Health Protection Scotland

SEPA Scottish Environment Protection Agency

NHS National Services Scotland

# Incineration of Waste and Reported Human Health Effects

Health Protection Scotland

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Health Protection Scotland
Clifton House
Clifton Place
Glasgow G3 7LN

Tel: +44 (0) 141 300 1100

Email: NSS.HPSEnquiries@nhs.net

## Foreword

The Scottish Environment Protection Agency (SEPA) acknowledges Health Protection Scotland's review of the evidence currently available on human health effects associated with the thermal treatment of waste.

SEPA requested this review to support its work in improving the regulation of thermal treatment of waste facilities. Part of this is about ensuring that both the health and environmental impacts of incineration are examined and addressed in line with our regulatory responsibilities. SEPA have also reviewed the thermal treatment guidelines published in 2004, and have replaced the 2004 version with the *Thermal Treatment of Waste Guidelines 2009*.

Thermal treatment technologies have had a limited role in Scotland, however, thermal treatment plays an important part in waste management and treatment infrastructure in many countries. Thermal treatment is important for producing energy, thereby reducing the use of fossil fuels and mitigating climate change. The technology associated with thermal treatment has evolved quickly over recent years and, as the technology has advanced, so has the means by which emissions are controlled.

The regulatory requirements relating to the operation of these plants and the emissions they produce have also tightened in line with technological developments. The Waste Incineration (Scotland) Regulations 2003 provide a firm and robust foundation to ensure that existing and future thermal treatment of waste facilities will be regulated to ensure a high level of protection for the environment and human health. This regulation includes setting stringent operational conditions, technical requirements and emission limits in order to prevent or limit potential effects on the environment and human health.

The thermal treatment of waste, in the form of incineration, is one of several options for the disposal of waste. In the Zero Waste plan currently out for consultation (final version expected in 2010) Scottish Government promotes minimising the production of waste, as well as increasing recycling and reuse. The Zero Waste plan objectives include increasing the value recovery of waste and reducing the amount of waste going for final disposal, either to landfill or alternative treatment, including energy from waste. The thermal treatment of waste with energy recovery is recognised as a necessary part of sustainable waste management.
SEPA asked Health Protection Scotland to consider scientific studies on health effects associated with the incineration of waste; specifically non-occupational health effects and health effects from different waste streams such as clinical, hazardous, industrial and municipal. We

also requested that the review take any recent studies (post 2004) into account, particularly those not included in the Defra publication *Review of Environmental and Health Effects of Waste Management* and after implementation of the revised European Waste Incineration Directive.

This report recognises that in older studies there remains uncertainty associated with the heath effects of incineration. However, it is important to note that the magnitude of any past health effects on populations living near incinerators is likely to have been small. Also, levels of airborne emissions from individual incinerators should be lower now than in the past, due to stricter legislative controls and improved technology, therefore further reducing risks to human health. This is in line with the recently published HPA review *The impact on Health of Emissions to Air from Municipal Waste Incinerators*, which states that 'While it is not possible to rule out adverse health effects from modern, well regulated municipal waste incinerators with complete certainty, any potential damage to the health of those living close-by is likely to be very small, if detectable.'

The recommendations in this report highlight inherent variations and weaknesses in existing studies, which creates a challenge when determining an overall conclusion on current health impacts. SEPA therefore acknowledge that any new studies, if commissioned, should be encouraged to focus on specific aspects of incineration and, where possible, examine non-occupational health effects.

SEPA is content with the recommendation that the current precautionary regulatory approach is continued. Present controls are designed to protect human health and they are precautionary due to a level of uncertainty; therefore there is little rationale for an even more precautionary approach. SEPA will continue to apply the precautionary approach when regulating new and existing thermal treatment plants, and will take any new evidence into account.

We are grateful to Health Protection Scotland for its support, and we hope this joint working will continue to protect and improve Scotland's environment and human health.

Signed

Calum MacDonald
SEPA's Director for Environmental and Organisational Planning

## SUMMARY

### Introduction

The Scottish Environment Protection Agency (SEPA) requested a report from HPS on the evidence of human health effects associated with incineration to complement their issue of updated guidance on incineration (SEPA 2009). Previously published reviews on this topic have generally focused on health effects associated with incineration of *municipal* waste. SEPA requested that this report should consider evidence from studies of health effects associated with incineration of *clinical, hazardous, industrial and municipal* waste streams, particularly non-occupational health effects.

### Background

Thermal Treatment of Waste (TTW) is the technical term which covers a wide variety of technologies and processes involving the heat treatment of waste (e.g. direct combustion (incineration), pyrolysis, gasification) and is one of a number of options for the treatment of waste included in Scottish Government proposals for waste management. This Zero Waste strategy promotes a comprehensive approach to minimising the production of waste, recycling, reuse and final disposal of residual waste. The overall objective is to prevent waste, increase value recovery of resources and minimise the amount of waste going for final disposal, especially to landfill. This is supported by the Scottish Government commitment to limit the amount of municipal waste to be treated by energy recovery incineration, to no more than 25% of total waste municipal arisings by 2025.

The term "incineration" (i.e. direct combustion of waste) is the term generally used (rather than TTW) in the literature on human health effects, usually without specifying precisely what actual technology or process is in use. Incineration of waste requires high temperatures, 850°c to1200°c, which can produce airborne stack emissions and ash as its final outputs. The focus of interest regarding possible (non-occupational) adverse human health effects associated with incineration relates mainly to the airborne emission of hazardous chemicals, especially dioxins and other combustion products, including particulates.

**Methods**

A systematic search of the literature on human health impacts of incineration was carried out including peer-reviewed primary publications, reviews, government and non-governmental reports and other grey literature. The majority of identified material focussed on municipal solid waste (MSW) (or its equivalent), with a smaller research output identified on clinical, industrial and hazardous waste streams. A wide range of human health indicators and effects have been studied in both occupational and non-occupational populations including:

- evidence of chemical exposure in the form of biomarkers (present in blood, plasma or tissues),
- changes in physiological parameters (e.g. respiratory function),
- morbidity as incidence of clinical disease (e.g. cancer, respiratory disease, adverse birth outcomes and congenital malformations), and
- population mortality from specified causes.

The methods used by researchers to study this topic have varied considerably and included epidemiological studies, with a marked bias towards *'ecological'* type studies using geographical proximity to TTW sites as a proxy for human exposure to incinerator emissions. Risk Assessment type studies have featured using either actual or modelled emissions data to determine if potentially harmful population exposures had occurred. Other studies used measurement of environmental contamination with selected chemicals as proxies for human exposure. Much less commonly, *'Life-Cycle Assessments'* have been carried out, where incineration emissions are considered as part of an entire waste life-cycle for exposure assessment purposes.

**Findings**

Most of the published work relates to the health impact of incineration of municipal solid waste (MSW) (alone, or in combination with other waste streams), with (in descending order) comparatively less specifically on hazardous waste, clinical waste then industrial waste. The evidence base is therefore more robust for MSW than for the other waste streams. Much of the evidence, especially that published in reports and reviews, does not clearly differentiate effects associated with particular waste streams. This makes it particularly difficult to differentiate the findings associated with clinical, hazardous and industrial waste incineration from those of MSW incineration or *'incineration'* in general.

A number of reviews of the research evidence have been carried out in recent years but published as reports outside the normal peer reviewed literature. These included reports from:

- the Medical Research Council Institute for Environment and Health (Humphrey *et al* 1997),
- the US National Research Council Committee on Health Effects of Waste Incineration (NRC 2000),
- the Department for Environment and Rural Affairs (DEFRA) (Enviros Consulting *et al* 2004),
- the Health Protection Agency (HPA 2005),
- Greenpeace (Allsopp 2005), and
- the British Society for Ecological Medicine (BSEM) (Thompson and Anthony 2005).

The UK Independent Expert Advisory Committee on Carcinogenicity (CoC) also issued a position statement (CoC 2000) commenting on a UK study on cancer and proximity to municipal waste incineration sites (Elliot *et al* 1996, 2000) and issued an update statement in March 2009 (CoC 2009).

The reviews by Greenpeace and BSEM in 2005 both concluded that there was convincing evidence of an association between incineration and adverse human health outcomes and cited this as grounds for advising against the use of incineration. The basis for their conclusions was difficult to determine from the reports and their methods for assessing the strength of evidence have been criticised by other reviewers. The majority of the other reports acknowledged the potential for incineration to generate potentially harmful toxic emissions. However, they generally noted that although there was some evidence of association with adverse effects on human health, in the main it was not conclusive evidence. Several of these reports noted that methodological problems in designing and executing adequate studies might prevent the identification of adverse health effects and that such effects could not therefore be completely excluded. It was however concluded by some authors, that if (non-occupational) adverse health effects did exist, they were likely to be small in magnitude and probably very difficult to detect using conventional epidemiological study methods. CoC (2000) were of a similar view specifically in relation to cancer associated with MSWI.

Five additional systematic reviews, published in peer reviewed journals between 1990 and 2004, were also identified. These reviews considered a range of papers on various waste processes, again with a preponderance of investigations involving municipal waste incineration or a mixture of waste streams. These reviews varied considerably in the range of primary published sources that they cited. The conclusions of these reviews varied depending on the specific health outcomes studied. Evidence of association between incineration and the incidence of some cancers was noted including: laryngeal, oesophageal, gastric, liver, colorectal, lung, childhood cancers in general and leukaemias in particular, non-Hodgkin's lymphoma, and soft tissue and visceral sarcomas. The authors often qualified their findings by acknowledging the potential impact of confounding variables and sources of bias. The evidence on respiratory disease in residents living near any type of incinerators was considered on balance to be negative (no association) or inconclusive. On birth outcomes, evidence from primary studies ranged from positive evidence of association with increased twinning rates, to no association or inconclusive evidence with congenital malformations or other birth outcome measures. One review (Franchini *et al* (2004)) concluded that there was "*significant*" evidence for soft tissue sarcomas and others forms of cancer. None of the remaining systematic reviews reported conclusive evidence of an association between incineration and any specific health effect.

Eight additional primary papers were also identified, published in peer-reviewed journals but which had not been included in previous reports or reviews. Again, there was an emphasis on municipal waste incineration and its (non-occupational) health impacts. Cancers, birth outcomes and respiratory disease were studied. Hazucha *et al* (2002) found no evidence of impacts on lung function associated with living near (mixed type) TTW incineration sites. Three of four studies on birth outcomes did find evidence of effects. Obi-Osius (2004) found increased rates of twin pregnancy in Germany among women living nearer hazardous waste incinerators. Cordier *et al* (2004) found increased risks for renal dysplasia and facial cleft in France associated with MSW incinerators but identified that this was complicated by a parallel association with traffic density (and by implication potential traffic-related air pollution). Tango *et al* (2004) identified a significant *"peak-decline"* increase in risk of infant death and infant death ascribed to congenital malformation in Japan for children living near MSW incinerators, with a peak risk at one to two kilometres from an incinerator. This finding was not apparently confounded by social deprivation factors. These three birth outcome studies used different methodologies and different end points and were not directly comparable. The fourth study by Cresswell *et al* (2003) also studied congenital anomalies within three kilometres of an *"urban"* (MSW) TTW Incineration site but found no evidence of association. Two studies from Italy (Comba 2007, Zambon *et al* 2007) on sarcomas and connective tissue cancers, reported evidence of association between illness and dioxins and other chemical exposures but of differing magnitude. The sources of emissions were industrial incineration (Comba 2007) and mixed (municipal, industrial and clinical) (Zambon 2007). The study by Comba *et al* reported a larger effect but was based on very small case numbers, an ecological proximity based exposure assessment and was potentially subject to confounding. The study of Zambon *et al* was based on a large population (423,000), with a relatively large number of cases (205 histologically confirmed cases of sarcoma) and used modelled dioxin exposures, rather than the weaker exposure surrogate of proximity to an incinerator, commonly used by other researchers. The evidence provided by Zambon *et al*, though still not conclusive in terms of an association specifically with incinerator emission *per se*, was more persuasive than previous studies. Viel *et al* (2008) also reported evidence suggesting a possible effect of (modelled) dioxin exposures from MSWI in relation to a lowered incidence of breast cancer among women over 60 years old. This was considered to be compatible with an anti-oestrogenic (protective) effect of dioxins. However, Viel noted that residual confounding could not be excluded as an explanation for the finding. The findings of these eight papers add to the overall body of conflicting and inconsistent evidence but with a balance towards finding positive associations between incineration and adverse (non-occupational) health effects, albeit that these were heavily qualified by their authors and not considered absolutely conclusive.

**Discussion**

There are significant problems in conducting research in this area and consequently there are weaknesses in the published research evidence base. The wide range of variation makes comparison of studies in this field problematic.

Areas of significant variation include:

- study designs and methods
- criteria used to define the type of waste stream being incinerated
- description of thermal treatment technology and processes used
- emission and exposure models
- data measurements, ranging from use of home residence proximity as a proxy for exposure to quantitative pollutant monitoring levels
- study populations, their size, composition and sub-groups (residential, occupational and mixed)
- types of country studied and the regulatory regimes in place
- time periods studied, with different durations and intensities of exposure
- types and quality of health data sources used, with outcome measures ranging from physiological functions to broadly, or conversely, narrowly defined morbidity or mortality measures (e.g. *'all cancers'* in all ages versus *'adult soft tissue sarcoma'*).
- treatment of confounding factors and sources of bias

There is some evidence of measured increases in the risk of certain health effects associated with incineration from studies of incinerators operating before 2003. However, only a minority of past reviews of this evidence concluded that such effects were significant. The majority opinion from systematic reviews and other peer-reviewed sources (up to 2004) was that there was no consistent evidence of specific (non-occupational) health effects directly attributable to incineration activities.

Newer original papers, not previously included in published reviews or published after these reviews were completed, reported mixed findings. Some new evidence of adverse effects was reported, some of it consistent with previous evidence, particularly in relation to forms of cancer (especially sarcoma). Other newer studies failed to find any associations with adverse health effects. Authors who reported evidence of effects often acknowledged difficulties in controlling adequately for all the potential confounding variables. Reported effects were therefore acknowledged to be potentially influenced by confounding factors or sources of bias. While still not conclusive and despite the qualifications, the evidence from more recent studies does add weight to the view that there might have been a plausible association between some (non-occupational) adverse health effects, particularly some forms of cancer and incinerator emissions in the past, when levels were higher than would now be considered acceptable.

There is a consistent theme throughout the review literature on this topic; the lack of conclusive or consistent evidence does not preclude there being some adverse effect which has defied confirmation to date, e.g. *the absence of evidence does not equate to evidence of absence*. Methodological and other difficulties may simply have prevented their identification. However, this might also be reasonably interpreted as suggesting that whatever (non-occupational) effects do exist, they are likely to be relatively small.

The US NRC (2000) and others have explicitly argued that small but important effects might be virtually impossible to detect, given the complexity of the subject matter and the inherent difficulties of measuring an effect with the inadequate tools at the average investigator's disposal.

Where effects are detected but are low in magnitude or are not statistically significant, it is tempting to dismiss them. However, as Bradford Hill (1965) noted: *"We must not be too ready to dismiss a cause and effect hypothesis merely on the grounds that the observed association appears to be slight"*.

It must be emphasised, however, that the majority of epidemiological studies to date related to incinerators operating before introduction (in Europe) of the Waste Incineration Directive (WID) (Council of the European Union (2000)) and associated domestic (UK) legislation. Hence, emissions in the past were likely to have been higher than at present. Consequently, any associations identified with adverse health effects and incineration in the past cannot be extrapolated automatically to the present.

## Conclusion and Recommendations

### *Overall Conclusions*

- *Based on the limitations of available research literature, attempting to provide an overall conclusion on the health effects of incineration in total is particularly difficult.*

- *For waste incineration as a whole topic, the body of evidence for an association with (non-occupational) adverse health effects is both inconsistent and inconclusive. However, more recent work suggests, more strongly, that there may have been an association between emissions (particularly dioxins) in the past from industrial, clinical and municipal waste incinerators and some forms of cancer, before more stringent regulatory requirements were implemented.*

- *For individual incineration waste streams (clinical, hazardous, industrial and municipal), the evidence for an association with (non-occupational) adverse health effects is inconclusive.*

- *The magnitude of any past health effects on residential populations living near incinerators that did occur is likely to have been small.*

- *The majority of research work in this field is of historical relevance but tells us little about the current risk of (non-occupational) adverse effects potentially associated with incineration plants in operation now.*

- *Levels of airborne emissions from individual incinerators should be lower now than in the past, due to stricter legislative controls and improved technology. Hence, any risk to the health of a local population living near an incinerator, associated with its emissions, should also now be lower. It is possible that in the future the number of incinerators or the throughput of individual incinerators may increase and consequently the total mass of airborne emissions could increase. However, this has been addressed by the Scottish Government commitment to limit the total amount of waste destined for energy recovery via thermal treatment. In addition, planning controls should prevent new incinerators being sited within the locality of existing facilities.*

### *Recommendations*

Based on these findings, a number of recommendations are proposed:

**i. Future research should be more clearly focussed on specific aspects of incineration and (non-occupational) health impacts**

Carrying out adequate retrospective studies in this field is problematic. Where new incinerators are to be built, consideration could be given to conducting prospective investigations of their potential (non-occupational) health effects. Ideally this would provide better quality evidence on the health of local communities living near incinerators operating under the latest regulatory regimes.

However, prospective studies pose a particular challenge given that residential populations living near incinerators may be individually small. Health outcomes of interest, particularly rarer cancers, may occur in very small numbers. Prolonged follow up periods may therefore be required. Further individual studies of small populations, especially where exposure to risk is assessed only on the basis of residential proximity to an incinerator, are unlikely to yield any more conclusive evidence than such studies in the past. A more productive strategy might be to develop a robust standardised research methodology and apply it to multiple sites simultaneously, to increase the total study population.

It is beyond the scope of this report to make detailed proposals on future study design. However, some suggestions on priorities for future research are provided. It might be in the interests of regulators and the environmental epidemiology community to consider collectively how best such future studies might be carried out. A collective effort to design and coordinate future research might improve the probability of detecting any health effects which do exist or alternatively, might add to the strength of the evidence base indicating that any such effects are not in fact significant.

- Future primary studies on non-occupational risks should ideally rely less on proxy measures of exposure to pollutants such as residential proximity to a facility and should be more consistent in controlling sources of bias and residual confounding.

- Future investigations would ideally use Health Impact Assessment models and Life-Cycle Assessment methods to analyse more fully the additional pollutant burden associated with the complete waste management process. Emissions associated with the transport of waste to a site and removal of residual solid wastes should be included. The extra mass of pollutants added to the existing environmental pollution impacting on a local community, should be considered.

- Future reviews could focus specifically on clarifying and comparing differences in exposures and effects before and after improvements to the regulatory standards.

- Future reviews of evidence should specify clearer criteria for comparing studies and focus on research where epidemiological and toxicological paradigms have been applied adequately (e.g. the source/pathway/receptor model). Ideally there would be a clearly described hypothesis under study; comparability in the incinerators studied (the types of inputs, incinerator process and emissions) and more use of accurately characterised quantitative measurements of emissions. Ideally, future reviews would use analytical techniques, such as meta-analysis, to increase the reliability of their conclusions.

