma, and other blood components, and their containers, which were used or intended for use in either patient care, testing and laboratory analysis or the development of pharmaceuticals. Intravenous bags are also included in this category.*

(4) Sharps that have been used in animal or human patient care or treatment or in medical, research, or industrial laboratories, including hypodermic needles, syringes (with or without the attached needle), pasteur pipettes, scalpel blades, blood vials, needles with attached tubing, and culture dishes (regardless of presence of infectious agents). Also included are other types of broken or unbroken glassware that were in contact with infectious agents, such as used slides and cover slips.

(5) Animal waste including contaminated animal carcasses, body parts, and bedding of animals that were known to have been exposed to infectious agents during research (including research in veterinary hospitals), production of biologicals or testing of pharmaceuticals.

(6) Isolation wastes including biological waste and discarded materials contaminated with blood, excretions, exudates, or secretions from humans who are isolated to protect others from certain highly communicable diseases, or isolated animals known to be infected with highly communicable diseases.

(7) *Unused sharps including the following unused, discarded sharps: hypodermic needles, suture needles, syringes, and scalpel blades.*

Appendix C Specified Wastes Listed in Regional Plans

C.1 Proposed Bay of Plenty regional air plan

Rule 18 (defines specific discretionary activities):
(k) Enclosed incineration of the following materials:

- *(i) Chlorinated organic chemicals including but not limited to dioxins, furans, polychlorinated biphenyls (PCB);*
- *(ii) Contaminated material from contaminated sites and buildings;*
- *(iii) Elemental materials some of which can produce toxic gases, including but not limited to boron, halides, phosphorus, sulphur;*
- *(iv) Heavy metals including but not limited to lead, zinc, arsenic, chromium, cadmium, copper, mercury, thorium;*
- *(v) Material associated with the recovery of metal from insulated electrical cables;*
- *(vi) Materials or metals used in motor vehicles;*
- *(vii) Mineral fibres including but not limited to asbestos;*
- *(viii) Paint and other surface protective coatings;*
- *(ix) Pathological waste excluding animal carcasses on production land;*
- *(x) Pesticides, pesticide waste (excluding cardboard pesticide containers);*
- *(xi) Plastic including but not limited to polyvinylchloride (PVC), polystyrene, nylon, styrofoam;*
- *(xii) Tyres and other rubber;*
- *(xiii) Treated timber or timber treatment chemicals;*
- *(xiv) Waste oil or other waste petroleum products.*

C.2 Proposed Otago regional plan: air

Rule 16.3.3.2 (defines incineration as a discretionary activity):

- *a) Chlorinated organic materials including but not limited to dioxins, furans, polychlorinated biphenyls;*
- *b) Contaminated material from contaminated sites and buildings;*
- *c) Food wastes;*
- *d) Materials containing heavy metals;*
- *e) Material associated with the recovery of metal from coated or covered cables;*
- *f) Motor vehicles and vehicle parts;*
- *g) Materials containing mineral fibres including but not limited to asbestos;*
- *h) Paint and other surface coatings;*
- *i) Pathological materials excluding animal carcases on production land;*
- *j) Agrichemicals and agrichemical waste;*
- *k) All plastic, including, but not limited to, polyvinylchloride (PVC), polystyrene, nylon, stryofoam, but not including polyethylene;*
- *l) Tyres and other rubber;*
- *m) Timber treated with copper, chrome and arsenic (CCA) or organochlorine preservatives;*
- *n) Waste oil or other waste petroleum products; or*
- *o) Sewage sludge and associated solids, or solids derived from liquid-borne municipal, industrial or trade wastes.*

C.3 Proposed Waikato regional plan

Rule 6.1.12.2 (discretionary incineration)

i) *Fluorine, chlorine, phosphorus, or nitrogen that has been chemically combined;*
ii) *Sulphur;*
iii) *Rubber;*
iv) *Halogenated organic chemicals;*
v) *Materials containing heavy metals;*
vi) *Pitch, paint and paint residues and surface coatings;*
vii) *Metal from insulated electrical cable;*
viii) *Pathological waste (excluding animal carcasses on production land);*
ix) *Agrichemicals and agrichemical waste containing residues;*
x) *Polyvinylchloride (PVC) plastic and plastics containing halogenated material;*
xi) *Waste oil, other waste petroleum products including petroleum sludge*.