**ii. The level of uncertainty, regarding the actual risk to human health associated with incineration emissions, justifies the existing approaches aimed at minimising human exposure to such emissions via regulatory controls and modern operating practice. The present controls are precautionary and are designed to protect human health. There is, therefore, little rationale for a more precautionary approach at present.**

Some of the more recently published studies discussed in this report have provided limited additional evidence of a possible association between some incinerator emissions, particularly dioxins, and some forms of cancer. Although some of this new evidence is stronger than that previously available it is still not conclusive and is inconsistent with other findings. Also, these more recently published studies involved older generation incinerators operated in periods when emissions were likely to be higher than is now acceptable and some studies were carried out around an incinerator (not in the UK) for which emissions greatly exceeded even the earlier higher limits. The design and operational controls applied at modern facilities are highly sophisticated and as such they are now capable of operating to more stringent standards. The period during which these stricter emission standards have been in place is relatively short. Consequently there is as yet relatively little useful published epidemiological data on the newer generation of incinerators. However, it remains reasonable to conclude that any risk to human health associated with emissions from newer incinerators, operated within the current regulations, is very likely to be less than was the case previously. In view of this, the balance of evidence suggests that a more precautionary approach to either the location or the operation of incinerators is currently not recommended.

The residual 'uncertainty' regarding the actual level of risk to human health does however justify maintaining the existing *'precautionary'* stance to waste incineration activities. *'Precautionary'* as used in this report is in line with the guidance on the '*Precautionary Principle'*, published by the Scotland and Northern Ireland Forum for Environmental Research (SNIFFER 2005). This report describes principles of good practice in relation to dealing with uncertainty in relation to environmental issues. Adopting *'precaution'* implies making use of all reasonable and practical opportunities to minimise human exposure to avoidable environmental hazards. Precautionary measures in this case must however, remain proportionate to the low level of risk. The level of scientific uncertainty is not sufficient to justify adopting more extreme measures, nor is it sufficient to justify setting an arbitrary *'safe'* distance between incinerators and human habitation or activity.

The most recent regulatory standards implemented in line with the Waste Incineration Directive (WID) are consistent with a precautionary approach. The Pollution Prevention and Control (PPC) Regulations (Scotland) (2000), governing the siting and operation of existing and future waste incineration facilities also incorporate precaution as a concept. Regulatory interventions focus mainly on the '*downstream*' (emissions) end of the incineration process. There is also scope to identify additional potential interventions '*upstream*' (e.g. the inputs and processes) using the '*source-pathway-receptor'* model*.*

*Source Issues*

Minimising the '*source'* waste material requiring incineration might reduce the totality of emissions. However, other routes of waste disposal, including landfill, may also generate environmental health risks of uncertain scale. Incineration may be the best or the only realistic environmental policy option for a proportion of waste that cannot be managed by other routes. In addition to the traditional emission control approach, the hazard potential of the outputs may also be influenced via control of the inputs; e.g. the fuel mix used. Increased intervention at the *'source'* might therefore allow less reliance on emissions regulation, treatment and control at the process end-point.

*Pathway Issues*

Existing emissions regulations are currently the primary means of minimising human exposures via air and water *'pathways'*. There are opportunities to reduce *'pathway'* risks associated with the transmission of potentially harmful emissions using additional techniques such as a '*life-cycle model'*. This would enable assessment of the pollution hazards associated with transport of the waste and final by-products as well as those of the incineration process emissions and waste products. This could provide a more holistic approach to health risk reduction, via all the relevant contributions to the emission pathways.

*Receptor Issues*

Finally, the '*receptor*' aspect of the model is addressed by the Pollution Prevention and Control (PPC) Regulations (Scotland) (2000). This provides for risk reduction via awareness of the potential impact of locating and operating incinerator plants near population centres and sensitive (human) receptors. In particular, as part of the PPC application process, the cumulative effect of any planned additional emissions should be considered in the context of the existing background levels of pollution from other sources of emissions in that local environment. The PPC application process therefore allows for an assessment of emissions impacts on local air quality.

The *'receptor'* aspects can be also addressed via Strategic Environmental Assessment (SEA) or Best Practicable Environmental Option (BPEO) for waste plans. These incorporate assessments of the impact of specific emissions (such as particulate matter) on local communities, especially in more sensitive air quality areas (e.g. Local Air Quality Management Areas) and assessment of emissions associated with multiple facilities. Life-Cycle Assessment (LCA) modelling has been used to support this.

The conclusion on (non-occupational) human health effects associated with incineration (under modern operating conditions) is relatively reassuring. However, when new incinerators are planned and where there are sensitive receptors, there will remain a need to take account of background ambient air quality especially in localities with other sources of similar emissions (including road traffic and other industrial sources).

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# 1 BACKGROUND

This report was produced by HPS at the request of the Scottish Environment Protection Agency (SEPA), as a summary of the evidence relating to human health effects associated with the incineration of waste. SEPA requested this report to complement their work on issuing updated guidance on Thermal Treatment of Waste (TTW) (SEPA 2009). This collaboration is supported by a joint working agreement between HPS and SEPA. This report is primarily concerned with incineration of waste and not alternative waste processing technologies or solutions, such as landfill. Most of the previous reviews on this topic have focussed on Municipal Solid Waste Incineration (MSWI). SEPA requested that evidence relating to incineration of all relevant waste streams be considered including clinical, hazardous, industrial and municipal waste incineration.

One of the aims in writing this report was to draw definitive conclusions, if possible, as to whether or not incineration of clinical, hazardous, industrial and municipal waste streams has been reported to be conclusively associated with (non-occupational) health effects. The term *'health effects'* where used in this report generally means adverse human health effects, unless otherwise stated.

A number of reviews and reports have been published on incineration of waste in recent years, reflecting the level of concern regarding potential associations with non-occupational adverse health effects. Reports include those of the US National Research Council (NRC 2000), the World Health Organisation (Batterman 2004) and Greenpeace (Allsopp 2005). The UK Independent Expert Advisory Committee on Carcinogenicity of Chemicals in Food, Consumer Products and the Environment (CoC) published a statement on Municipal Solid Waste (MSW) incinerators and cancer in March 2000 (Committee on Carcinogenicity 2000). DEFRA commissioned a review of evidence on MSW incineration and health effects in 2004 (Enviros Consulting *et al* 2004). This DEFRA sponsored review was subsequently considered by the Health Protection Agency (HPA) in a position statement on municipal solid waste incineration (Health Protection Agency 2005). The CoC also produced an updated statement in March 2009, which considers epidemiological studies on cancer incidence and municipal solid waste incineration published since 2001.

Another aim of this report was to provide a bibliography and summary of existing evidence for future reference, including more recently published primary research not previously included in systematic reviews to date. However, given the range of previously published systematic reviews and other reports, this report was not intended to be another critical review of all the original literature. This body of evidence as a whole has been used to draw conclusions about the impact of waste incineration on human health.

The literature has been grouped by type of report and publication. Summarised details of the reports are provided, together with key conclusions as quotations from the authors, to minimise the risk of reinterpreting the authors' original words. Key features of reports are provided in evidence summary tables, allowing readers to more readily identify key features of the work.

An introduction to thermal treatment of waste and the terminology used to describe different waste streams and processes is provided in *Section 2.* The systematic literature search strategy is described in *Section 3.*

*Section 4* provides the summarised evidence. This consists of reports published outside the conventional peer-reviewed literature, review papers published in peer-reviewed literature and more recently published original papers not included in previously published systematic reviews. A bibliography of the relevant original papers is provided *(Appendix 1)*, together with tabular summaries of key results by waste stream considered and by health outcome studied. Author names are used in the text for references, which are listed alphabetically in the reference section. References were also numbered in the reference section for ease of use in relevant summary tables.

The topic is complex and researchers have approached it in a variety of ways. Time and resource constraints did not permit an in-depth critique of each individual study. Any form of meta-analysis was likewise beyond the scope of this report. The body of research evidence as a whole has therefore been considered critically, focusing on methodological issues. Very different methodologies have been used to investigate aspects of incineration processes, their outputs and their effects on human health. Different populations have been studied; some are primarily occupational, other studies focus mainly on local populations and yet others include both. The health outcomes studied also vary considerably, with most research focussing on cancers, respiratory health effects, birth outcome measures (not all necessarily “adverse” eg. rates of twin births) and congenital malformations. Some work considers only biomarkers (biochemical evidence of chemical exposures), rather than actual health outcomes. This lack of consistency and comparability of studies makes it particularly difficult to draw overall conclusions on the health impact of incineration, involving all waste stream sources. The limitations of the existing evidence base are discussed in *Section 5.*

Conclusions are drawn in *Section 6* and recommendations are made. These recommendations are consistent with Health Protection Scotland’s perspective on a public health issue where there is incomplete knowledge and therefore a significant degree of scientific uncertainty, yet where there is potential to minimise avoidable risks to public health by adopting a precautionary approach (SNIFFER 2005).

Earlier drafts of this report have been independently peer reviewed. As a result of helpful comments received from a variety of sources, including the HPA, a number of amendments have been incorporated to the final version to clarify the scope, nature and purpose of this report to SEPA and to add value to previously published work on this evidence base.

# 2 INTRODUCTION

Thermal treatment of waste, both within and outside Scotland has its own terminology. To allow meaningful comparisons of data, it is important to be aware of the terms employed in legislation and in the wider body of scientific literature, government reports etc. Where there are anomalies in the use of terminology, uncertainties can arise over the comparability of scientific and epidemiological research and consistency in terms of comparison of legislative requirements.

When considering the scientific and epidemiological evidence on this topic, it is also important to be clear on the study methods used, as well as the range and nature of investigative tools and statistical techniques employed in the different types of studies.

## 2.1 Definitions of Waste

_Waste_

The Waste Incineration Directive (WID) (2000/76/EC) (Council of the European Union 2000) came into force in 2000, and governs the treatment of waste by incineration. In order to determine the substances covered by the WID, a clear understanding of how *'waste'* is actually defined, is useful.

Article 3(1) of the WID states that "*'waste'* means any solid or liquid waste as defined in Article 1(a) of Directive 75/442/EEC", (i.e. the Waste Framework Directive (WFD) Council of the European Union 2006).

The WFD definition of waste is given as follows:

> *" 'waste' shall mean any substance or object in the categories set out in Annex 1 which the holder discards or intends or is required to discard"*
>
> [Annex 1 relates to Annex 1 of the WFD].

Annex 1 of the WFD then specifies a number of *'categories'* of waste covering a very broad spectrum of waste types. Therefore, given the wide range of categories listed, as well as the presence of a *'catch-all'* category, one could generally assume a definition of waste as "*any substance or object … which the holder discards or intends or is required to discard*", apart from some specific exclusions as laid out in the WFD.

The WFD has been revised and the definition of waste in the new Directive is: *"any substance or object which the holder discards or intends or is required to discard".* Scottish regulations are required to transpose this Directive into national legislation by 12 December 2010.

*Controlled Waste*

SEPA offer the following definition of *'controlled'* waste in their Waste Digest 7 (SEPA, 2007):

> *"Controlled waste is waste regulated by SEPA and includes five major waste streams:*
>
> - *household waste collected by, or on behalf of, local authorities;*
> - *commercial and industrial wastes produced by businesses;*
> - *construction and demolition wastes;*
> - *agricultural wastes;*
> - *mines and quarries wastes (non-mineral wastes)."*

[Agricultural wastes and non-mineral wastes from mines and quarries (excluding mineral wastes from site workings) were only included into the controlled waste regime in 2005.]

*Hazardous Waste*

The Hazardous Waste Directive (HWD) (Council of the European Union 1991) outlines the requirements within the European Community to control the movement of *'hazardous'* wastes. The aim of the HWD is to provide a precise and uniform European-wide definition of hazardous waste and to ensure the correct management and regulation of such waste. The HWD defines hazardous waste as those wastes featuring on a list drawn up by the European Commission, because they possess one or more of the hazardous properties set out in the HWD.

The European Waste Catalogue (EWC) (Council of the European Union 2002) is a comprehensive list of all wastes, hazardous or otherwise, based on the properties set out in the HWD. It is divided into twenty main chapters, most of which are industry-based but some of which are based on materials and processes. Hazardous wastes are highlighted within the catalogue.

SEPA employs the terminology *'special waste'* when referring to hazardous waste, and the following extract from their Waste Digest 7 (2007) aims to clarify this use of terminology and how this relates to the HWD:

> *"The Hazardous Waste Directive (91/689/EC) provides the framework for the control of hazardous or 'special' waste. Council Decision 2000/532/EC of 1 January 2002 established the European Waste Catalogue List of Waste, a harmonised, non-exhaustive list of waste types (see Appendix III). It categorises wastes based on a combination of what they are and the process or activity that produces them. Certain wastes on the list are classified as hazardous because they display one or more hazardous characteristics or properties such as being explosive, highly flammable, toxic or carcinogenic. The Special Waste Regulations 1996 transposed the requirements of the Hazardous Waste Directive into UK law. However, they did not fully transpose all the Directive's requirements. Nor did they take into account possible amendments to, and expansions of, the European Waste Catalogue and the list of hazardous wastes. The Special Waste Amendment (Scotland) Regulations 2004 address these issues."*

Within the literature, the terms, *'special'*, *'toxic'* and other terms may be used to describe hazardous waste of this sort. Given that *'hazardous'* is the term most widely employed in scientific and epidemiological literature, within this report, the preferred terminology to refer to such wastes will be *'hazardous'*.

<u>*Municipal Waste*</u>

The definition of municipal waste used by SEPA in their Waste Data Digest is that set out in the Interim Guidance on the Landfill Allowance Scheme (Scotland) Regulations 2005 (Scottish Government, 2005). In the Regulations, municipal waste is defined as:

> *"all waste for which the local authority makes arrangements excluding:*
>
> - *abandoned vehicles;*
> - *road maintenance waste;*
> - *commercial waste that is delivered to local authority owned or run landfill sites, where the local authority has no part in the collection or disposal arrangements that have led to this delivery;*
> - *industrial waste, collected from industrial premises and taken for disposal or treatment separately from any other waste;*
> - *construction and demolition waste that is collected and taken for disposal or treatment separately from any other waste. Bricks and rubble taken to civic amenity sites must be included in collected municipal waste."*

In the scientific/epidemiological literature, the most common terminology employed in relation to municipal waste is *'municipal solid waste'*. SEPA's definition (i.e. as defined in the Interim Guidance on the Landfill Allowance Scheme (Scotland) Regulations 2005 (Scottish Government, 2005) and the subsequent Guidance on the Landfill Allowance (Scotland) Regulations (Scottish Government, 2005)), does not make reference specifically to *'solid waste'*, therefore it is possible that some anomalies may exist between the composition of *'municipal waste'* as defined by SEPA/Scottish Government and *'municipal solid waste'* as referred to in the scientific literature. In practical terms there is unlikely to be a significant difference.

Within the literature, the terms *'municipal waste'*, and other terms may be used to describe waste of this sort. Given that *'municipal solid waste'* is the term most widely employed in scientific and epidemiological literature, therefore within this report, the preferred terminology to refer to such wastes will be *'municipal solid waste'*.

*Clinical Waste*

The Controlled Waste Regulations 1992 (http://www.opsi.gov.uk/SI/si1992/Uksi_19920588_en_1.htm, accessed October 2009) give the following definition of *'clinical waste'*:

> *" 'clinical waste' means—*
>
> *(a) any waste which consists wholly or partly of human or animal tissue, blood or other body fluids, excretions, drugs or other pharmaceutical products, swabs or dressings, or syringes, needles or other sharp instruments, being waste which unless rendered safe may prove hazardous to any person coming into contact with it; and*
>
> *(b) any other waste arising from medical, nursing, dental, veterinary, pharmaceutical or similar practice, investigation, treatment, care, teaching or research, or the collection of blood for transfusion, being waste which may cause infection to any person coming into contact with it;"*

SEPA employ the term *'clinical waste'* within their Waste Data Digest based on the above definition. Clinical-related waste is generally referred to in the scientific and epidemiological literature by a number of terms including *'clinical waste'*, *'medical waste'* or *'healthcare waste'*, which could (correctly or incorrectly) be assumed to be synonymous. However, given the lack of definitions provided on the terms used, it is very difficult to assume that comparisons can easily be made between studies employing different terminologies.

Within this report, the terminology used to refer to clinical-related waste will be *'clinical waste'*, given that this term, by its very definition, encapsulates all other biological/medical waste terms employed in the scientific and epidemiological literature and is also in keeping with terminology both used by SEPA and contained in the Controlled Waste Regulations. Where authors of scientific or epidemiological publications make reference to more specific types of clinical waste (e.g. medical waste) this terminology will be used in summarising their work.

*Commercial / Industrial Waste*

SEPA refer to "*commercial and industrial waste*" within their Waste Data Digest, and give the following definitions of the terms '*commercial' and 'industrial waste'*.

> *"Commercial waste: Waste arising from premises that are used wholly or mainly for trade, business, sport, recreation or entertainment, excluding household and industrial waste (as defined in Environmental Protection Act 1990, section 75)."*

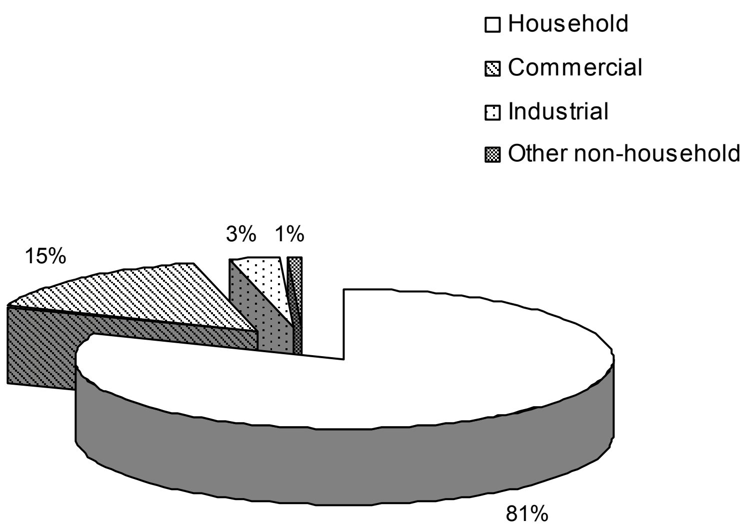
> *"Industrial waste: Waste from a factory (within the meaning of the Factories Act 1961) or from any premises used for, or in connection with*
> - *provision of public transport*
> - *public supply of gas, water, electricity or sewerage services*
> - *provision to the public of postal or communication services"*

*'Industrial waste'* is the term frequently used in specific studies within the scientific and epidemiological literature. Due to the heterogeneous nature of waste from industry and commerce activities, it is impossible to say whether or not the *'industrial waste'* referred to in specific studies could also be classed as *'hazardous'* within the European Waste Catalogue. There is also a level of uncertainty as to whether the waste in scientific studies termed as industrial might in fact be commercial. However, for the purposes of this report, the term *'industrial waste'* will be used when discussing studies wherein the authors have employed this same terminology.

## 2.2 Waste Management in Scotland

Waste management is a highly complex and very topical subject. The total amount of waste produced, and collected for disposal by local authorities, in Scotland from 2005 to 2006 was 2,586,817 tonnes (SEPA, 2007). Figure 1 illustrates the different waste sectors that comprise the total waste collected for disposal in this period. As can be seen from the chart, household waste is a significant area of concern due to the large volumes generated.

**Figure 1: Total waste (tonnes) collected for disposal by, or on behalf of, local authorities in 2005/2006 in Scotland (SEPA 2007)**

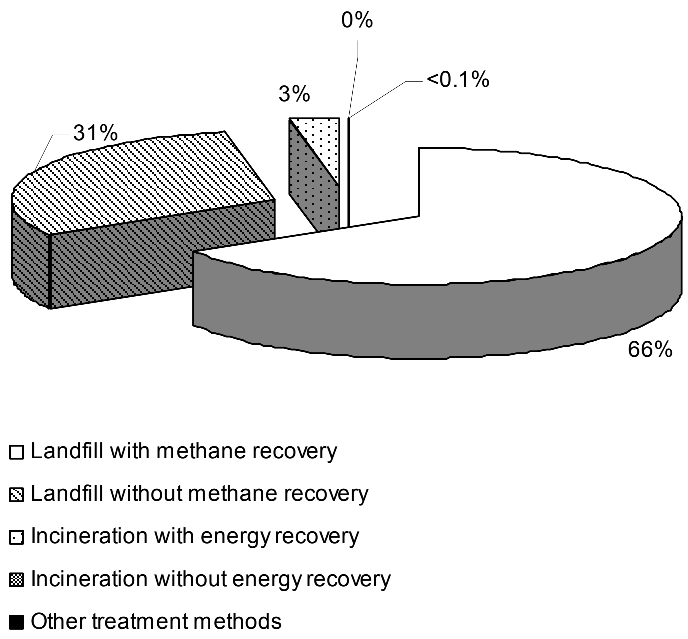



The process of waste management in Scotland is addressed by the National Waste Plan for Scotland (SEPA 2003) and on a local basis via Area Waste Plans for the 11 designated waste areas. (http://www.sepa.org.uk/waste/moving_towards_zero_waste/area_waste_plans.aspx, accessed October 2009).

Most of the waste produced and collected for disposal by local authorities between 2005 and 2006 in Scotland was sent to landfill as shown in Figure 2. Existing methods of waste disposal are considered by the Government to be unsustainable and a move is in place to reduce the volume of waste produced across all waste sectors. The European Landfill Directive is a main driver of this movement towards more sustainable waste disposal.

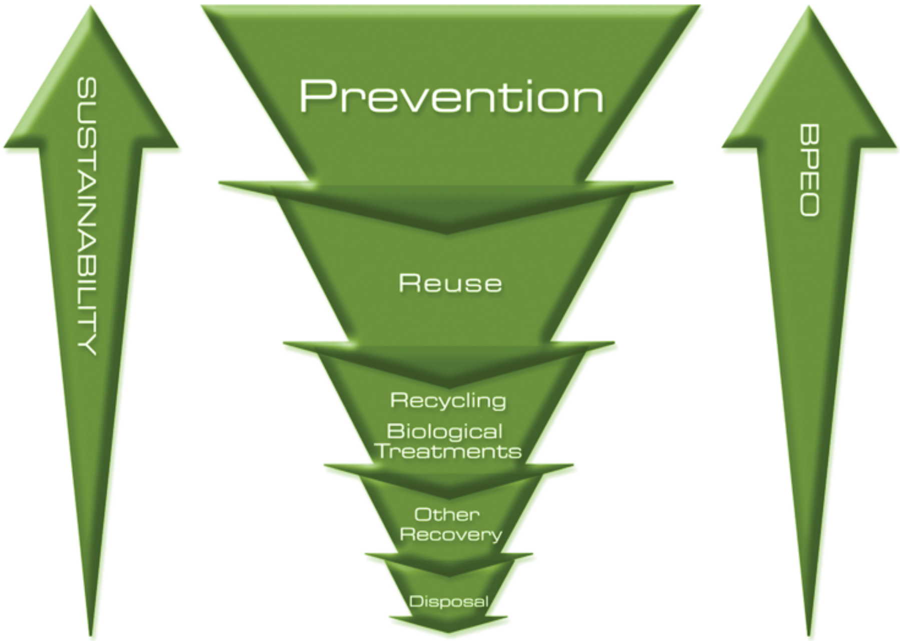
(http://ec.europa.eu/environment/waste/landfill_index.htm, accessed October 2009)

**Figure 2: Waste treatment and disposal methods (SEPA 2007)**




The Landfill Directive represents a phased approach to the management of waste disposal in this country and is intended to drive increased levels of recovery, recycling and waste minimisation (prevention) (Figure 3). The reduction of the biodegradable fraction of waste being disposed to landfill will be realised through statutory targets contained within the EU Landfill Directive. Due to the heterogeneous nature of municipal solid waste, not all options in the hierarchy may be applicable, although increased sustainability will be the ultimate goal.

**Figure 3: Waste hierarchy**




(Source: SEPA, http://www.sepa.org.uk/waste/moving_towards_zero_waste/waste_hierarchy.aspx, accessed October 2009)

The Landfill Directive has a number of targets, summarised in Table 1.

**Table 1: Landfill Directive targets (DEFRA 2003)**

| Target date | Target Level |
|---|---|
| 2010 | reduce biodegradable municipal waste land-filled to 75% of that produced in 1995 |
| 2013 | reduce biodegradable municipal waste land-filled to 50% of that produced in 1995 |
| 2020 | reduce biodegradable municipal waste land-filled to 35% of that produced in 1995 |

The Scottish Government is committed to reducing the volume of waste dealt with by landfill; therefore alternatives to this waste disposal method are being explored and encouraged. The main long-term drive within Scotland is to reduce waste production, increase waste reuse and recycle more.

### 2.1.1 Thermal Treatment of Waste in Scotland

Thermal treatment of waste (TTW) is a term covering a variety of processes, involving heating of waste (e.g. direct combustion (incineration), pyrolysis, gasification). Thermal treatment involving direct combustion reduces the volume of waste by incinerating it at high temperatures (850°C to 1200°C), leaving a residual ash which is processed and then recycled and re-used or disposed of. Thermal treatment can be used to recover energy as heat or electricity as the waste is processed. The revised WFD now includes an efficiency calculation that defines when Thermal Treatment is a 'disposal' or 'recovery' operation. Figure 2 shows that a relatively small amount of waste (3%) was processed by incineration with energy recovery between 2005 and 2006.

SEPA produced guidance on the thermal treatment of waste (SEPA 2009), which replace and update the '*Guidelines for thermal treatment of municipal waste August 2004*'. Applying to all thermal treatment plants that recover energy from municipal waste and/or commercial and industrial waste, the practical implications of the guidelines are that plants should:

- only treat residual waste (i.e. waste remaining after all efforts have been made to extract recyclable materials, either prior to or after delivery to the plant) in order not to impede recycling and waste prevention efforts;
- be part of an integrated network of recycling and composting and other waste management facilities;
- recover and use the energy derived from waste efficiently.

In addition, SEPA is the environmental licensing authority for waste thermal treatment plants, which requires that:

- emissions from the plant will not have any adverse impacts on the environment and human health;
- all wastes generated on site will be minimised and where generated shall be recovered or disposed of without causing any significant harm to the environment or human health.

SEPA also produced a document, "*Thermal Treatment in Scotland: Addressing Public Concern (SEPA 2007)".* (Thermal Treatment Criteria Stakeholder Seminar - April 2008)

### 2.2.2 Emissions from Thermal Treatment of Waste

In terms of emissions from thermal treatment processes and their potential impact on human health, Table 2 summarises the potential sources of toxins, the potential receptors of the toxins and the potential pathways they might take.

**Table 2: Source-pathway-receptor model for incinerator emissions**

| **Source** (Emissions) | **Pathway** (Routes of exposure) | **Receptor** (At risk populations) |
|---|---|---|
| Stack exhaust gas | 1) Direct inhalation<br>2) Aerial deposition to water<br>a. consumption of water<br>b. contamination of fish<br>3) Deposition onto farm land and crops<br>4) Deposition to pasture and ingestion by livestock<br>5) Deposition to soil and subsequent<br>a. ingestion of soil<br>b. uptake into crops / plants<br>6) Direct inhalation of fugitive emissions | 1) Human<br>2) Animal / fish<br>3) Plants |
| Residual ash<br>(Fly ash and bottom ash) | 1) Landfill – leaching of contaminants into soil<br>a. Ingestion of soil<br>b. Uptake into plants<br>2) Landfill – leaching into groundwater<br>a. Contamination of potable water ingested by humans / animals<br>b. Contaminated groundwater mixes with surface water ingested by animals<br>c. Uptake into plants | 1) Human<br>2) Animal / fish<br>3) Plants |
| Waste water | 1) Discharge to water courses | 1) Animal / fish<br>2) Human<br>3) Plant |

*Stack Exhaust Gas*

The incineration of waste in Scotland is regulated by SEPA through the Pollution Prevention and Control (PPC) Regulations (Scotland) 2000, which implement the EU Integrated Pollution Prevention and Control (IPPC) Directive 1996. IPPC and PPC are designed to prevent or, where that is not possible, minimise emissions from installations by ensuring compliance with emission limits for various substances. When considering findings from incinerator research presented in this report, the reader must consider the IPPC Directive and the subsequent EU Waste Incineration Directive 2000 that provide increasingly stringent legislation regarding emissions. As a result of these directives a number of non-compliant incineration plants ceased operation. At the time of writing this report there were nine incinerators operating in Scotland under PPC permits. Of these nine incinerators, two process municipal waste, five process clinical (including animal) waste and two process hazardous waste.

The following list details the constituents that may be present in stack exhaust emissions produced from the incineration of waste. The actual composition of the emissions will vary between incinerators depending on the waste that is being treated and the age and type of Thermal Treatment process (Pyrolysis, Gasification, Fluidised Bed Incineration, Fixed Grate). The emission list was modified from UK technical guidance entitled; *"Guidance for the Incineration of Waste and Fuel Manufactured from or Including Waste"*, available from the SEPA website (http://www.sepa.org.uk/air/process_industry_regulation/pollution_prevention__control/uk_technical_guidance/s5_waste/s501.aspx, accessed October 2009).

| EMISSION CATEGORY | EMISSION COMPOUND |
|---|---|
| **Dust** | Particulate matter ($PM_{10}$, $PM_{2.5}$) |
| **Hydrocarbons** | Dioxins<br>Dioxin-like Polychlorinated Biphenyls (PCBs)<br>Furans<br>Polycyclic Aromatic Hydrocarbons<br>Volatile Organic Carbons |
| **Gaseous compounds** | Ammonia ($NH_3$)<br>Carbon monoxide (CO)<br>Hydrogen chloride (HCl)<br>Hydrogen fluoride (HF)<br>Nitrogen oxides (NOx)<br>Sulphur dioxide ($SO_2$) |
| **Metallic compounds** | Cadmium<br>Chromium<br>Cobalt<br>Copper<br>Lead<br>Manganese<br>Mercury<br>Nickel<br>Thallium<br>Vanadium |
| **Metalloid compounds** | Antimony<br>Arsenic |

Of the gaseous emissions, dioxins give rise to particular public concern due to their potential association with adverse effects on reproduction and development as well as their carcinogenic potential.  Most human exposure to dioxins is via the diet with a very small contribution via inhaled air. Incineration of waste itself accounts for a very small proportion of the total dioxin emission to air (less than 1% of total emissions of dioxins in the UK to air were estimated to be due to incineration of waste in 2006). (http://www.naei.org.uk/data_warehouse.php, accessed October 2009)

*Residual Ash*

The main by-product from waste incineration is the ash that is formed during the incineration process. The *'bottom ash'* is generally the heavy fraction that falls through the bottom of the incinerator. This fraction can contain heavy metals, dioxins and furans, but has not generally been regarded as hazardous waste.

Fly ash is collected in the stack by filtering and is much finer than bottom ash. The fly ash may also contain heavy metals, dioxins and furans, along with PAHs, at higher concentrations than bottom ash. Fly ash is therefore handled as a hazardous waste.

*Waste Water*

In an incineration plant, water is used as part of the pollution control system to facilitate cleaning the exhaust gases. The water is usually cleaned and re-used within the system. Where the water is required to be discharged the activity is controlled under The Pollution Prevention and Control (Scotland) Regulations 2000 which implement Article 8 of the WID (Council of the European Union 2000). In summary:

- Discharge of the waste water would be controlled under a PPC permit
- Pollutants within the water must be within emission limit values after treatment and before it is released into the environment.

## 3 LITERATURE SEARCH AND STUDY METHODS

A systematic search strategy was used to identify relevant literature for this report (Fig 4). A modification of the Scottish Health Protection Network (HPN) guideline development methodology was used, itself derived from the Scottish Intercollegiate Guideline Network (SIGN 50) methodology. (http://www.documents.hps.scot.nhs.uk/about-hps/hpn/hpn-review-activities.pdf, accessed October 2009)

### 3.1 Phase 1

Key questions were defined to help identify evidence and focus the scope of the search strategy. These were then converted into search phrases, using the *source-pathway-receptor* model to analyse the life-cycle of the thermal waste treatment process.

Key search phrases were identified covering potential sources of hazard, how they might come into contact with receptors (including humans), and the range of potential pathways. The *sources* of concern for thermal treatment of waste are: the gaseous emissions from the exhaust stack, the residual solid ash left after combustion and the water used to cool the exhaust emissions. The potential *pathways* include: direct contact via air to lungs, uptake by plants subsequently ingested, and contamination of ground water by compounds leaching from land-filled ash. The search identified that some but not all of the potential pathways had been investigated in peer-reviewed published research. The *receptors* of principle interest were human populations exposed to the outputs from incineration; though the literature often included both those living in the vicinity and those occupationally exposed in their study populations. Occupational exposure might be expected to be higher than local population exposure assessed by proximity of home address alone, though not necessarily if stack emissions are the primary source of emissions.

### 3.2 Phase 2

#### 3.2.1 Primary Studies and Reviews

The *source-pathway-receptor* model generated a number of high level search terms that were used in the search. The search for primary studies and reviews published in peer-reviewed journals was conducted using the Ovid search website interface

(Wolters Kluwer Health, Ovid Industries http://ovidsp.uk.ovid.com/spb/ovidweb.cgi, accessed October 2009).

The following databases were selected to perform the searches:

- Cochrane Database of Systematic Reviews (COCH)
- Cochrane Central Register of Controlled Trials (CCTR)
- Ovid MEDLINE(R) 1950 to 2008
- CINAHL - Cumulative Index to Nursing & Allied Health Literature 1982 to 2008
- EMBASE 1996 to 2008
- PsycINFO 1806 to 2008

Based on the high level search terms, an initial total of 3,084,201 scientific paper titles were identified and reduced to 1040 titles through combinations of the search terms using the "AND" Boolean operator. The full matrix of high level search terms and combinations with results are given in Appendix 4.

#### 3.2.2 Inclusion / Exclusion Criteria and Sifting of Papers

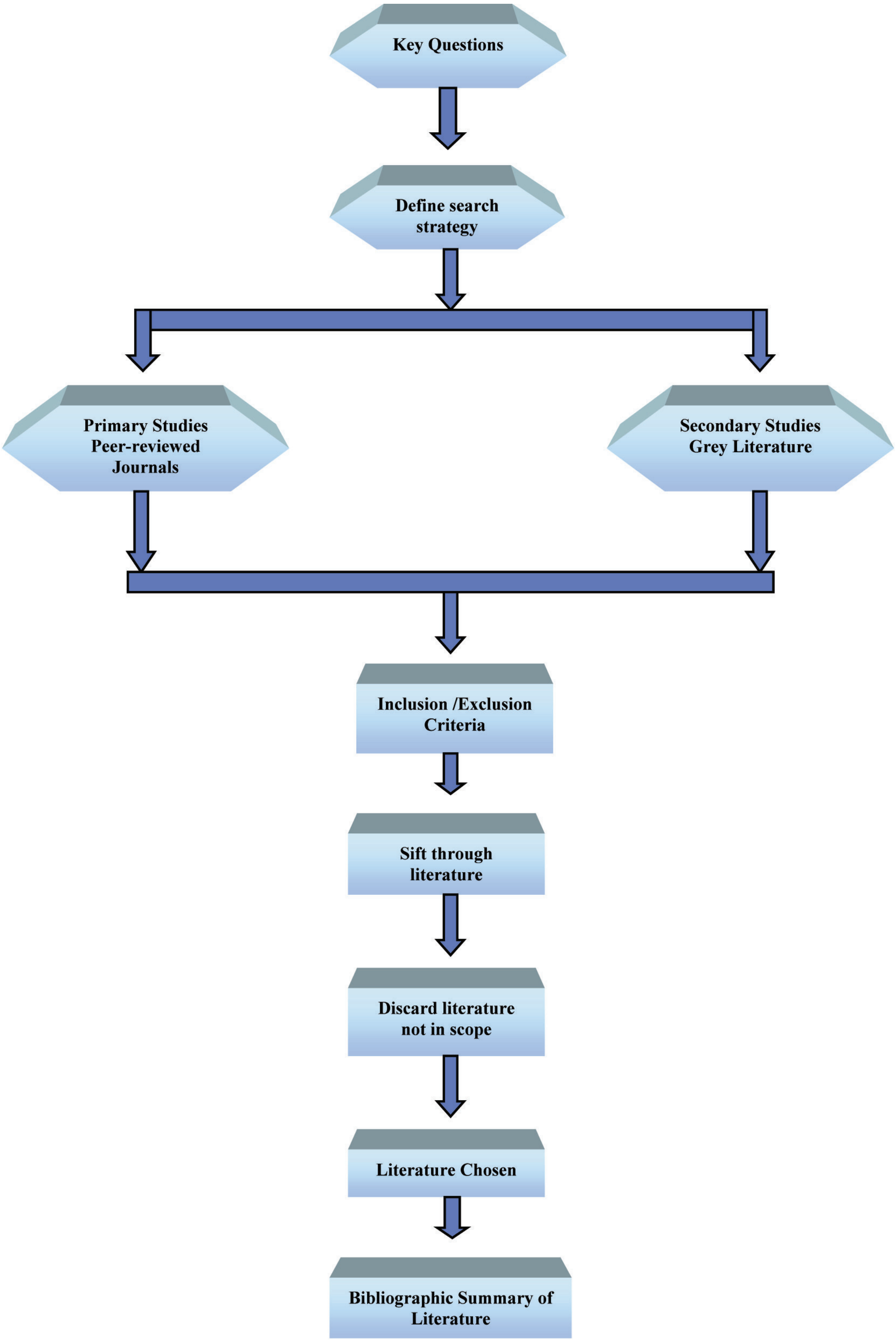
The abstracts of the 1040 results were used to assess their relevance. Papers that did not describe some aspect of the human health effects of TTW in the abstract were excluded, resulting in a final total of 51 peer-reviewed papers published in scientific journals, including some reviews, ranging in publication date from 1988 to end September 2008.

### 3.3 Phase 3

#### 3.3.1 Secondary Studies

The secondary search was designed to identify literature not available in peer-reviewed journals (the *"grey literature"* (Debachere 1995)). Some of this literature was identified from lists of references in primary papers. The remainder was identified via the Google search web pages (http://www.google.co.uk, accessed October 2009) using the key search phrases identified in Phase 1. The search identified a total of 10 relevant reports produced by government agencies, non-government and special interest groups, and conference proceedings.

**Figure 4: Search strategy process**



### 3.4 Investigative Methods

Researchers have used a wide variety of approaches to investigate aspects of the topic resulting in a wide range of published studies on the human health effects of waste incineration. A variety of tools and techniques have been used to assess human health impacts. The US National Research Council (NRC) (NRC 2000) categorised the tools typically employed in this work as:

- Epidemiological studies (population based)
- Risk Assessment (hazard analysis based)
- Environmental monitoring (environmental impact based)
- Biological markers of exposure (biomarker or physiological effect based)
- Life-Cycle Assessment (whole-waste process based)

However, these categories are not mutually exclusive and studies have used combinations of study methods.

#### 3.4.1 Epidemiological Studies

Epidemiological studies (ecological, cohort or case-control studies) may be used to generate or test hypotheses about the incidence or prevalence of health outcomes and the relationship between such outcomes and potential aetiological factors. Data used in such work may include various (arbitrary) exposure categories, proxy indicators of exposure (eg. proximity to an incinerator) (qualitative measures) or actual measured physical exposure (objective quantitative measurements).