Rule 6.1.12.3 (prohibited open burning)

1. *Halogenated organic chemicals;*
2. *Materials containing heavy metals;*
3. *Pitch, paint and paint residues and surface coatings;*
4. *Agrichemicals and agrichemical waste containing residues;*
5. *Polyvinylchloride (PVC) plastic and plastics containing halogenated material;*
6. *Copper-chrome-arsenic (CCA) treated timber or timber treated with organochlorine (PCP);*
7. *Rubber and tyres;*
8. *Waste oil, other waste petroleum products including sludge;*
9. *Materials associated with the recovery of metals from cables;*
10. *Components of motor vehicles;*
11. *Tar and bitumen;*
12. *Any material within a landfill or a refuse transfer station.*

C.4 Discussion document for the future Auckland regional plan

Clause 7.5.10 (Prohibiting outdoor burning)

Including but not limited to:

1. *Refuse;*
2. *Sewage sludge or screenings;*
3. *Plastic, rubber (e.g. tyres), paint, oil, solvents or bituminous materials;*
4. *Coated or covered metal cable, motor vehicles or parts of motor vehicles or any other mixture or combination of metals and combustible substances;*
5. *Pathological, clinical or veterinary wastes;*
6. *Animal carcasses;*
7. *Solid, liquid or gaseous chemical wastes;*
8. *Construction or demolition waste.*

Clause 8.5.4.3 (Commercial incineration as a discretionary activity)
Including but not limited to:

1. *Garbage or refuse;*
2. *Crates, pallets or other wood wastes;*
3. *Agricultural, food, organic or greenwastes;*
4. *Sewage sludge or screenings;*
5. *Coated or covered metal cable, motor vehicles or parts of motor vehicles or any other mixture or combinations of metals and combustible substances;*
6. *Pathological, clinical or veterinary wastes;*
7. *Solid, liquid, or gaseous wastes.*

Appendix D Incinerator Operating Conditions in New Zealand Resource Consents

Facility (Regional Council)	Dioxin emission limit (TEQ) 0°C, 101.3 kPa, 11% O_2, dry.	Combustion conditions	Waste feed restriction	Continuous monitoring	Process conditions	Dioxin testing frequency	Consent expires
Medical Waste Group Ltd. (Auckland)	0.1 ng/m^3	1000°C, 6% oxygen	Waste types defined	O_2, CO, temperature, opacity	Maximum likely emissions	Once before expiry in Aug 2000	Aug 2000
Waste Resources Ltd. (Auckland)	0.1 ng/m^3	1000°C, 6% oxygen	Waste types defined	O_2, CO, temperature, opacity	Maximum likely emissions	Annual	Nov 2009
Dow Agrosciences (NZ) Ltd. (Taranaki)	5 ng/m^3 or 5 µg/hr	1000°C and, 1100°C, 6% oxygen	< 0.8% halogens for liquid wastes	O_2, CO, temperature, opacity	Not specified	Unspecified	June 2014, review June 2002
Medical Waste (Wellington) (Wellington)	0.1 ng/m^3 from 1 Aug 2001	1000°C, 6% oxygen	Generally minimise chlorine	O_2, CO, temperature, opacity	Not specified	6-monthly from 1 Aug 2001	May 2005
Kapiti Coast District Council (Wellington)	0.1 ng/m^3	1000°C, start, 1300 °C gen.	Sewage sludge only	O_2, temperature,	Not specified	Annual	Sept 2019
Christchurch International Airport Ltd. (Canterbury)	0.1 ng/m^3 from 1 Dec 2004	1000°C, 6% oxygen	Not specified	O_2, temperature, opacity	Normal operation	Annual	Nov 2027
Kaputone Woolscour Ltd. (Canterbury)	No limit specified	Not specified	Wool scour liquor only	Not specified	Feed rate over 385 kg/hr	3-yearly	Dec 2031

References

17.BImSchV. 1990. *Seventeenth Ordinance on the Implementation of the Federal Immission Control Act (Ordinance on Incinerators for Waste and similar Combustible Material).* Bundesgesetzblatt Teil 1, 2832, Germany.

27.BImSchV. 1997. *Twenty Seventh Decree for Enforcement of the German Law for Reduction of Immissions (Directive on Crematoria)*. Bundesgesetzblatt Jahrgang 1997 Teil 1 Nr. 18, 545, Germany.

Ahlborg, UG, Becking, GC, Birnbaum, LS, Brouwer, A, Derks, HJGM, Feeley, M, Golor, G, Hanberg, A, Larsen, JC, Liem, AKD, Safe, SH, Schlatter, C, Wærn, F, Younes, M, Yrjänheikki, E. 1994. Toxic equivalency factors for dioxin-like PCBs. *Chemosphere*, 28, 1049–1067.

ATSDR. 1998. *Toxicological Profile for Chlorinated Dibenzo-p-Dioxins* (update). Agency for Toxic Substances and Disease Registry, Atlanta, GA.