#### 3.4.2 Risk Assessments

Risk Assessment procedures follow a stepwise process of identifying, characterising then quantifying the risks likely to be associated with exposure to defined hazards resulting from an incinerator process. The accuracy of such assessment processes is heavily dependent on the availability of good quality data, (e.g. on incinerator emissions) which is frequently not available in sufficiently robust form. There may therefore be a heavy reliance on modelling of emissions based on theoretical plant operating parameters.

### 3.4.3 Environmental Monitoring Studies

Such studies use actual environmental monitoring data to quantify emission products available via pathways of direct potential human exposure (e.g. air, water, or food) or from indirect exposure via soil or vegetation used for grazing animals. Monitoring may not, however, be able to distinguish the contribution from an individual incinerator from other local or regional sources of the same pollutants. Environmental monitoring may form a component of an epidemiological investigation or a risk assessment study.

### 3.4.4 Biological Markers (biomarkers) of Exposure or Effect

Measurements of biological markers, which indicate the direct presence of, or the effects from exposure to, pollutants have been used to confirm the extent of exposure to incinerator emissions. Analysis of blood or tissue samples is used to obtain quantitative estimates of exposure (e.g. dioxins). The lack of specificity of available biomarkers is a problem, in that detecting their presence cannot be directly related to an individual incinerator due to the lack of any unique biomarker. There are therefore limitations on the interpretation of biomarker data. Biomarkers may be used in conjunction with epidemiological studies or risk assessment methods.

### 3.4.5 Life-Cycle Assessment

This technique seeks to assess the contribution of any particular chemical or item to health impacts by looking at waste in the context of its sources and original uses, its transport to a processing facility, and the full implications of disposal of any by-products (the *'life-cycle'*). Such techniques may be used as part of risk assessment methods.

# 4 EVIDENCE ON INCINERATION AND HUMAN HEALTH EFFECTS

## 4.1 Introduction

One aim of this report was to provide a bibliography of the evidence on incineration and human health effects for future reference. The evidence is therefore summarised and collated in this section and appendices. Evidence tables are used extensively to provide summarised data and key facts.

The systematic literature search identified primary research and systematic reviews published in peer-reviewed journals, official government sponsored reports, non-governmental reports and other grey literature relating to studies on the human health impact of incineration.

The majority of relevant original research has already been considered in one or more of the published systematic reviews or other reports considered in this report. The majority of readers are expected to be interested primarily in these systematic reviews and other reports on the existing literature. The primary research papers assessed in these previously published reviews are therefore not reviewed again in this section (4) but are listed in Appendix 1. However, a small number of additional papers were identified, which were published after these existing systematic reviews had been completed. These newer primary research papers are therefore considered separately and in greater depth in Section 4.4 of this report.

*Section 4.2* provides a summary of reports which were published in sources other than peer-reviewed journals. These comprise reports of the UK independent expert Committee on Carcinogenicity (CoC) in 2000, government department sponsored reviews (e.g. DEFRA in 2004) and other non-governmental agency reports (e.g. Greenpeace in 2005). Some were subject to independent peer-review before final publication. Additional grey literature, such as conference proceedings, is also considered in Section 4.2. In keeping with SIGN guidance, an evidence summary table (Table 3) provides key data including: date of publication, authors, year date-range studied, numbers of papers included in the review, incineration types considered and health outcomes considered. A final column indicates whether the report authors drew any clear conclusions regarding: (i) an association between adverse health effects and incineration, (ii) no association or (iii) that the evidence was inconclusive. Key conclusions are provided as quotations in the authors' own words to minimise the risk of re-interpretation.

*Section 4.3* provides a summary of evidence from reviews that were published in peer-reviewed journals. They are further sub-divided into reviews which described a systematic literature search method and those that did not. In keeping with SIGN guidance, an evidence table (Table 4) is provided summarising key features of each review including: the year date-range of publications considered, the number of papers reviewed, the types of incineration considered and the health outcomes covered by the papers. A final column indicates whether or not the review authors drew an overall conclusion as to the evidence for or against there being adverse health effects associated with incineration.

*Section 4.4* provides the summary of evidence and a critical review of more recent work not already included in any of the previously published reviews described earlier. These primary papers have been assessed using criteria derived from those cited by Saffron *et al* (2003) in their review and using criteria published by SIGN (2008) for reviewing published evidence.

For readers who wish to refer to the primary literature itself, the original papers considered most relevant are summarised in Appendix 1. Papers are grouped by waste stream category (e.g. multiple waste streams, municipal solid waste, hazardous, clinical and industrial waste). For each waste stream category, relevant papers are grouped by health outcomes studied (e.g. cancers, genetic/congenital malformations, reproductive/birth outcomes, respiratory disease or biochemical markers/ body burden of metabolites). For each paper a brief description is provided with summarised key facts and conclusions. In keeping with SIGN methodology, each sub-section has an evidence table summarising key facts about the study including: the country studied, number of subjects, waste stream studied, outcomes studied and key results (Tables 7 to 11). Two final summary evidence tables provide listings by year of publication for the key data on each study (Table 12) and by health outcomes studied (Table 13).

## 4.2 Reports on Incineration and Health Effects Not Published in Peer-Reviewed Journals

A number of reports on thermal treatment technologies and their health effects have been produced by UK and other government agencies, non-government organisations and special interest groups in recent years. Although none in this category were published in a peer-reviewed journal, some were subject to other forms of critical peer-review. Key information on these reports is summarised in Table 3.

### 4.2.1 UK Government Organisation Reports

The **Medical Research Council Institute for Environment and Health (IEH) (Humfrey *et al*, 1997)** reported on the health effects of waste combustion products, relating mainly to MSW incineration. The overall conclusion was that there was no conclusive evidence of association; the findings are summarised in the following quotations:

> *"Epidemiological studies of people who work at or live near incinerators have shown no consistent excess incidence of any specific disease. Many of these studies, however, have not been able to detect adverse effects reliably, either because they were too small in size or could not adequately account for confounding factors."*
>
> *"In general, few data are available on the human health effects associated with low levels of exposure to the individual pollutants considered in this report; most of the information originated from either environmental accidents or occupational studies in which exposures have been generally much higher".*
>
> *"No consistent pattern of ill-health has emerged from studies of incinerator workers or populations living near incinerators. Any future epidemiological studies investigating the health effects associated with living near incinerators should be designed so that small increases in risk can be detected, and should also adequately account for the various confounding or modifying factors."*

The **Committee on Carcinogenicity (CoC) (CoC 2000)** produced a statement on the evidence from two (peer-reviewed) papers published by Elliott *et al* (1996 & 2000) of the Small Area Health Statistic Unit (SAHSU). Elliott *et al* investigated cancer incidence near municipal solid waste (MSW) incinerators in Great Britain from 1974-86 for England, 1974-84 for Wales and 1975-87 for Scotland. The CoC conclusions were summarised as follows:

> *"The SAHSU studies found a small excess of primary liver cancer near municipal solid waste incinerators (estimated to be between 0.53-0.78*

*excess cases 10-5 year-1). It is not possible to conclude that this small increase in primary liver cancer is due to emissions of pollutants from incinerators, as residual socio-economic confounding cannot be excluded. The Committee agreed that an excess of all cancers, stomach, lung and colorectal cancers was due to socio-economic confounding and was not associated with emissions from incinerators."*

*"The finding of two cases of angiosarcoma during the histopathology review in individuals who were resident within 7.5 km of a municipal solid waste incinerator was unexpected. The Committee considered that the evaluation of this finding was difficult given the limitations in the registration of angio-sarcoma and lack of information regarding accuracy of diagnosis in the general population. The Committee, however, agreed that there was no evidence more generally of clustering near incinerators of cases ascribed to angiosarcoma in a national register."*

The Committee was reassured that any potential risk of cancer due to residency (for periods in excess of 10 years) near to municipal solid waste incinerators was exceedingly low and probably not measurable by the most modern epidemiological techniques. The Committee advised that, at that time, there was no need for any further epidemiological investigations of cancer incidence "*near municipal solid waste incinerators*".

The **Department for Environment Food and Rural Affairs (DEFRA) (Enviros Consulting *et al*, 2004)** commissioned a report on the management of municipal solid waste (MSW) by a number of methods including waste incineration. This was a comprehensive critical review that identified 23 relevant epidemiological studies and a further 4 review papers. An earlier draft of this review was itself peer-reviewed by The Royal Society. Most weight was given to studies that had accounted for confounding factors, had a valid means of estimating exposures and had sufficient statistical power to detect results with small confidence intervals. This review considered a variety of health outcomes including specific cancers, respiratory effects and reproductive outcomes.

The overall conclusion of this review in relation to all of the waste management options considered (including incineration) was as follows:

*"For most of the municipal solid waste facilities studied, we found that the health effects in people living near waste management facilities were either generally not apparent, or the evidence was not consistent or convincing. However, a few aspects of waste management have been linked to health effects in local people. We would need more research to know whether or not these are real effects. "*

With respect specifically to MSW incineration it concluded:

> *"The lack of consistent evidence of adverse health effects associated with MSW incineration indicates that emissions under routine and non-standard conditions does not give rise to consistently detectable health effects."*
>
> *"We found no consistent evidence for significantly elevated levels of ill health in populations potentially affected by emissions from MSW incineration."*
>
> *"Additionally, the health effects associated with exposures to dioxins and furans from thermal processes were found to have no significant adverse health effects."*

In relation to cancer it concluded:

> *"Despite reports of cancer clusters, no consistent or convincing evidence of a link between cancer and incineration has been published."*

With respect to respiratory function:

> *"Overall there is little evidence to suggest that waste incinerators are associated with increased prevalence of respiratory symptoms in the surrounding population."*

Similarly, the authors concluded that no impact was demonstrated on reproductive outcomes. However, the review does not conclude that there are no health effects at all but that evidence is inconsistent and that if effects exist, they will be of comparatively low level impact. The DEFRA Chief Scientific Adviser noted that:

> *"The review has concluded that the effects on health from emissions from incineration, largely to air, are likely to be small in relation to other known risks to health."*

The **Health Protection Agency (HPA) (2005)** produced a statement on municipal solid waste incineration. HPA noted the findings of the DEFRA (2004) review and acknowledged that incinerators are a source of pollutants. However, they concluded with respect to respiratory outcomes that:

> *"there is little evidence to suggest that incinerators are associated with increased prevalence of respiratory symptoms in the surrounding population. However, the contribution to local pollutant levels should be assessed on a site specific basis".*

HPA also noted that there are public concerns regarding release of dioxins and furans and supported Government policy to reduce such emissions further by all practicable means.

The conclusion on these pollutants was:

> *"However, current levels of dioxins emissions from incinerators are unlikely to increase the human body burden appreciably as incineration of municipal solid waste accounts for less than 1% of UK emissions of Dioxins"*

In relation to incinerators and cancer, HPA concurred with the view of the Committee on Carcinogenicity (CoC), that any risk associated with living near an incinerator (for more than ten years) was:

> *"exceedingly low and probably not measurable by the most modern techniques".*

Commenting on health studies in general examining adverse health effects around incinerators, the Agency stated that it:

> *"is not aware of any consistent or convincing evidence of a link with adverse health outcomes. However it is accepted that the lack of evidence of adverse effects might be due to the limitations regarding the available data".*

The Agency noted that providing incinerators are operated in accordance with the latest regulations they should add little to levels of monitored pollutants in ambient air. Regarding the evidence on health effects, it concluded:

> *"Epidemiological studies and risk estimates based on estimated exposures, indicate that the emissions from such incinerators have little effect on health".*

The UK **Committee on Carcinogenicity** issued an updated statement on Cancer Incidence near Municipal Solid Waste Incinerators **(Committee on Carcinogenicity 2009)** which considered new research published since 2000. CoC concluded that there was some new evidence of a positive association between two uncommon cancers; non-Hodgkin's lymphoma (NHL) and soft tissue sarcomas (STS), and residence near to incinerators. However, CoC highlighted that the periods of exposure studied were in the past and that the study findings could not therefore be extrapolated to incinerators in current operation, given the lower amount of emissions that they now discharge. CoC concluded that it saw no need to change its previous advice regarding the *"exceedingly low"* risk of cancer due to residency near MSWIs but it did note that the situation should be *"kept under review".*

### 4.2.2 Other (Non UK Government) Reports

The **US National Research Council Committee on Health Effects of Waste Incineration (NRC) (NRC 2000)** reviewed evidence as part of a wide ranging report. This identified that the approaches to assessing the health effects associated with incineration had defined weaknesses:

Studies were noted to be:

> *"typically site-specific and facility-specific and so fail to answer two important questions regarding a facility or site:*
>
> - *To what extent does an incineration facility alter the environmental concentrations of substances of concern or alter the existing magnitudes of human exposure to those substances?*
> - *What are the overall local and regional contributions of waste incineration to human exposures?"*

The NRC Committee also emphasised the need to allow for "*uncertainties and variability*" in relation to:

> *"types of waste incinerated; operating practices; allowable magnitudes of emissions; emission - control technologies; types of substances emitted; environmental conditions; proximity to other sources of contaminants and frequency of process upsets. The people who might be exposed to the contaminants are likely to differ in their susceptibilities and activity patterns."*

The Committee acknowledge further limitations in the research into this topic, especially in relation to the effects studied:

> *"The effects might be economic (such as job creation or decrease in property values), psychological (such as stress or stigma), or social (such as community factionalization or unity). However, there is little rigorous information on those impacts of waste-incineration facilities."*

The Committee recommended that special attention be paid in future to health risks associated with emissions of particulate matter, lead, mercury, dioxins and furans in that these pollutants have the greatest potential to cause adverse health effects. It also advised that future research should focus on: multi-site epidemiological studies, use of biological monitoring and other exposure-assessment techniques, and on emissions resulting from "*off-normal*" operating conditions (e.g. where regulatory standards are breached or during periods of non-optimal working, as in start-up and shut down procedures).

The Committee view of the published evidence was summarised in a key conclusion:

> *"Few epidemiological studies have attempted to assess whether adverse health effects have actually occurred near individual incinerators, and most of them have been unable to detect any effects. The studies of which the committee is aware that did report finding health effects had shortcomings and failed to provide convincing evidence. That result is not surprising given the small populations typically available for study and the fact that such effects, if any, might occur only infrequently or take many years to appear. Also, factors such as emissions from other pollution sources and variations in human activity patterns often decrease the likelihood of determining a relationship between small contributions of pollutants from incinerators and observed health effects. Lack of evidence of such relationships might mean that adverse health effects did not occur, but it could mean that such relationships might not be detectable using available methods and sources."*

The **Food Safety Authority of Ireland (FSAI) (2003)** investigated possible implications on health associated with food contamination from waste incineration and concluded:

> *"In relation to the possible impact of introduction of waste incineration in Ireland, as part of a national waste management strategy, on this currently largely satisfactory situation, the FSAI considers that such incineration facilities, if properly managed, will not contribute to dioxin levels in the food supply to any significant extent. The risks to health and sustainable development presented by the continued dependency on landfill as a method of waste disposal far outweigh any possible effects on food safety and quality."*

### 4.2.3 Non-Governmental Organisation (NGO) Reports

A report published by **World Health Organisation (WHO)** included one of the few reviews of evidence relating to (small-scale) incinerators for healthcare (clinical) waste **(Batterman 2004)**. It concluded that there were potential risks to health for both workers and local populations but drew no definitive conclusion:

> *"Incinerator emissions of both conventional (e.g. particulate matter) and toxic pollutants (e.g. dioxins/furans) may pose risks that potentially affect:*
>
> - *Waste workers and incinerator operators*
> - *Local communities through both inhalation exposure and through the consumption of locally-produced food that becomes contaminated from incinerator emissions*
> - *Regional/global environment, through the discharge of toxic and*

*persistent chemicals."*

**Greenpeace** commissioned a review on incineration and human health **(Allsopp 2005)** which reported that there was conclusive evidence of adverse effects:

> *"This report was undertaken to draw together scientific findings on incinerator or releases and their impacts on human health. A broad range of health effects have been associated with living near to incinerators as well as with working at these installations. Such effects include cancer (among both children and adults) adverse impacts on the respiratory system, heart disease, immune system effects, increased allergies and congenital abnormalities. Some studies, particularly those on cancer, relate to old rather than modern incinerators. However, modern incinerators operating in the last few years have also been associated with adverse health effects."*

However, the authors do not explain the basis for their conclusion that there is an association between incineration and adverse effects in terms of criteria used to assess the strength of evidence. The weighting factors used to derive the assessment are not detailed. The objectivity of the conclusion cannot therefore be easily tested.

The **British Society for Ecological Medicine (BSEM)** report on the evidence of health effects associated with incineration **(Thompson & Anthony 2005)** also concluded that there was convincing evidence for an association and recommended that all incineration should cease:

> *"Large studies have shown higher rates of adult and childhood cancer and also birth defects around municipal waste incinerators: the results are consistent with the associations being causal. A number of smaller epidemiological studies support this interpretation and suggest that the range of illnesses produced by incinerators may be much wider."*
>
> *"Incinerator emissions are a major source of fine particulates, of toxic metals and of more than 200 organic chemicals, including known carcinogens, mutagens, and hormone disrupters. Emissions also contain other unidentified compounds whose potential for harm is as yet unknown, as was once the case with dioxins. Since the nature of waste is continually changing, so is the chemical nature of the incinerator emissions and therefore the potential for adverse health effects."*
>
> *"Present safety measures are designed to avoid acute toxic effects in the immediate neighbourhood, but ignore the fact that many of the pollutants bio-accumulate, can enter the food chain and can cause chronic illnesses over time and over a much wider geographical area. No official attempts have been made to assess the effects of emissions on long-term health."*
>
> *"Incinerators produce bottom and fly ash which represent 30-50% by volume of the original waste (if compacted), requiring transportation to landfill sites.*

> *Abatement equipment in modern incinerators merely transfers the toxic load, notably that of dioxins and heavy metals, from airborne emissions to the fly ash. This fly ash is light, readily windborne and mostly of low particle size. It represents a considerable and poorly understood health hazard."*

The authors concluded that there was persuasive evidence of adverse health impacts associated with thermal treatment. As with the Greenpeace report however, the basis for this conclusion is not easily identified, making it difficult to assess the objectivity of the decision. This report was subject to critical comment by the HPA and others (e.g. Enviros Consulting (http://www.ecomed.org.uk/publications/reports/the-health-effects-of-waste-incinerators, Accessed: October 2009)) who questioned the failure to carry out a systematic review, as well as failure to consider other critical reviews such as the DEFRA review (Enviros Consulting *et al* 2004) and the statement by CoC 2000. The validity of the conclusions was therefore challenged by critics on the basis of weaknesses in the review method, raising doubts as to the review's objectivity.

#### 4.2.4 Conference Proceedings

A number of conference papers on incineration and health effects were identified, not referred to elsewhere. Some refer to the use of waste as a fuel in cement kilns, a particular form of incinerator activity not discussed in other literature in depth. Most papers presented at conferences in this category related more to hazard or exposure assessment, than to directly measured health effects and have not therefore been included. Only one was considered relevant:

**Kelly (1995)** presented conclusions from a review on hazardous incineration studies where there was objective data on health outcomes or measured pollutants rather than estimated contamination. The Authors appeared to consider that there was no "*clear"* evidence of association.