Ballschmiter, K, Zell, M. 1980. Analysis of polychlorinated biphenyls (PCB) by glass capillary gas chromatography. *Fresenius Zeitschrift für Analytische Chemie*, 302, 20–31.

Blumenstock, M, Zimmerman, R, Schramm, K-W, Kettrup, A. 2000. Influence of combustion conditions on the PCDD/F-, PCB-, PCBz- and PAH-concentrations in the post-combustion chamber of a waste incinerator pilot plant. *Chemosphere*, 40, 987–993.

Buckland, SJ, Ellis, HK, Dyke, P. 2000. *New Zealand Inventory of Dioxin Emissions to Air, Land and Water, and Reservoir Sources*. Ministry for the Environment, Wellington.

CEC. 1999. *Amended Proposal for a European Parliament and Council Directive on the Incineration of Waste.* 98/0289 (COD), COM (1999)330 final. Commission of the European Communities, Brussels.

CEC. 2000. *Directive 2000/76/EC of the European Parliament and of the Council of 4 December 2000 on the Incineration of Waste.* Official Journal of the European Communities, L 332/91. Commission of the European Communities, Brussels.

DoE. 1995. *Secretary of State Guidance – Crematoria*. PG5/2(95). Department of the Environment, UK.

EC. 1975. *Council Directive 75/442/EEC of 15 July 1975 on Waste*. European Community legislation document 31975L0442.

EC. 1991. *Council Directive 91/689/EEC of 12 December 1991 on Hazardous Waste*. European Community legislation document 391L0689.

Ehrlich, C, Kalkoff, W-D, Albrecht, W. 1996. Industrial emissions of PCDD/F and of dioxin-like PCBs in Saxony-Anhalt. *Organohalogen Compounds*, 27, 50–55.

Espourteille, FA, Altwicker, ER, Talbot, S. 1996. Polychlorinated biphenyls and polychlorinated dibenzo-p-dioxins/furans: observations from incineration and laboratory studies. *Organohalogen Compounds*, 27, 133–138.

Fängmark, I, Strömberg, B, Berge, N, Rappe, C. 1994. Influence of postcombustion temperature profiles on the formation of PCDDs, PCDFs, PCBzs and PCBs in a pilot incinerator. *Environmental Science and Technology*, 28, 624–629.

GDC. 2000. *Proposed Regional Air Quality Management Plan for the Gisborne Region*. Gisborne District Council, Gisborne.

Kutz, FW, Barnes, DG, Bottimore, DP, Greim, H, Bretthauser, EW. 1990. The international toxicity equivalency factor (I-TEF) method of risk assessment for complex mixtures of dioxins and related compounds. *Chemosphere*, 20, 751–757.

MfE. 1998. *Air Quality Compliance Monitoring and Emission Testing of Discharges to Air*. Ministry for the Environment, Wellington.

MfE. 2000. *Guidelines for the Management and Handling of Used Oil*. Ministry for the Environment, Wellington.

MfE. 2001a. *Guide for the Management of Closing and Closed Landfills in New Zealand*. Ministry for the Environment, Wellington.

MfE. 2001b. *Guide to Landfill Consent Conditions*. Ministry for the Environment, Wellington.

Miyata, H, Aozasa, O, Mase, Y, Ohta, S, Khono, S, Asada, S. 1994. Estimated annual emission of PCDDs, PCDFs and non-ortho chlorine substituted coplanar PCBs from flue gas from urban waste incinerators in Japan. *Chemosphere*, 29, 2097–2105.

NSW EPA. 2000. *Approved Methods for the Sampling and Analysis of Air Pollutants in New South Wales.* EPA 2000/9. NSW Environmental Protection Agency. http://www.epa.nsw.gov.au.amsaap/.

Pernin, H, Ménard, T, Ferrières, C. 1998. Coplanar PCB and dioxin emissions of 2 MSWI. *Organohalogen Compounds*, 36, 253–255.

Petersen, A. 1999. *Compilation of EU Dioxin Exposure and Health Data. Task 1 – Review of Member State Legislation and Programmes.* Report for the European Commission DG Environment and the UK Department of the Environment, Transport and the Regions, by AEA Technology, Abingdon, UK.

Sakai, S, Hiraoka, Takeda, N, Shiozaki, K. 1996. Behavior of co-planar PCBs and PCNs in oxidative conditions of municipal waste incineration. *Chemosphere*, 32, 79–88.

Smith, AH, Lopipero, P. 2001. *Evaluation of the Toxicity of Dioxins and Dioxin-like PCBs: A Health Risk Appraisal for the New Zealand Population*. Ministry for the Environment, Wellington.