> *"This review includes only formal studies of actual data or measurements of health impacts, and excludes any discussion of EPA-driven health risk assessments based on estimated emissions, dispersion, and impact data. Particular emphasis is placed on those cases included in Chapter 5 of Greenpeace's report, "Playing with Fire," which alleges adverse health effects due to hazardous waste incineration. The facilities reviewed include those in the United Kingdom, Louisiana, and Arkansas; additional reports of facilities in Germany, Texas, and North and South Carolina are also discussed. The general finding is that no clear evidence of adverse impacts on human health could be determined through past scientific investigations, although many studies are still underway."*

However, the wording used in this study illustrates the difficulty with it and others in determining whether individual authors have definitively concluded that there is *'no association'* or are stating that the evidence is *'inconclusive'*:

### 4.2.5 Summary of Conclusions from Reports Not Published in Peer-Reviewed Journals

Of the 10 reports considered in this section (summarised in Table 3) only two Greenpeace (Allsopp *et al* 2005) and the British Society for Ecological Medicine (Thompson & Anthony 2005)) concluded that incineration of waste was associated with adverse health outcomes. However, the findings of these two particular reports were not peer-reviewed in the conventional sense and were criticised by others for methodological flaws and lack of justification for their conclusions. Their findings should therefore be interpreted with caution.

The remaining reports considered in this category either concluded that there was no convincing evidence of an association or that the evidence was inconclusive. It can be difficult to decide which of these options the authors actually mean. However, the majority of these reports did not support the view that there was conclusive evidence for adverse health outcomes being attributable to residence near or exposure to the emissions from waste incinerators, either in general, or for specific health outcomes. It is of interest though, that these reports generally carry some degree of qualification in their findings relating to the weakness of the evidence base and the methodological problems in the risk assessment and epidemiological approaches used in the studies reviewed. These weaknesses are acknowledged to make it difficult to devise investigations capable of providing definitive evidence for, or against there being any attributable adverse health effects. There is recognition, even in the negative finding reports, that there *may* be some adverse health effects but that in relative terms they are likely to be small compared to other environmental risks.

The majority view of the reports considered in this category was that if adverse health risks were present in the past, any risk (in the UK at least) is likely to be comparatively reduced now, due to increasingly stringent regulation of incinerator emissions. This assumes however, that modern incinerator plants are being operated continuously within these new stricter regulatory limits. It is acknowledged in some of these reports, that during periods of sub-optimal operation, incinerator emissions may in practice exceed limits and may pose more of a hazard than expected.

**Table 3: Summary of reports on incineration and human exposure/effects not published in peer-reviewed journals**

| Publication Date | Report Author/ Agency | Date Range | Topic Area | | Number of Papers | Incinerator Types | | | | | Outcome Measures | | | | Summary Conclusion | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Inc | Inc + Other | | M | I | C | H | UN | E | B | MB | MT | Y | N | I |
| 1995 | Kelly | 1985-1994 | X | | i) 36<br>ii) 17<br>iii) 12 | X | X | X | X | | | | X | | | | X |
| 1997 | MRC / IEH (Humfrey *et al)* | 1988 - 1996 | X | | i) 176<br>ii) 14<br>iii) 12 | X | | | | | | | X | X | | | X |
| 2000 | Committee on Carcinogenicity | 1991 - 1999 | X | | i) 8<br>ii) 7<br>iii) 4 | X | | | | | | | | X | | X | |
| 2000 | NRC | 1948-1999 | X | | i) 633<br>ii) 47<br>iii) 19 | X | | X | X | | | X | X | X | | | X |
| 2003 | Food Safety Authority of Ireland | 1989 - 2003 | X | | i) 16<br>ii) 2<br>iii) 1 | | | | X | | X | X | | | | | X |

**Topic area:** Inc = Incineration

**Number of papers:** (i) Total number of references cited
(ii) Number of references referring to waste incineration/thermal treatment (clear from title)
(iii) Number of references referring to WI/TT AND human exposures/effects (clear from title)

**Incinerator types:** M=Municipal solid waste, I=Industrial waste, C=Clinical waste, H=Hazardous waste, U=Unspecified.

**Outcome measures:** E=Environmental monitoring, B=Biological monitoring, MB= Morbidity, MT=Mortality.

**Summary Conclusion:** Y=Yes there is evidence of association with health effects, N=No there is no evidence of association with health effects, I=Inconclusive; the evidence was inconsistent or inconclusive.

**Table 3 continued**

| Publication Date | Report Author/ Agency | Date Range | Topic Area | | Number of Papers | Incinerator Types | | | | | Outcome Measures | | | | Summary Conclusion | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Inc | Inc + Other | | M | I | C | H | UN | E | B | MB | MT | Y | N | I |
| 2004 | WHO (Batterman) | 1989 - 2003 | X | | i) 53<br>ii) 21<br>iii) 5 | | | X | | | X | X | | | | | X |
| 2004 | DEFRA (Enviros *et al*) | 1978 - 2003 | | X | i) 548<br>ii) 76<br>iii) 23 | X | | | | | | | X | | | X | |
| 2005 | BSEM (Thompson & Anthony) | 1969 - 2005 | X | | i) 257<br>ii) 15<br>iii) 12 | | | | | X | X | X | X | X | X | | |
| 2005 | Greenpeace (Allsopp et al) | 1984 - 2000 | X | | i) 212<br>ii) 101<br>iii) 25 | X | | | X | | X | X | X | X | X | | |
| 2005 | Health Protection Agency | 1997-2004 | X | | i) 8<br>ii) 0<br>iii) 0 | X | | | | | X | | X | | | | X |

**Topic area:** Inc = Incineration

**Number of papers:** (i) Total number of references cited
(ii) Number of references referring to waste incineration/thermal treatment (clear from title)
(iii) Number of references referring to WI/TT AND human exposures/effects (clear from title)

**Incinerator types:** M=Municipal solid waste, I=Industrial waste, C=Clinical waste, H=Hazardous waste, U=Unspecified.

**Outcome measures:** E=Environmental monitoring, B=Biological monitoring, MB= Morbidity, MT=Mortality.

**Summary Conclusion:** Y=Yes there is evidence of association with health effects, N=No there is no evidence of association with health effects, I=Inconclusive; the evidence was inconsistent or inconclusive

## 4.3 Review Papers Published in Peer-Reviewed Literature

Section 4.3.1 summarises the conclusions of reviews published in peer-reviewed scientific journals. A number of other non-systematic review papers dealing with other aspects of incineration (e.g. on well-being and in relation to planning considerations etc.) are considered separately in Section 4.3.3.

### 4.3.1 Systematic Reviews of Health Effects of Waste Incineration

The conclusions from 5 systematic reviews of evidence on health effects and incineration of waste, including municipal solid waste, clinical waste and hazardous waste, are described. The publication dates of the primary papers covered in these reviews overlapped and some considered very similar material. Key details of these reviews are summarised in Table 4.

**Oppelt (1990)** presented an early summary of existing knowledge regarding air emissions produced from *'hazardous'* waste incineration processes between 1984 and 1986. The author drew a number of conclusions relating to the wider topic of incineration. However, in terms of health risks, the author concluded that there was little evidence of adverse health impacts, while recognising that the studies reviewed gave only a partial picture:

> *"There appears to be little human health risk from hazardous waste incinerator emissions, based on assessments done to date. Metal emissions appear to be most significant in the risk values which have been derived. However, a complete assessment of all of the potentially hazardous materials in incinerator emissions has not been completed. This information is needed to enable a comprehensive risk assessment of incinerator emissions. "*

**Hu & Shy (2001)** reviewed epidemiological papers relating to the health effects of MSW and hazardous waste incineration published between 1985 and 1999. The authors carried out a critical review of the evidence and reported conflicting findings for a range of health outcomes in residents of communities near incinerators.

For birth outcomes, the authors reported the following:

> *"Higher frequency of twinning was found in the areas at most risk in one study, but not observed in municipalities with incinerators in another study."*
> *"Waste incineration was associated with significantly lower male-to-female ratios of births in areas at most risk, but not with cleft lip and palate malformations."*

For cancers:

> *"Three studies observed a significantly positive relation with lung cancer incidence, mortality, or laryngeal cancer deaths. Yet, two studies found no excess in lung cancer incidence and deaths or laryngeal cancer incidence."*

For respiratory symptoms, the authors concluded:

> *"… prevalence of several respiratory symptoms was not significantly related to living in an area with a waste incinerator in both studies reviewed."*

The authors also examined the scientific literature in relation to exposure of incinerator workers and concluded the following:

> *"The studies of incineration workers consistently showed higher frequency of urinary mutagens and promutagens and increased blood levels of certain organic compounds and some heavy metals."*

In terms of cancer risk in occupationally exposed individuals, the authors concluded:

> *"…significantly excessive deaths from gastric cancer were observed in one occupational cohort and a non-significant increase in esophageal cancer mortality was found among another group of incinerator workers."*
>
> *"The findings for lung cancer mortality were conflicting – significantly increased in one study, but decreased in another study."*

Additionally, in terms of other non-carcinogenic health-effects, the authors offered the following comments:

> *"…working in an incinerator was associated with excess deaths from ischemic heart disease and higher prevalence of hypertension."*
>
> *"There was no evidence of adverse effects on lung function."*

Overall, the authors concluded:

> *"… these epidemiologic studies consistently observed higher body levels of some organic chemicals and heavy metals, and no effects on respiratory symptoms or pulmonary function. The findings for cancer and reproductive outcomes were inconsistent."*

Two papers published in 2003 reviewed the evidence in relation to the health impacts of waste management processes.

**Rushton (2003)** provided an overview of waste, waste management processes, and research into health hazards associated with these processes.

The authors outlined the five key waste management options as recycling, composting, sewage treatment, incineration and landfill, and evaluated the benefits and disadvantages of each option. In relation to incineration, the authors examined the literature relating to exposure of residents nearby municipal, industrial and hazardous waste incineration facilities, as well as occupational exposure.

For residential exposure, the authors concluded the following:

For birth outcomes:

> *"Little evidence has been found for an association between modern waste incinerators and reproductive or developmental effects."*

For respiratory symptoms:

> *"… there is little evidence of increased prevalence of respiratory illness near incinerators, using either self-reported symptoms or physiological measures."*

For cancers:

> *"Studies focusing on a single waste incinerator suggested some relationship between distance from the site and mortality or incidence from some cancers, for example laryngeal and lung cancers, childhood cancers and leukaemias and soft-tissue sarcoma and non-Hodgkin's lymphoma."*
>
> *"No evidence of an increasing risk of lung and laryngeal cancer was found with proximity to incinerators used for the disposal of solvents and oils."*
>
> *"… a study of residence near municipal waste incinerators found statistically increasing risk with increasing proximity for all cancers and for colorectal, lung, liver and stomach cancers, although there was evidence of residual confounding for all cancers, stomach and lung."*

For occupational exposure, the authors reported conflicting evidence in relation to certain cancers.

In drawing their conclusions, the authors again highlight the difficulties involved in attributing adverse health outcomes to environmental exposures. They highlight some of the methodological problems in studying this field and identify some of the confounding factors which may complicate efforts to associate incineration outputs with health outcomes.

> *"High levels of contamination of air, soil and water in a few well publicized situations have led to widespread unease about the potential health effects*

*of waste management processes, particularly within communities living in the proximity to relevant sites. Overall, however, the vast body of literature does not generally support these concerns, particularly for the two most common methods, incineration and landfill disposal. There is also a lack of evidence as to the precise substance(s) implicated. Any emissions from waste management processes are likely to be a mixture of many substances for which a toxicological profile is unknown.*

*Many of the studies are hampered by a lack of good exposure information and use surrogate indirect measures perhaps leading to exposure misclassification. The levels of most of the potential substances would also be expected to be extremely low, even if all sources of exposure were taken into account. Lack of specificity can also occur in defining health outcomes, particularly if these are self-reported. Many outcomes, such as cancers, would not be expected to occur until several years after exposure, requiring analysis for latency which is lacking in many studies. Migration into and out of relevant areas is also often ignored."*

**Saffron *et al* (2003)** reviewed the literature and evaluated the findings on the human health impact of waste management practices. They used an algorithm to analyse the strength and reliability of evidence presented in the literature and to provide a systematic means of making a judgement on the overall quality of the evidence. The waste management processes reviewed were landfill, incineration, (municipal, hazardous and unspecified waste) composting and sewage treatment. The authors found that there was "*insufficient*" evidence to conclude that there was a causal link between incineration and human health effects.

As with several other reviews of this topic, the authors concluded by highlighting the inherent weaknesses of studies in this area. This is a consistent theme in many of the review articles considered here and emphasises how complex this field is and the difficulty in comparing findings from differing original papers.

*"Most epidemiological studies linking waste management practices and health outcomes are based on weak or non-existent exposure data. These studies are very rarely based on quantitative environmental measurements and on direct measurements on people at the time of exposure. Also, they usually do not include an evaluation of statistical significance and show no control of confounding factors. The algorithm we used to appraise the epidemiological evidence leads to the conclusion that the evidence reported in the literature is not usually of the standard required to consider an association as convincing or probable. The exception is studies on microbiological hazards.*

*The interpretation of the evidence, although based on rigorous and objective criteria, may still lead to subjective judgements. To reduce the degree of uncertainty, new methods of exposure assessments are required, together with a better understanding of the adverse effects of a wide range of* *substances for which toxicological and teratogenic data are still not available."*

In a review covering an overlapping period with Hu & Shy, **Franchini *et al* (2004)** evaluated the epidemiological literature on health effects in relation to incineration facilities (municipal, industrial, hazardous and unspecified waste) published between 1987 and 2003. The authors highlighted the difficulties of reviewing literature in this area:

> *"Often the lack of comparability among study results make findings on health effects of incinerators inconsistent though some significant results were found. In addition, in most studies health effects that have been associated with incinerators cannot be tied down to a particular pollutant and therefore no causal role can be established."*

However, the authors go on to conclude:

For cancers:

> *"Analysis by specific cause, notwithstanding the poor evidence for each disease, has found nevertheless significant results for lung cancer, non-Hodgkin lymphoma, soft tissue sarcomas and childhood cancers. On the other hand studies on cancer of the larynx and liver found contradictory results."*

For respiratory outcomes:

> *"Findings on non-carcinogen pathologies are inconclusive, in particular for acute and chronic respiratory disease."*

For birth outcomes:

> *"Some results point out a relationship between exposure to incinerators and congenital malformations but the lack of statistical consistency makes it difficult to conclude if the association is causal or not."*

### 4.3.2 Interpretation of Systematic Review Paper Findings

A total of five review papers dealing specifically with the health impacts of waste incineration and published in peer reviewed journals between 1990 and 2004 (covering literature published between 1980 and 2003) were identified. Table 4 summarises key features of these five papers. Three papers dealt solely with incineration of waste (municipal solid, hazardous, industrial) and the other two considered incineration as part of a wider waste management picture.
Table 4 also presents information on the numbers of citations included in each of the

reviews. Citations are detailed as (i) total number of references cited, (ii) number of references cited that have incineration or thermal treatment clearly stated in the title and (iii) the number of references with incineration/thermal treatment and human exposures/effects/health outcomes clearly stated in the title. For (ii) and (iii), these numbers should be taken as the minimum number of papers dealing with these specific areas. As can be seen from Table 4, the proportion of papers in each of these reviews that relate specifically to incineration and human health outcomes range from 5% to almost 70%, in itself a significant variation.

The authors of these reviews noted that a range of outcomes had been used to assess human exposure to incineration emissions including biological and physiological exposure indicators, as well as more conventional morbidity measures and mortality rates from a range of illnesses.

*Birth Outcomes*

For birth outcomes, three reviews provided conclusions.

Hu and Shy found conflicting evidence on twinning, positive associations between low male-to-female birth ratios and proximity to incinerators, and no association between cleft palate/lip malformations and incinerator proximity. Franchini *et al* concluded that some results reported a relationship between congenital malformations (no further breakdown given) and exposure to incinerators, but did not draw any firm conclusions due to the lack of statistical consistency in the evidence. Finally, Rushton concluded that little evidence existed to show an association between modern incinerators and reproductive effects. Hence the review findings were themselves inconsistent.

*Respiratory Symptoms*

For respiratory symptoms in residents living in the vicinity of waste incinerators, Hu and Shy concluded that, in the two applicable studies reviewed, no association was found between prevalence of symptoms and living in areas with an incinerator. Additionally, in relation to occupational exposure, the authors reported no evidence of adverse effects on lung function. Franchini *et al* stated that findings in the areas of acute and chronic respiratory disease were inconclusive (for residential exposure) and thus drew no specific conclusion on this. Rushton concluded that little evidence could be found of increased prevalence of respiratory illness near incinerators.

Hence, on balance there was agreement by the reviewers regarding the lack of evidence for respiratory effects associated with incineration.

*Cancers*

Hu and Shy reported conflicting evidence on both lung and laryngeal cancers (for both residential and occupational exposures). The authors also identified literature hypothesising (i) an excess of gastric cancer deaths and (ii) a non significant increase in oesophageal cancer deaths in occupational cohorts. Franchini *et al* reported evidence of positive associations between incinerators and lung cancer, non-Hodgkin's lymphoma, soft tissue sarcomas and childhood cancers. The authors reported contradictory findings for laryngeal and liver cancers. In general agreement with Franchini *et al* (with the possible exception of a more definitive statement on cancer of the larynx), Rushton reported that some relationship may exist between proximity to incinerators and incidence of lung and laryngeal cancers, childhood cancers and leukaemias, soft tissue sarcomas and non-Hodgkin's lymphoma. In quoting single studies, the authors also reported (i) no increase in lung or laryngeal cancers with proximity to incinerators processing waste solvents and oils and (ii) an increase in "*all cancers*", colorectal, lung, liver and stomach cancers (with some evidence of confounding for several of these) with proximity to incineration plants. On balance these reviewers appeared to consider that there was some evidence of association between incinerators and some forms of cancer but there was no real unanimity on which forms of cancer the evidence was strongest or most conclusive for.

## Table 4: Summary of scientific review papers on incineration and human exposure/effects

| Publication Date | Lead Author | Date Range | Topic Area | | Number of Papers | Incinerator Types | | | | | Outcome Measures | | | | Summary Conclusion | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Inc | Inc + Other | | M | I | C | H | UN | E | B | MB | MT | Y | N | I |
| 1990 | Oppelt | 1984 - 1986 | X | | i) 83<br>ii) 52<br>iii) 5 | | | | X | | X | | X | | | | X |
| 2001 | Hu | 1985 - 1999 | X | | i) 28<br>ii) 22<br>iii) 18 | X | | | X | X | | X | X | X | | | X |
| 2003 | Saffron | 1980 - 2001 | | X | i) 53<br>ii) 5<br>iii) 5 | X | | | | X | | X | X | X | | | X |
| 2003 | Rushton | 1983 - 2002 | | X | i) 48<br>ii) 9<br>iii) 9 | X | X | | X | X | | | X | X | | | X |
| 2004 | Franchini | 1987 - 2003 | X | | i) 72<br>ii) 33<br>iii) 30 | X | X | | X | X | X | X | X | X | X | | |

**Topic area:** **Inc = Incineration**

**Number of papers:** (i) Total number of references cited
(ii) Number of references referring to waste incineration/thermal treatment (clear from title)
(iii) Number of references referring to WI/TT AND human exposures/effects (clear from title)

**Incinerator types:** M=Municipal solid waste, I= Industrial waste, C=Clinical waste, H=Hazardous waste, U=Unspecified.

**Outcome measures:** E=Environmental monitoring, B=Biological monitoring, MB= Morbidity, MT=Mortality.

**Summary Conclusion:** Y=Yes there is evidence of association with health effects, N=No there is no evidence of association with health effects, I=Inconclusive; the evidence was inconsistent or inconclusive

#### 4.3.3 Additional Non-Systematic Incineration Reviews

A number of other published reviews on TTW were not systematic and are therefore considered separately. These papers did not confine themselves to epidemiological assessments of the evidence but considered wider aspects of incineration processes and their impacts. Some authors also commented on factors which might be relevant in deciding where such facilities should be located. Although these additional reviews add little to the evidence base on health effects, they do consider relevant aspects of incineration worthy of mention.

**Gochfeld (1995)** reviewed the health and environmental consequences of incineration, with particular emphasis on the need to consider the community around the plant from the early planning stages.

> *"This paper has emphasized public health concerns related to the potential toxic emissions to air or water from alternative waste management facilities. In addition, aesthetic, economic, traffic, and other considerations have a profound impact on the willingness of a community or governmental jurisdiction to accept any kind of waste management facility."*

In relation to the siting of waste technology plants, the authors concluded the following:

> *"Regardless of the choice of technology, siting of a facility should take into account:*
>
> - *Site selections which minimize proximity to residential areas and to unrelated areas of employment, and which also minimize exposure to sensitive terrestrial and aquatic ecosystems.*
> - *Adequate site size to minimize exposure to surrounding communities.*
> - *Adequate distance from high-rise buildings to reduce impact on elevated receptor populations."*

In a review of toxic emissions from municipal solid waste and hazardous waste incinerators, **Rowat (1999)** concluded that:

> *"Any decision about incineration construction, moratorium, or closure should take into account at least the following:*
>
> 1. *Incinerator chemical reactions are extremely complex, and many of the resultant organic chemicals have not been identified and therefore have not been measured or tested for toxic effects.*

2. *Regardless of how well an incinerator operates, metals will still be emitted, often in combination with chlorine (or other halogens such as fluorine and bromine). Insufficient data exists on the amounts and hazards of these metals.*

3. *Some studies have demonstrated that incinerators often operate at less than peak efficiency, and polycyclic organics emissions can be increased 1000-fold during a cold start-up.*

4. *Some of the emissions are almost invariably dioxins and furans, which are formed in the incinerator stack. These are highly toxic and are apparently building up in the fat tissues of all humans, world-wide, with an estimated 7-year half-life in the human body.*

5. *Incinerator fly ash and wash-water must at present be regarded as hazardous waste themselves, and no universally adequate solution has been found for their disposal.*

6. *Emitted gases such as $NO_2$ and $SO_2$ contribute heavily to acid rain and smog, and to the formation of ozone in smog in sunlight. $NO_2$, $SO_2$ and ozone have been proved to cause respiratory illnesses, and smog has been shown to cause increased death-rate.*

7. *Toxic effects and build-up in human tissue of other incinerator-emitted organics such as benzene, toluene, PCBs, alkanes, alcohols, and phenols are well documented.*

8. *As of 1990 reports, more than half of existing incinerators had no pollution control equipment, and no real-time monitor existed for measuring destruction and removal efficiency."*

**Cormier *et al* (2006)** discussed the origin and health impacts of emissions created during the thermal treatment of hazardous waste. The main focus of the review was on fine particle emissions and the authors reviewed all available research up to 2006. Whilst the authors described a number of health effects relating to exposure to *"toxic combustion by-products"*, they did not draw any firm conclusions on the health effects of waste incineration.

These non-systematic review papers, while of interest in relation to issues associated with the hazards of incineration, generally add little additional evidence on health impacts to the more comprehensive systematic reviews considered earlier.

### 4.3.4 Summary of Conclusions from Review Papers Published in Peer-Reviewed Literature

A common theme in reviews considered in this section, is the recognition that evidence in this area is lacking in both quantity and in quality. Concerns are expressed by reviewers on the lack of specificity in research questions, of good exposure data and of appropriate correction for confounding factors. Most of these reviews tend to conclude that the existing evidence base is inadequate for making definitive statements about whether or not incineration has a negative impact on human health.

In terms of ***birth outcomes***, the summary findings of the review studies highlight another problem in that the terminology employed varies significantly, e.g. "*congenital malformations*", "*reproductive or developmental effects*" etc. are all used. The balance of evidence presented by the review authors suggests that, whilst contradictory evidence exists, the overall conclusion is that there is little definitive evidence of associations between *congenital malformations* and proximity to incinerators. However, the only review to detail *birth outcomes* more specifically was Hu and Shy, who reported positive associations for proximity to incinerators with twinning and lower male-to-female birth ratios but no association with cleft palate/lip.

For ***respiratory symptoms***, the general conclusion would appear to be that research thus far suggests little if any association between geographic proximity to (or even occupational exposure to) incinerators and adverse respiratory outcomes.

Conclusions drawn for associations between ***cancers*** and incinerators are probably the most contradictory, possibly due to the degree of correcting that may or may not have been carried out for confounding factors in the primary studies. For associations between proximity to incinerators and gastric, colorectal, oesophageal and childhood cancers, non-Hodgkin's lymphoma and soft tissue sarcoma, overall the authors of the reviews report either clear evidence of an adverse effect or conflicting evidence. In relation to cancers of the lung, larynx and liver, evidence was also contradictory in that some studies reported an association but others reported no association between these cancers and proximity to incinerators. Of all health outcomes studied the consensus appeared to be that there was more evidence of a relationship between incineration emissions and cancers though little, if any, of the evidence was strong enough to be considered as conclusive.

## 4.4 Additional Primary Papers Not Considered in Previously Published Systematic Reviews

### 4.4.1 Peer-Reviewed Papers

A total of 21 peer-reviewed publications were identified (up to end September 2008) that had not been included in any of the pre-existing reviews considered in this report. Of these additional papers, eight were epidemiological papers relating to the assessment of health impacts and were therefore considered relevant. The remainder were primarily concerned with measuring exposure via biochemical monitoring (biomarker studies) and are therefore not considered further.

Of the eight epidemiological papers, six were studies of populations in the EU, one in the USA and one in Japan. The populations were exposed before 1999, some having potential exposure periods as far back as 1960. Hence, it is doubtful if even the more recently published papers reflect patterns of exposure likely to be experienced in very recent years following the introduction of stricter emission regulations, within the EU at least.

The incinerator types studied in these 8 papers ranged from MSWIs (4), hazardous waste (1), industrial (1) or mixed types (2).

Health effects studied in the 8 relevant papers included: respiratory function (1), birth outcomes (twinning, congenital anomalies and infant deaths) (4), sarcoma and connective tissue cancers (2) and breast cancer (1).

Table 4A summarises key features of the studies based on a modified version of the criteria used by Saffron *et al* (2003) in their review (Appendix 6). Additionally for each of the publications, the table provides a grading of the quality of evidence, based on the recommendations of the Scottish Intercollegiate Guidelines Network (SIGN (2008)).

### 4.4.2 Peer Reviewed Papers by Health Outcomes Studied

*Respiratory Function*

**Hazucha *et al* (2002)** investigated lung function among a group of non-smoking volunteer individuals resident in communities surrounding incinerators of hazardous, biomedical and municipal solid waste in the United States, over a three year period.

Findings were compared to those for residents in 3 comparison communities considered to be at less risk of incinerator emission exposures. The relationship with airborne levels of particulate matter, particularly 2.5 microns ($PM_{2.5}$) or less in diameter was studied. Overall, the authors found no significant changes in lung function parameters associated with living near either the hazardous, clinical or municipal solid waste incinerators. However, the authors noted that the contribution to overall $PM_{2.5}$ levels from the incinerators was less than 3%; the overall levels of particulate matter were within regulatory parameters; the lung function measurements consisted of one measurement each year; the air monitoring was for a period of one month per year only; the lung function tests were administered just prior to the air monitoring (rather than after as might have been preferable if a cause/ effect relationship was postulated); there was a high drop out rate of volunteers which reduced the power of the study; the number of subjects might have been too small to detect changes in lung function associated with small variations in particulate matter levels; there may have been some *"cross exposure"* between study and control areas due to incinerator emission wind blown drift; there may not have been a sufficient gradient in $PM_{2.5}$ exposure across the groups to enable detection of any association with lung function measurements. In addition, not all confounding factors (e.g. migration) could be taken into account and there were some significant differences in composition of the groups and their participation rates. Although this study reported negative findings (no association between adverse effects and incinerators) the study may have had inadequate power to detect a difference if it had existed. The presentation of the results was not amenable to assessment using the Saffron criteria. However, a SIGN grading of *'2-'* would be appropriate for the evidence of *'no association'*.

*Birth Outcomes*

**Cresswell *et al* (2003)** investigated the risk of congenital anomalies in residents living within 7 km of an urban waste incinerator near Newcastle upon Tyne, divided into two zones; up to 3km and 3 to 7km. This investigation resulted from assertions by the local community of an excess of malformations. The waste plant began operating burning *"urban waste"* in 1988 and ceased in 1999. From 1985 to 1999, 1508 cases of chromosomal and non-chromosomal anomalies were identified using a local registry. The authors reported no significant overall association between proximity of residence to the incineration plant and incidence of congenital anomalies in births (rate ratio 1.11; 95% CI 0.96 to1.28). They did however note a trend with increasing rate ratios for the inner zone (up to 3km) over time with some significantly higher annual rates in 3 of the last 5 years of the incinerator operation using waste as fuel. When adjusted to allow for social deprivation (Carstairs Deprivation score), these rates were still significant (e.g. in the last year studied 1999, the OR for inner to outer zones was 2.05; 95% CI: 1.20 to 3.52 based on 33 cases). This trend could not be explained. The authors postulated that the increased rates in later years might be due to accumulated exposure to emissions. However, the effect of bias and confounding could not be excluded. Although the population was considered to be relatively stable, migration effects were not controlled for. Ascertainment bias due to differing abnormality registration rates by hospital of birth may have been a factor but was thought unlikely. Exposure assessment was purely on the basis of proximity with no adjustment for personal activity, duration of residence, or meteorological effects on emission dispersal. The main result was a non-significant increase in risk associated with the inner zone of exposure. This would be classed as *"no association"* using the Saffron review criteria. The evidence of association with increased abnormality risk in only one of fifteen years would be classed as *strong (*RR 2.05) but only just. In SIGN criteria terms the study would be assessed as *'2-'* and does not provide conclusive evidence one way or another.

**Obi-Osius *et al* (2004)** investigated twinning rates in residents living in the vicinity of a toxic waste incinerator (TWI) in South Hesse, Germany between 1994 to 1997 using an ecological cohort study of births, comparing areas considered to be at high and low risk of exposure to pollution from the TWI and other industry. The authors reported significant increases in annual twinning rates in areas surrounding the toxic waste incinerator and other industries compared with rates in low risk comparison communities, within the study period. This paper reported results from two distinct data sets. One cohort was selected by contacting second grade children in schools in 18 local communities, divided into three regions by proximity to the TWI. One control area had some industry and potential for resulting airborne pollution, the other was predominantly rural and was used as the low risk reference area. Of the children contacted 61.5% agreed to participate with 95% of their mothers subsequently providing data. Hence, nearly 40% of the selected potential cohort did not participate, creating significant potential for non-response bias. Mothers were asked about their reproductive history; only live birth twin sets were counted. Efforts to correct for spontaneous abortion, terminations and still-births were not described. The twin rate in the TWI region was 5.3% (5.2% if 2 assisted reproduction births were excluded) compared to 2.3% in the low risk control region, 3.8% overall (Chi squared test; p<0.05 for both total and *'natural'* pregnancies). However, there were between two and three times as many total births in the TWI study region compared to either of the two control regions. Also, the total number of twin births identified in the study group was small (24) with 18 sets of twins in the TWI region alone, only 2 in the industrial control region and 4 in the rural control region. Hence, there were relatively small numbers for statistical comparison. The second dataset was derived from a regional birth register, which was considered to provide a more complete birth cohort, and gave a twinning rate of 1.4 – 1.6 per 100 births in 3 postal areas nearest the TWI compared to 0.8 for two rural postal areas not subject to TWI or industrial emissions (over the 4-year period); an odds ratio of 2.03 (95% CI: 1.28 to 3.22) for twinning in the postal area where the TWI was located. Efforts to control for confounding factors such as age, parity and ethnicity were described. However, the relatively small numbers of twin births and the distribution in the study and control areas raises questions as to the robustness of the results. The authors note that there was possibly misclassification due to restrictions in the amount of data they were allowed to have on the mothers. The main conclusion noted by the authors was: *"Twinning rates may be associated with exposure to industrial pollution".* This paper provides no definitive evidence but recommends further research. Given the ecological nature of the studies, there was no objective assessment of exposure to pollutants. Using the Saffron (2003) review criteria the evidence for association would be classed as *'strong'* (OR > 2, statistically significant). Based on the SIGN evaluation criteria, this study has some significant weaknesses and would be consistent with a *'2 –'* grading. Hence, the evidence on twinning and proximity to a TWI cannot be considered as conclusive.

**Cordier *et al* (2004)** compared the rates of congenital anomalies in residents of communities (of fewer than 50,000 population) in the vicinity of 70 MSW incinerators in the Rhône – Alpes region of France with those in a number of communities classed by the authors as unexposed. The incinerators studied were in operation for at least one year between 1988 and 1997. Expert panel assessments were made using data on incinerator characteristics, emissions and monitoring information to grade each area with a score at the point of maximum population density. Each area was then classified into exposed (194 communities) or unexposed (2678 communities). There was no overall increase in rates of congenital anomalies in the *'exposed'* areas. An excess of facial cleft and renal dysplasia was found in *'exposed'* populations; a relative risk of 1.3 (95% CI 1.06 to 1.59) for facial cleft, with 152 cases and 586 controls; a relative risk of 1.55 (95% CI 1.1 to 2.2) for renal dysplasia, based on 60 cases and 194 controls. Both relative risks were adjusted for multiple confounding factors including population density, average income and maternal age. There was a *'dose-response'* effect (based on a grading of exposure levels in exposed areas) in relation to the MSW incinerator emissions and obstructive uropathies. However, there was also a *"linear increase"* in relative risk with traffic density for obstructive uropathies, cardiac anomalies and skin anomalies, with a significant excess of major anomalies associated with the heaviest traffic density in the localities. The authors cited evidence of malformations associated with dioxins in animal studies as evidence of the biological plausibility for their findings, in relation to proximity to incinerator emissions. The study was considered to be an improvement on others which based exposure estimates on proximity of residence near an incinerator alone, in that meteorological data was used to refine the exposure assessment. However, in effect, all residents within a given area were assumed to have the same level of exposure to incinerator emissions, acknowledged to have probably resulted in some miss-classification of subjects.  The authors were not able to allow for individual exposure variation to important sources of dioxins in terms of dietary intake, or time and activities outdoors, nor for migration effects in the areas studied.  The magnitude of effects was relatively small (RR less than 2) and would be classed as *'weak'* for renal dysplasia and *'no association'* for facial cleft using the Saffron review criteria (2003). The authors note that the evidence of association is not conclusive and that the positive findings could be due to residual confounding, exposure misclassification, ascertainment bias and traffic pollution exposure. In SIGN guidelines terms the study would rate a '2-'.

**Tango *et al* (2004)** reported a study of adverse reproductive outcomes associated with maternal residential proximity within 10km of 63 municipal solid waste incinerators with highest dioxin emission levels (above 80 ng TEQ/$m^3$ based on a single measurement) in Japan between 1997 and 1998. They found evidence of an association between residential proximity to incinerators, infant deaths and infant deaths due to congenital malformations, with the "*peak*" rates for births to mothers recorded as living at 1 to 2 km from the plants.  Rates were found to decline from the *"peak"* out to a distance of 10km.  The results showed a peak for infant deaths at 1-2km (O/E 1.3, 95%CI 0.96 to 1.71) declining out to 10km and a similar peak at 1-2km for infant deaths due to all congenital malformations (O/E 1.34, 95%CI 0.81 to 2.10). These ratios were not significant in term of the 95% Confidence Intervals (straddling unity). Analysis using *"Stones unconditional p values"* did not find any of the O/E ratios to be significant. However, further analysis using Tango's previously published *“conditional peak decline”* model to detect a *“peak decline in risk with distance”* from an incinerator, did identify significant findings. Of 11 outcome combinations tested for evidence of a *“peak-decline”* distribution in risk, with a peak risk at 1 to 2km, 2 had *“p values”* of less than 0.05; infant deaths (p=0.023) and infant deaths due to congenital malformations (p=0.047). Although only limited validation was carried out, the authors reported a similar decline in environmental dioxin deposition with distance from 2 of the 63 MSWIs studied. The authors considered socio-economic factors as possible confounding variables. Low birth weight (LBW) and very low birth weight (VLBW) are strongly correlated with social deprivation, yet there was no association in this study between either LBW or VLBW and proximity to an MSWI. This suggested that social deprivation was not a confounding variable in this study. However, the authors were not able to control for other relevant factors such as smoking behaviour, parental occupation, diet or nutritional status or other sources of dioxin exposure (e.g. burning of vegetable remains in rural areas), duration of exposure to incinerator emissions or population migration effects. The authors acknowledged that they had no direct measures of dioxin emissions or exposure and advised caution in the interpretation of their study findings. As with many such ecological cohort studies, exposure assessment relied on simple proximity to an incinerator with no modification for differential exposures. The findings which were not considered to be conclusive and further studies were advised to corroborate the results. The strength of association, expressed as *“peak-decline” ‘p values’* was difficult to compare to other studies. The scale of effects, expressed as observed to expected (O/E) ratios, was relatively low and was not significant in terms of 95% CIs. Using the Saffron (2003) review criteria the evidence of adverse effects in relation to distance from an incinerator would be classed as *“no association”*. Using the SIGN evidence grading, the lack of control for confounding in particular is consistent with a grading of *‘2-‘.*

Although three of the four birth outcome studies described here found evidence of effects, they used very different study methods, very different health outcome end-points and different statistical techniques, making it difficult to compare the findings. Although the authors of each study acknowledged weaknesses in their methods, the papers do, nonetheless, add some weight to the balance of possible evidence associating adverse reproductive outcomes to proximity to incinerators cited in earlier studies.

*Sarcoma and Connective Tissue Cancers*

**Comba 2007**, used a proximity based ecological type study in Italy, which identified a total of 37 soft tissue sarcomas (STS) in people aged 26 to 85 years living in an area surrounding an industrial waste incinerator handling toxic waste; 65% were non-visceral tumours. The study was triggered by the previous identification of a cluster of STS cases around the same Mantua industrial area. The incinerator began operating in 1974 but prior to that a large chemical plant operated from 1956 onwards. This study used a different time window (1989 to 1998) from that original cluster with only one overlapping case included. A significantly increased risk of STS was identified where the main residence for the case for the period up to ten years before diagnosis was within 2km of the incinerator (OR 31.4; 95% CI 5.6 to 176.1). This was based on five cases, of which one had an occupational history in the chemical process industry. Additionally, whilst generalised matching was carried out in the study, only one control was matched to the 5 cases within 2km of the incinerator. Removal of the case identified in the previous cluster study reduced the OR to 25.1 for the four remaining cases (95% CI: 4.2 to 150.8). The odds ratios beyond 2km were substantially lower (0.7 to 1.6) and were not found to be significantly increased (all 95% confidence intervals crossed unity). The adverse effects reported were hypothesised to be associated with dioxins emitted from the incinerator. There was no validation of the exposures associated with the incinerator. The condition considered was relatively rare (STS incidence was 5/100,000), the number of cases identified was small and there was a history in the region of a previous cluster identified from 1984 to 1989. Emissions from a hospital incinerator in the locality were not considered relevant as there was no evidence of clustering specifically near it. Other potential confounding due to exposure from other industrial chemical activities and sources in the locality (the chemical plant, an oil refinery, paper industry, and mechanical plant) could not be excluded. In terms of the strength of findings, given the magnitude of the excess risk (greater than 2) the Saffron review criteria class the findings as *'strong'* evidence. However, the authors were limited by the ecological study design, the small case numbers and the relative inability to control for confounding factors. Hence, the findings could not be considered as conclusive and the study would be classed as *'2-'* using SIGN criteria.