Stevenson, C, Noonan, M, Buckland, SJ. 2001. *Multi-pathway Estimates of Exposure to Dioxin from Emissions to Air from Waste Incinerators*. Ministry for the Environment, Wellington.

TRC. 1997. *Regional Air Quality Plan for Taranaki*. Taranaki Regional Council, Stratford.

US EPA. 1995a. Method 23 – Determination of Polychlorinated Dibenzo-p-dioxins and Polychlorinated Dibenzofurans from Municipal Waste Combustors. 40 CFR Part 60, Appendix A. US Government Printing Office, Washington, DC.

US EPA. 1995b. Standards of Performance for New Stationary Sources and Emission Guidelines for Existing Sources: Municipal Waste Combustors. 40 CFR Part 60. *Federal Register*, 60, 65387–65436.

US EPA. 1996. Method 0023A – Sampling Method for Polychlorinated Dibenzo-p-dioxins and Polychlorinated Dibenzofuran Emissions from Stationary Sources. 40 CFR Part 60, Appendix A. US Government Printing Office, Washington, DC. Method available from: http://www.epa.gov/epaoswer/hazwaste/test/under.htm.

US EPA. 1997a. Performance Specification 4 – Specifications and Test Procedures for CO Continuous Emission Monitoring Systems in Stationary Sources. 40 CFR Part 60, Appendix B. US Government Printing Office, Washington, DC.

US EPA. 1997b. Standards of Performance for New Stationary Sources and Emission Guidelines for Existing Sources Hospital/Medical/Infectious Waste Incinerators. 40 CFR Part 60. *Federal Register*, 62, 48348–48391.

US EPA. 1999. Standards of Performance for New Stationary Sources: Commercial and Industrial Solid Waste Incineration Units. 40 CFR Part 60. *Federal Register*, 64, 67092–67127.

US EPA. 2000a. Health Assessment of 2,3,7,8-Tetrachlorodibenzo-p-dioxin (TCDD) and Related Compounds; Chapter 9, Toxic Equivalency Factors (TEF) for Dioxin and Related Compounds. EPA/600/P-00/001Be, September 2000. United States Environmental Protection Agency, Washington DC.

US EPA. 2000b. National Emission Standards for Hazardous Air Pollutants for Secondary Aluminium Production. 40 CFR Part 63. *Federal Register*, 65, 15690–15737.

US EPA. 2000c. New Source Performance Standards for New Small Municipal Waste Combustion Units; Final Rule. 40 CFR Part 60. *Federal Register*, 65, 76350–76375.

Van den Berg, M, Birnbaum, L, Bosveld, ATC, Brunström, B, Cook, P, Feeley, M, Giesy, J, Hanberg, A, Hasegawa, R, Kennedy, SW, Kubiak, T, Larsen, JC, van Leeuwen, FXR, Liem, AKD, Nolt, C, Peterson, RE, Poellinger, L, Safe, S, Schrenk, D, Tillitt, D, Tysklind, M, Younes, M, Wærn, F, Zacharewski, T. 1998. Toxic equivalency factors (TEFs) for PCBs, PCDDs, PCDFs for humans and wildlife. *Environmental Health Perspectives*, 106, 775–792.

Van Leeuwen, FXR, Younes, MM (eds). 2000. Proceedings of the World Health Organization and International Programme on Chemical Safety consultation, 25–29 May 1998, Geneva, Switzerland: *Assessment of the Health Risk of Dioxins: Re-evaluation of the Tolerable Daily Intake (TDI)*. In: *Food Additives and Contaminants*, 17, 223–240 (executive summary).

WA EPA. 1998. *Management of Air Emissions from Biomedical Waste Incinerators.* Guidance for the Assessment of Environmental Factors, No 13. Environmental Protection Authority, Western Australia.

Wilken, M, Böske, J, Jager, J, Zeschmar-Lahl, B. 1993. PCDD/F, PCB, chlorobenzene and chlorophenols emissions of a municipal solid waste incineration plant (MSWI) – variation within a five day routine performance and influence of $Mg(OH)_2$ addition. *Organohalogen Compounds*, 241–244.

Wikström, E, Persson, A, Marklund, S. 1998. Secondary formation of PCDDs, PCDFs, PCBs, PCBzs, PCPhs and PAHs during MSW combustion. *Organohalogen Compounds*, 36, 65–68.

Wright, JC, Millichamp, P, Buckland, SJ. 2001. *The Cost-effectiveness of Reductions in Dioxin Emissions to Air from Selected Sources: Economic Analysis for Section 32 of the Resource Management Act*. Ministry for the Environment, Wellington.