**Zambon *et al* (2007)**, in a second Italian study also reviewed the risk of STS and connective tissue cancer by place of residence within the province of Venice. The authors identified 205 cases of sarcoma diagnosed histologically between 1990 and

1996 (with potential exposure from 1960). After exclusions, the final analysis was conducted on 172 cases and 405 controls over 14 years old. Potential exposure to incinerator emissions was modelled rather than based purely on proximity to an incinerator site. A total of 33 incinerator plants were identified in the province processing MSW, medical waste and industrial waste. In addition, there were thermal power plants, industrial plants and an oil refinery in the region studied. There was a peak in emissions between 1972 and 1986. A specific exposure rating was calculated for each case and control address based on sophisticated modelling of historical and other data. The ratings were weighted according to the duration of stay at each address and expressed as Toxic Equivalency Factor (TEF) values. In order to ascertain evidence for a dose/response effect, three classes of average dioxin exposure were used with two classes of length of exposure for analysis based on the median length of exposure of 32.74 years. A significantly higher risk of sarcoma (visceral and extra-visceral), OR 2.08 (95% CI: 1.19 to 3.64) was identified for those with the highest average exposure. This increased to an OR of 3.3 (95% CI 1.24 to 8.76) for those living in areas modelled to have been exposed to the highest levels of dioxins for the longest period. There was also an increased risk of connective tissue and other soft tissue cancers (OR 3.27; 95% CI: 1.35 – 7.93). There was opportunity for exposure with some 40% of the study population living within 2km of an incinerator or industrial plant and 88% living within 5km. However, modelled exposures could not be compared directly with measurements of dioxin levels at the time. The authors acknowledged the potential for confounding factors in terms of diet, occupational exposures, personal risk factors (smoking), social deprivation or income. They felt that it was unlikely that the diets of cases were substantially different from controls and that dietary exposure was likely to be relatively uniform in the region. Efforts were made to identify individuals who may have worked in occupations at risk of dioxin exposure but none were identified. The consistency of the excess risk in females as well as males was cited as evidence that an occupational effect was unlikely. The authors concluded that the findings provided evidence linking dioxin exposures to sarcoma risk. The study is relatively robust in having used a graded exposure assessment based on modelled data rather than proximity to a potential source alone. The population studied was large (423,000) as was the number of cases identified compared to previous studies. The authors attempted to control for major confounding factors, though they were not able to do so for socioeconomic variables, tobacco smoking or for occupation entirely. The evidence of an excess risk associated with a dose/response effect, consistent with maximal exposure for maximum duration is persuasive. Of note is the fact that the model allowed for cumulative exposures at each address location from more than one incinerator and industrial site. Hence, it was not possible to differentiate a specific effect attributable to incinerator emissions (versus the other industrial sources), nor was it possible to assess specific effects separately associated with particular classes of incinerator (e.g. industrial versus MSWI). The scale of effects would be classed as *'strong'* using the Saffron (2003) criteria (odds ratios above 2) and the study would be consistent with a rating of *'2+'* using the SIGN evidence assessment criteria. While not entirely without weaknesses, this study provides some of the most persuasive evidence to date that there was a relationship between dioxin exposures and STS and other connective tissue cancers in that region over the study period.

Results from other previous studies on sarcoma and proximity to incinerators or exposure to dioxins have been conflicting. The study by Comba but particularly that by Zambon, strengthen the case suggested in earlier work elsewhere, for a possible association between exposure to dioxins from past incinerator emissions and forms of cancer.

*Breast Cancer*

**Viel *et al* (2008)** investigated breast cancer in relation to a MSWI in France and dioxin exposures. They noted that previous evidence of a relationship between breast cancer and dioxins was conflicting. They identified 434 cases of invasive breast cancer affecting women over 20 years registered between 1996 and 2002 and living within the study area at the time of diagnosis. These were matched to 2170 randomly selected age matched population controls. The results failed to find evidence of any increased or decreased risk of illness among younger women but did identify a reduced risk of breast cancer among women over 60 years old (OR 0.31; 95% CI: 0.08 – 0.89) in the highest compared to the lowest exposed zone. They were unable to measure past exposure to dioxins but used dispersion-modelled dioxin exposures to plot zones of different dioxin exposure. The authors noted that there was a lack of individual data on social and other risk factors for breast cancer but commented that some social and demographic data was available at the "*block*" level used for the geographic comparison. Potential confounders for the disease, such as occupation, education and social class were found not to be related to the distribution of modelled dioxin exposure levels. The reduced risk of late onset cancer was considered potentially compatible with an anti-oestrogenic effect of dioxins. However, the authors considered the results to be inconclusive and residual confounding was thought to be a possible explanation. Further research was suggested to investigate the relationship between breast cancer risk and environmental dioxin exposures, taking account of potential confounders. Using the Saffron *et al* (2003) evidence classification the reduced risk (RR=0.31) is *'strong'*, being less than 0.5. However, given the potential impact of residual confounding on the conclusions, a SIGN grading of *'2-'* would be appropriate.

### 4.4.3 Summary of Additional Findings of Papers Not Previously Considered in Systematic Reviews

It is possible that the positive findings of associations identified in some of these more recent peer-reviewed papers may reflect publication bias. Additional studies may have been conducted more recently with negative findings (i.e. no evidence of association between incineration and health effects) but have not been published. However, negative findings were also published so this may not be a significant source of bias.

The additional evidence of adverse health impacts associated with incineration from these recent studies does not alter the general balance of evidence sufficiently to make it conclusive. However, the additional positive findings of these more recent studies, taken together with previous evidence, do lend more support to the view that there may be have been some relationship between incinerator location and/or emissions and adverse health impacts in the past. This suggests that it was plausible that incinerators operating in the past, with higher levels of emission than would be acceptable now, may have had some adverse impacts on the health of local residents, particularly in relation to forms of cancer such as soft tissue sarcoma.

**Table 4A Summary evidence table for additional primary papers not included in previous systematic reviews**

| Author (Publication Date) | Population Studied | Health Outcome Studied | Period Studied | Hazards Identified | Exposure Data | Correction for Confounding | Strength of Risk Ratio (Saffron *et al*)* | SIGN Rating (SIGN, 2008)** |
|---|---|---|---|---|---|---|---|---|
| **Hazucha (2002)** | 358 residents | Spirometric lung function | 1992 - 1994 | $PM_{2.5}$ | Measured emissions | SOME | **Not applicable** | 2 - |
| **Cresswell (2003)** | 1508 residents | Congenital anomalies | 1985 - 1999 | None specifically identified – dioxins mentioned | Proximity of residence | SOME | RR 1.11 Non-significant **No Association** | 2 - |
| **Cordier (2004)** | 94,239 exposed 470,369 unexposed | Congenital anomalies | 1988 - 1997 | $PM_{10}$, dioxins, metals | Modelled emissions | SOME | RR 1.3 to 1.55 Statistically significant **No Association/ Weak** | 2 - |
| **Obi-Osius (2004)** | 1091 mothers | Twinning rates | 1994 - 1997 | None specifically identified | Proximity of residence | SOME | OR 2.03 Statistically significant **Strong** | 2 - |
| **Tango (2004)** | 229,437 residents | infant deaths (ID) and ID with congenital abnormalities (CA) | 1997 - 1998 | Dioxins | Proximity of residence | LIMITED | O/E 1.3 for ID at 1-2km. O/E 1.34 for ID with CA Non-significant **No Association** | 2 - |
| **Comba (2007)** | 37 cases 171 controls | Visceral and extra-visceral sarcoma | 1989 -1998 | Dioxins | Proximity of residence | NO | OR 31.4 Statistically significant **Strong** | 2 - |
| **Zambon (2007)** | 172 cases 405 controls | Soft tissue sarcoma | 1990 -1996 | Dioxins | Modelled emissions | SOME | OR 2.08 to 3.3 Statistically significant **Strong** | 2 + |
| **Viel (2008)** | 434 cases 2170 controls | Invasive breast cancer | 1996 - 2002 | Dioxins | Modelled emissions | SOME | RR (age 20-59) 0.88 Non-significant **Weak** RR (age >60) 0.31 Statistically significant **Strong** | 2 - |

* Strength of Risk Ratio as defined by Saffron *et al* (2003) (see also Appendix 6).
** SIGN Quality of Evidence Rating (SIGN, 2008) (see also Appendix 7)

# 5 DISCUSSION

The aim of this report was to summarise relevant scientific literature regarding the effects of the thermal treatment of all types of waste on human heath. A systematic literature search identified literature ranging in publication date from 1988 to 2008. This comprised primary literature, some of which was included in reviews, systematic and non-systematic reviews, reports published in peer reviewed and non-peer reviewed sources and newer primary publications not included in any previous systematic review.

Determining whether waste incinerators are associated with (non-occupational) ill health in humans is complicated due to the multiple determinants of health in any locality where an incinerator exists. Social determinants of health and other environmental influences are particularly relevant. In any given area there may be a number of sources of the same pollutants (dioxins, particulates, heavy metals) due to industrial facilities and road traffic.  Distinguishing those effects attributable solely to incinerator activities, their emissions or by-products is therefore problematic. Efforts made by researchers to address these potentially confounding factors have varied from rudimentary to extensive. The net result is a wide spectrum of studies, characterised by different investigation parameters and methods, much of which is difficult to compare. The lack of consistency in the approaches by primary researchers and the apparent lack of reproducibility of their findings, even into broadly similar questions, makes meaningful comparison of the findings particularly difficult.

Reviewers of this primary literature have likewise shown little consistency in their approaches to assessing the strength of the evidence for association of incineration with adverse health effects. Reviewers have used different inclusion criteria for their systematic literature searches and different approaches to assessing the strength of the evidence. Sometimes it is not even clear what processes have been used to evaluate the evidence other than expert opinion. None appear to have used systematic data analysis techniques to compare study findings, such as a meta-analysis. The conclusions of reviews covering this topic have therefore also to be interpreted in the light of their limitations.

This report was not intended as a definitive critical review of the entire literature. It provides summaries of the key features and main findings of relevant review studies and provides a bibliography of original papers. This report also considered more recent studies not previously reported in published reviews and assessed whether these alter the balance of previously reviewed evidence. However, the conclusions of this report must be qualified due to the incomplete and contradictory state of knowledge on the topic, the multiple limitations of the evidence base and the resulting level of uncertainty in the existing level of understanding of the topic.

### 5.1 Weaknesses in the Existing Evidence Base

The published literature in this field is characterised by researchers' efforts to overcome the methodological difficulties of trying to correlate defined health effects with exposure to outputs from incineration processes. A common reported difficulty was in obtaining meaningful data on exposure of populations to identifiable candidate toxic chemical emissions. This has resulted in a heavy reliance on proxy measures for human exposure, which are themselves inherently inaccurate and flawed. Use of geographic proximity of a resident population to an incineration site is frequently the closest that studies come to estimating exposure. Such *'ecological'* association studies are inherently weak in relation to their ability to provide conclusive evidence of any association between incinerator emissions and adverse health effects.

The main areas of weakness in the literature base are summarised as follows:

i. Inadequate definitions of research questions and study parameters.
ii. Non-uniformity of subject matter and failure to use recognised epidemiological and toxicological paradigms (e.g. agent/host/environment and source/pathway/exposure models).
iii. Inadequate data on emissions and actual exposures; uncertainty as to its accuracy, representativeness and biological significance.
iv. Incomplete scientific knowledge base, particularly the toxicology of chemicals and mixtures at low exposure levels.
v. Use of limited and unreliable data on health status, including morbidity measures and mortality.
vi. Limitations of study designs used to detect correctly those associations that do or do not exist (Type 1 and Type 11 errors).
vii. Limitations of data analysis, interpretation and statistical inference techniques.

viii. Over-interpretation of apparent associations between illness and incinerators due to failure to consider recognised criteria of causality and the relative magnitude of detected effects.

ix. Over-attribution of detected (non-occupational) health effects to an association with *'incineration'* due to inadequate control for multifactorial risk factors, including the contribution to total pollutant exposures from other sources of environmental contaminants in any locality (e.g. traffic and other industrial pollution).

x. Failure to consider incinerator emissions within an inclusive *'health impact assessment model'* and failure to consider incinerator operation and resulting pollutants from a waste process *'life-cycle'* perspective.

These issues are each explored in more detail in Appendix 2.

## 5.2 Balance of Existing Evidence Base in Relation to Waste Streams

There is relatively more published literature on the investigation of (non-occupational) health impacts of municipal solid waste incineration, and fewer studies focussing on the health effects of emissions from incineration of industrial, clinical or hazardous waste. Whilst many studies focus on the incineration of single waste streams, some explore the health effects of multiple types of waste incineration in one investigation. Table 5 summarises the types of publication considered in this report, in relation to specific waste streams. The terminology used to describe publication types is in line with that used in the rest of this report.

**Table 5: Summary of peer-reviewed publications in relation to waste streams**

| Incineration Type | Epidemiological Papers | Published Review Papers | Total |
|---|---|---|---|
| **Municipal Solid Waste** | 16 | 1 | 17 |
| **Hazardous Waste** | 5 | 1 | 6 |
| **Industrial Waste** | 2 | 0 | 2 |
| **Clinical Waste** | 0 | 0 | 0 |
| **Multiple Waste Types** | 8 | 3 | 11 |
| **TOTAL** | **31** | **5** | **36** |

The distribution of incineration types covered in the published studies reporting on *'multiple waste'* types is summarised in Table 6.

**Table 6: Summary of peer-reviewed publications in relation to waste streams with breakdown of multiple waste types**

| Incineration Type | Epidemiological Papers | Published Review Papers | Total |
|---|---|---|---|
| **Municipal Solid Waste** | 23 | 4 | 27 |
| **Hazardous Waste** | 7 | 4 | 11 |
| **Industrial Waste** | 4 | 2 | 6 |
| **Clinical Waste** | 7 | 0 | 7 |
| **TOTAL** | **41** | **10** | **51** |

In Table 6, any study investigating multiple incineration types is included in all of the relevant cells within the table; thus one study may potentially appear more than once; (e.g. the paper by Zambon *et al* (2007) will be included in cells for MSW, industrial and clinical waste incineration). Tables 5 and 6 in combination therefore show that 36 papers (Table 5) deal with investigations into 51 incinerator types; the difference being due to the 11 papers that dealt with *'multiple waste'* types.

Municipal solid waste incineration has dominated research in this area, with at least 53% of published studies or reviews addressing MSWI in some way. Additionally Table 5 shows that almost half the published literature in this area deals solely with MSWI.

Given that the health effects associated with MSWI have already been subject to extensive review (e.g. by DEFRA (Enviros Consulting *et al* 2004 and others) the findings for waste stream incineration types other than MSWI are now considered in more detail.

### 5.2.1 Hazardous Waste

Six published papers (5 epidemiological papers, 1 review) dealt solely with the health effects of hazardous waste (defined as such) incineration. Including studies of multiple processes, hazardous waste incineration was addressed in a total of 7 epidemiological papers and 4 reviews.

Of the five epidemiological papers dealing specifically with hazardous waste incineration, three were *inconclusive* in their findings; two found *no association* between hazardous waste incineration and adverse human health outcomes. The two other papers looking at hazardous waste incineration alongside other forms found *no association* with this form of incineration and adverse health outcomes.

The one published review dealing solely with hazardous waste incineration (Oppelt, 1990) concluded that little human health risk existed from hazardous waste incineration, although this was a very early review and the authors themselves identified the need for a complete assessment of all potentially hazardous emissions to be carried out. Other review papers failed to draw any definite conclusions in relation to the hazardous waste incinerators.

On balance there is therefore a lack of conclusive evidence of a specific association between hazardous waste incineration and adverse health effects.

### 5.2.2 Industrial Waste

Two epidemiological papers dealt specifically with industrial waste incineration and effects on human health. One reported *positive associations* between emissions and adverse effects on human health (soft tissue sarcoma, Comba 2007); the other found *no associations* between exposure and adverse health outcome.

Two additional epidemiological studies looked at industrial waste incineration as part of multiple waste stream incineration and other industrial exposures. Of these, one reported *inconclusive* findings in relation to adverse health outcomes; the other reported a *positive association* with increased risk of sarcoma and connective tissue cancers (Zambon 2007) but did not specify this risk as specifically associated with industrial waste incineration.

Two review studies did not draw any definite conclusions on adverse health outcomes where industrial waste was considered along with other types of incineration.

On balance there is therefore a lack of consistent, conclusive evidence specifically associating industrial waste incineration with adverse health effects.

### 5.2.3 Clinical Waste

No peer-reviewed publications dealing solely with CWI were identified and only one review paper (Batterman 2004). Clinical waste incineration (CWI) was considered along with other waste streams in seven peer-reviewed publications, with the majority of findings being *inconclusive*. The study by Zambon *et al* (2007) which identified an increased risk of sarcoma, included 12 *'medical waste'* incinerators among the 33 emission sources identified but did not apportion risk by waste stream category. On balance there is a lack of consistent, conclusive evidence specifically associating clinical waste (or equivalent) incineration with adverse health effects.

## 5.3 Balance of Existing Evidence Base in Relation to the Health Outcomes Studied

The majority of studies have considered cancers, reproductive outcomes (adverse birth outcomes and congenital malformations) or respiratory disease. These (non-occupational) health outcomes have generally been selected by the researchers on the basis of at least some plausible exposure/effect (e.g. source/pathway/receptor) linkage.

A variety of indicators of respiratory disease have been studied, including lung function tests. Overall there is a lack of consistent evidence for an association between incineration and adverse respiratory health effects.

Reproductive and birth outcomes have been studied extensively, ranging from sex (M/F) ratios, twinning rates, birth outcomes (infant deaths) and congenital defects such as facial cleft. Past reviews have generally not identified conclusive evidence for consistent adverse effects. Of the more recent primary studies considered some additional evidence of adverse effects was noted, though again there were inconsistencies and the magnitude of reported effects varied.

Cancers have also been investigated repeatedly either as *'all types'* or as *'specific'* types, relating to individual organs or body systems (e.g. liver, haemopoietic system). However, the data quality on cancer endpoints used in studies may be difficult to determine and is likely to be variable in different countries and over time periods. Also, the area postulated to be *'exposed'* may be relatively small geographically, meaning that normally there may be very few expected cases, in turn making statistical analysis difficult. There is also the increased risk of detecting spurious small clusters and falsely associating these with incineration output exposure. This may be a factor in the apparently high odds-ratio reported for soft tissue sarcoma reported by Comba (2007), relating to only 5 cases detected. Against this however, is the consistency of this association with that for sarcomas detected by Zambon *et al* (2007), postulated to be related to dioxin exposures. These studies add to the evidence from earlier work by Elliot *et al* (1996 and 2000) which identified two unexpected cases of rare angiosarcoma near MSW incinerators although there was no evidence more generally of clustering near incinerators of cases ascribed to angiosarcoma in a national register.  Evidence was also cited of increased sarcoma risk near an MSWI cited by Viel *et al* (2000). Further evidence reported by Viel *et al* (2008) of a protective effect of dioxin exposure on breast cancer may also add weight to the evidence that dioxin exposures in the past may have been sufficient to have even low scale effects. In total, while still not absolutely conclusive, there is now more evidence suggesting a plausible association between the risk of some forms of (non-occupational) cancer and emissions from incinerators operated in the past, when emission levels were generally higher than would be acceptable today.

# 6 CONCLUSIONS AND RECOMMENDATIONS

There are significant problems in conducting research in this area and consequently there are weaknesses in the published research evidence base. The difficulties in obtaining high quality data have resulted in a multitude of research techniques, with major differences in the study methods adopted. The wide range of variation makes comparison of studies in this field and the drawing of overall conclusions particularly challenging. Areas of significant variation include:

- study designs and methods
- criteria used to define the type of waste stream being incinerated
- description of thermal treatment technology and processes used
- emission and exposure models
- data measurements, ranging from use of home residence proximity as a proxy for exposure to quantitative pollutant monitoring levels
- study populations, their size, composition and sub-groups (residential, occupational and mixed)
- types of country studied and the regulatory regimes in place
- time periods studied, with different durations and intensities of exposure
- types and quality of health data sources used, with outcome measures ranging from physiological functions to broadly, or conversely, narrowly defined morbidity or mortality measures (e.g. *'all cancers'* in all ages versus *'adult soft tissue sarcoma'*).
- treatment of confounding factors and sources of bias

Much of the published work on TTW has investigated associations with Municipal Solid Waste Incineration (MSWI) (or equivalent) and (non-occupational) adverse health effects. There is much less evidence relating to the other waste streams (clinical, hazardous and industrial) of interest to SEPA.

There is some evidence of measured increases in the risk of certain health effects associated with incineration from studies of incinerators operating before 2003. However, only a minority of past reviews of this evidence concluded that such effects were significant. The majority opinion from systematic reviews and other peer-reviewed sources (up to 2004) was that there was no consistent evidence of specific (non-occupational) health effects directly attributable to incineration activities. Newer original papers, not previously included in published reviews or published after these reviews were completed, again reported mixed findings. Some new evidence of adverse effects was reported, some of it consistent with previous evidence, particularly in relation to forms of cancer (especially sarcoma). Other newer studies failed to find any associations with adverse health effects. Authors who reported evidence of effects often acknowledged difficulties in controlling adequately for all the potential confounding variables. Reported effects were therefore acknowledged to be potentially influenced by confounding factors or sources of bias. While still not conclusive and despite the qualifications, the evidence from more recent studies does add weight to the view that, on balance, there may be a plausible association between incinerator emissions at levels higher than would now be considered acceptable and some (non-occupational) adverse health effects, particularly some forms of cancer.

However, published reviews of the evidence have themselves varied in their scope, search strategies, methodologies and conclusions. The criteria used for inclusion of evidence in these reviews were not consistent. Different approaches have been used in assessing the strength of evidence and any associations detected. There has been a focus on relatively qualitative comparison of original studies and rather less quantitative analysis of the research results. No significant review has adopted quantitative techniques such as meta-analysis, though the inherent differences in the original research methods make application of such techniques difficult.

Some reports on the topic appear to assume that, if there was a significant effect attributable to incineration, it should be detectable even if research methods are less than optimal. This view suggests that if a health effect is meaningful in population health terms, it should be obvious. This is not apparently the case in this field.

Factors such as publication bias would normally tend to increase the probability that positive evidence of adverse effects will be published in preference to evidence that fails to confirm effects. The fact that a number of studies that failed to find evidence of effects were nonetheless published, suggests that publication bias may not be a significant issue in this field.

There is a consistent theme throughout the review literature on this topic; the lack of conclusive or consistent evidence does not preclude there being some adverse effect which has defied confirmation to date, e.g. *the absence of evidence does not equate to evidence of absence*. Methodological and other difficulties may simply have prevented their identification. However, this might also be reasonably interpreted as suggesting that whatever (non-occupational) effects do exist, they are likely to be relatively small.

The US NRC (2000) and others have explicitly argued that small but important effects might be virtually impossible to detect, given the complexity of the subject matter and the inherent difficulties of measuring an effect with the inadequate tools at the average investigators disposal.

Where effects are detected but are low in magnitude or are not statistically significant, it is tempting to dismiss them. However, as Bradford Hill (1965) noted: *“We must not be too ready to dismiss a cause and effect hypothesis merely on the grounds that the observed association appears to be slight”*.

## 6.1 Overall Conclusions

- *Based on the limitations of available research literature, attempting to provide an overall conclusion on the health effects of incineration in total is particularly difficult.*

In researching the material for this report it was apparent that the multiple sources of variation in the published research and in the methods used made it very difficult to draw valid comparisons between their findings. It would perhaps be better in future for any systematic reviews to restrict their analysis to sub-sets of the evidence base, where there is clearer consistency and comparability in the type of incinerators studied, the population studied (occupational vs. residential) and the type of health outcome considered. Work in progress by UK agencies and expert groups does to some extent already address this (e.g. the CoC’s focus on cancer outcomes).

- *For waste incineration as a whole topic, the body of evidence for an association with (non-occupational) adverse health effects is both inconsistent and inconclusive. However, more recent work suggests, more strongly, that there may have been an association between emissions (particularly dioxins) in the past from industrial, clinical and municipal waste incinerators and some* *forms of cancer, before more stringent regulatory requirements were implemented.*

Taking all the evidence on all waste streams as a whole, the evidence for harmful effects is inconsistent in relation to finding evidence both for and against there being an association with a range of different health end-points. On balance therefore, the evidence as to whether or not there are (non-occupational) human health effects attributable to incineration of waste from all the regulated waste streams, is considered to be *inconsistent and inconclusive*. However, more recent work adds weight to the view that in the past, where emission levels were more likely to have been higher than would be legal in the UK now, there may have been an association between emissions (particularly dioxins) and some forms of (non-occupational) cancer (e.g. sarcomas).

- *For individual incineration waste streams (clinical, hazardous, industrial and municipal), the evidence for an association with (non-occupational) adverse health effects is inconclusive.*

For *clinical waste* the evidence for adverse effects was very limited and *inconclusive*.

For *hazardous waste* the evidence was considered by researchers to be either conclusive evidence of *no association* with adverse effects, or the evidence was considered *inconclusive*.

Results of studies for *industrial waste* were inconsistent; some suggested *no association* but some looking at industrial and other waste streams suggested an association with sarcoma and connective tissue cancers. For *industrial waste*, the evidence was therefore also *inconclusive*.

For *municipal waste* (or equivalent), the largest body of work, the results were also very mixed; some studies found evidence of effects, some found none and some were inconclusive. Hence the body of evidence as a whole for *MSWI is inconsistent and inconclusive.*

- *The magnitude of any past health effects on residential populations living near incinerators that did occur is likely to have been small.*

Whatever past (non-occupational) health effects might be attributable to waste incineration in Scotland, these are likely to be have been relatively small in comparison to other sources of environmental pollution, particularly previous industrial emissions, domestic coal burning and more recently traffic pollution.

- *The majority of research work in this field is of historical relevance but tells us little about the current risk of (non-occupational) adverse effects potentially associated with incineration plants in operation now.*

Given the more strictly controlled conditions under which incineration now operates in the UK, much of the material reviewed in this report is now of historical relevance. Many of the epidemiological studies within Europe and elsewhere were conducted before changes in regulatory regimes. Consequently, levels of emissions from incineration plants were likely to be higher than now. There is however, a relative lack of published work relating to incinerators operating under the newest UK regulatory regime (e.g. WID 2003 or equivalents). It may be reasonable to assume that any (non-occupational) risk to health associated with exposure to incineration emissions should have decreased as a result of reduced emissions, consequent upon stricter regulation; however useful epidemiological evidence to confirm this is as yet scarce. *'Before and after'* studies straddling the period of regulatory change in the UK, or studies considering only exposures after regulatory changes came into force would be more relevant in terms of assessing the potential for adverse effects associated with newer incinerators.

- *Levels of airborne emissions from individual incinerators should be lower now than in the past, due to stricter legislative controls and improved technology. Hence, any risk to the health of a local population living near an incinerator, associated with its emissions, should also now be lower. It is possible that in the future the number of incinerators or the throughput of individual incinerators may increase and consequently the total mass of airborne emissions could increase. However, this has been addressed by the Scottish Government commitment to limit the total amount of waste destined for energy recovery via thermal treatment. In addition, planning controls should prevent new incinerators being sited within the locality of existing facilities.*

Any additional future incinerator emissions (including toxic, hazardous or greenhouse gases) may add to the overall burden of emissions in the environment. In most situations the contribution made by future additional incinerator emissions to the overall local population exposure to toxic chemicals, will be small. Where a health risk exists, exposure to small increments of pollutants is likely to add only a very small additional risk. Given the much stricter waste incinerator emission regulations now in place, the magnitude of any future (non-occupational) adverse effects will probably be smaller than any associated with past emissions. This assumption may only be valid however, if there is no significant increase in the overall burden of local pollution (especially airborne), in terms of the total mass of emissions added by new waste incinerators.

## 6.2 Recommendations

Based on these findings, a number of recommendations are proposed:

**i. Future research should be more clearly focussed on specific aspects of incineration and (non-occupational) health impacts**

Carrying out adequate retrospective studies in this field is problematic. Where new incinerators are to be built, consideration could be given to conducting prospective investigations of their potential (non-occupational) health effects. Ideally this would provide better quality evidence on the health of local communities living near incinerators that will be operated under the latest regulatory regimes.

However, prospective studies pose a particular challenge given that residential populations living near new incinerators may be individually small. Health outcomes of interest, particularly rarer cancers, may occur in very small numbers. Prolonged follow up periods may therefore be required. Further individual studies of small populations, especially where exposure to risk is assessed only on the basis of residential proximity to an incinerator, are unlikely to yield any more conclusive evidence than such studies in the past. A more productive strategy might be to develop a robust standardised research methodology and apply it to multiple sites simultaneously, to increase the total study population.

It is beyond the scope of this report to make detailed proposals on future study design. However, some suggestions on priorities for future research are provided. It might be in the interests of regulators and the environmental epidemiology community to consider collectively how best such future studies might be carried out.

A collective effort to design and coordinate future research might improve the probability of detecting any health effects which do exist or alternatively, might add to the strength of the evidence base indicating that any such effects are not in fact significant.

- Future primary studies on non-occupational risks should ideally rely less on proxy measures of exposure to pollutants such as residential proximity to a facility and should be more consistent in controlling sources of bias and residual confounding.

- Future investigations would ideally use Health Impact Assessment models and Life-Cycle Assessment methods to analyse more fully the additional pollutant burden associated with the complete waste management process. Emissions associated with the transport of waste to a site and removal of residual solid wastes should be included. The extra mass of pollutants added to the existing environmental pollution impacting on a local community, should be considered.

- Future reviews could focus specifically on clarifying and comparing differences in exposures and effects before and after improvements to the regulatory standards.

- Future reviews of evidence should specify clearer criteria for comparing studies and focus on research where epidemiological and toxicological paradigms have been applied adequately (e.g. the source/pathway/receptor model). Ideally there would be a clearly described hypothesis under study, comparability in the incinerators studied (the types of inputs, incinerator process and emissions) and more use of accurately characterised quantitative measurements of emissions. Ideally future reviews would use analytical techniques, such as meta-analysis, to increase the reliability of their conclusions.

**ii. The level of uncertainty regarding the actual risk to human health associated with incineration emissions, justifies the existing approaches aimed at minimising human exposure to such emissions via regulatory controls and modern operating practice. The present controls are precautionary and designed to protect human health. There is, therefore, little rationale for a more precautionary approach at present.**

Some of the more recently published studies discussed in this report have provided limited additional evidence of a possible association between some incinerator emissions, particularly dioxins, and some forms of cancer. Although some of this new evidence is stronger than that previously available it is not conclusive and is inconsistent with other findings. Also, these more recently published studies involved older generation incinerators operated in periods when emissions were likely to be higher than is now acceptable and some studies were carried out around an incinerator (not in the UK) for which emissions greatly exceeded even the earlier higher limits. The design and operational controls applied at modern facilities are highly sophisticated and as such they are now capable of operating to more stringent standards. The period during which these stricter emission standards have been in place is relatively short. Consequently there is as yet relatively little useful published epidemiological data on the newer generation of incinerators. However, it remains reasonable to conclude that any risk to human health associated with emissions from newer incinerators, operated within the current regulations, is very likely to be less than was the case previously. In view of this, the balance of evidence suggests that a more precautionary approach to either the location or the operation of incinerators is currently not recommended.

The residual '*uncertainty'* regarding the actual level of risk to human health does however justify maintaining the existing '*precautionary*' stance to waste incineration activities. '*Precautionary'* as used in this report is in line with the guidance on the '*Precautionary Principle'*, published by the Scotland and Northern Ireland Forum for Environmental Research (SNIFFER 2005). This report describes principles of good practice in relation to dealing with uncertainty in relation to environmental issues. Adopting '*precaution'* implies making use of all reasonable and practical opportunities to minimise human exposure to avoidable environmental hazards. Precautionary measures in this case must however, remain proportionate to the low level of risk. The level of scientific uncertainty is not sufficient to justify adopting more extreme measures, nor is it sufficient to justify setting an arbitrary '*safe*' distance between incinerators and human habitation or activity.

The most recent regulatory standards implemented in line with the Waste Incineration Directive (WID) are consistent with a precautionary approach. The Pollution Prevention and Control (PPC) Regulations (Scotland) (2000), governing the siting and operation of existing and future waste incineration facilities also incorporate precaution as a concept. Regulatory interventions focus mainly on the '*downstream*' (emissions) end of the incineration process. There is also scope to identify additional potential interventions '*upstream*' (e.g. the inputs and processes) using the '*source-pathway-receptor model'.*

*Source Issues*

Minimising the '*source'* waste material requiring incineration might reduce the totality of emissions. However, other routes of waste disposal, including landfill, may also generate environmental health risks of uncertain scale. Incineration may be the best or the only realistic environmental policy option for a proportion of waste that cannot be managed by other routes. In addition to the traditional emission control approach, the hazard potential of the outputs may also be influenced via control of the inputs; e.g. the fuel mix used. Increased intervention at the *'source'* might therefore allow less reliance on emissions regulation, treatment and control at the process end-point.

*Pathway Issues*

Existing emissions regulations are currently the primary means of minimising human exposures via air and water *'pathways'*. There are opportunities to reduce *'pathway'* risks associated with the transmission of potentially harmful emissions using additional techniques such as a '*life-cycle model'*. This would enable assessment of the pollution hazards associated with transport of the waste and final by-products as well as those of the incineration process emissions and waste products. This could provide a more holistic approach to health risk reduction, via all the relevant contributions to the emission pathways.

*Receptor Issues*

Finally, the '*receptor*' aspect of the model is addressed by the Pollution Prevention and Control (PPC) Regulations (Scotland) (2000). This provides for risk reduction via awareness of the potential impact of locating and operating incinerator plants near population centres and sensitive (human) receptors. In particular, as part of the PPC application process, the cumulative effect of any planned additional emissions should be considered in the context of the existing background levels of pollution from other sources of emissions in that local environment. The PPC application process therefore allows for an assessment of emissions impacts on local air quality.

The *'receptor'* aspects can be also addressed via Strategic Environmental Assessment (SEA) or Best Practicable Environmental Option (BPEO) for waste plans. These incorporate assessments of the impact of specific emissions (such as particulate matter) on local communities, especially in more sensitive air quality areas (e.g. Local Air Quality Management Areas) and assessment of emissions associated with multiple facilities. Life-Cycle Assessment (LCA) modelling has been used to support this.

Therefore, although the conclusion on (non-occupational) human health effects associated with incineration (under modern operating conditions) is relatively reassuring, where there are sensitive receptors, there will remain a need to take account of background ambient air quality especially in localities with other sources of similar emissions (including road traffic and other industrial sources), when new incinerators are proposed.

# 7 REFERENCES

1 Agramunt, M.C., Schuhmacher, M., Hernandez J.M. and Domingo J.L. (2005) Levels of dioxins and furans in plasma of non-occupationally exposed subjects living near a hazardous waste incinerator. [Article]. Journal of Exposure Analysis and Environmental Epidemiology, vol. 15, no. 1, January pp. 29-34.

2 Allsopp, M., Costner, P., Johnston, P. (2005) Incineration and human health, Greenpeace research laboratories, [Online], Available: http://www.greenpeace.org/international/press/reports/incineration-and-human-health [accessed October 2009].

3 Alvim-Ferraz, M.C., Afonso, S.A. (2005) Incineration of healthcare wastes: management of atmospheric emissions through waste segregation. Waste Management, vol. 25, no 6, pp. 638-48.

4 Alvim Ferraz, M.C., Afonso, S.A. (2003a) Dioxin emission factors for the incineration of different medical waste types. Archives of Environmental Contamination & Toxicology, vol. 44, no 4, pp. 460-6.

5 Alvim-Ferraz, M.C.M., Afonso, S.A.V. (2003b) Incineration of different types of medical wastes: emission factors for gaseous emissions. Atmospheric Environment, vol. 37, pp. 5415-5422.

6 Atkinson, R. (1991). Atmospheric lifetimes of dibenzo-*p*-dioxins and dibenzofurans. Science of the Total Environment. 104, 17-33.

7 Batterman, S. (2004) Findings on an assessment of small-scale incinerators for health-care waste. World Health Organisation Geneva, [Online], Available: http://whqlibdoc.who.int/icd/hq/2004/a85187.pdf [accessed October 2009].

8 Bradford Hill, A. (1965) The Environment and Disease: Association or Causation? Proceedings of the Royal Society of Medicine, vol. 58 pp. 295-300.

9 Bresnitz, E.A., Roseman, J., Becker, D., Gracely, E. (1992) Morbidity Among Municipal Waste Incineration Workers. American Journal of Industrial Medicine, vol. 22 pp. 363-378.

10 Comba, P., Ascoli, V., Belli, S., Benedetti, M., Gatti, L., Ricci, P., Tieghi, A. (2007) Risk of soft tissue sarcomas and residence in the neighbourhood of an incinerator of industrial wastes. Occupational and Environmental Medicine, vol. 60 pp. 680-683.

11 Committee on Carcinogenicity (CoC). (2000) Cancer incidence near municipal solid waste incinerators in Great Britain. [Online], Available: http://www.advisorybodies.doh.gov.uk/coc/munipwst.htm [accessed October 2009]

11A Committee on Carcinogenicity (CoC). (2008) First draft update statement on the review of cancer incidence near municipal solid waste incinerators. [Online], Available: http://www.iacoc.org.uk/papers/documents/UPDATECC0816statementonCancerIncidenceandMSWI.pdf [accessed October 2009]

12 Cordier, S., Chevrier, C., Robert-Gnansia, E., Lorente, C., Brula, P., Hours, M. (2004) Risk of congenital anomalies in the vicinity of municipal solid waste incinerators. Occupational and Environmental Medicine, vol. 61 pp. 8-15.

13 Cormier, S.A., Lomnicki, S., Backes, W., Dellinger, B. (2006) Origin and health impacts of emissions of toxic by-products and fine particles from combustion and thermal treatment of hazardous wastes and materials. Environmental Health

Perspectives, vol. 114, no 6 pp. 810-817.

14 Council of the European Union (2006) Directive 2006/12/EEC (75/442/EEC revised) (Waste Framework Directive (WFD)). [Online], Available: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32006L0012:EN:NOT [accessed October 2009]

15 Council of the European Union (2002) Directive 2000/532/EC (European Waste Catalogue (EWC)). [Online], Available: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32000D0532:EN:NOT [accessed October 2009]

16 Council of the European Union (2000) Directive 2000/76/EC (Waste Incineration Directive (WID)). [Online], Available: http://europa.eu/scadplus/leg/en/lvb/l28072.htm [accessed October 2009]

17 Council of the European Union (1999) Directive 1999/31/EC (European Landfill Directive). [Online], Available: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:31999L0031:EN:NOT [accessed October 2009]

18 Council of the European Union (1991) Directive 91/689/EEC (Hazardous Waste Directive (HWD)). [Online], Available: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:31991L0689:EN:HTML [accessed October 2009]

19 Cresswell, P.A., Scott, J.E.S., Pattenden, S., Vrijheid, M. (2003) Risk of congenital anomalies near the Byker waste combustion plant. Journal of public healthy medicine, vol. 25, no 3 pp. 237-242.

20 Debachere, M.C. (1995) Problems in obtaining grey literature. International Federation of Library Associations Journal, vol. 21, no 2 pp. 94-98.

21 DEFRA, Incineration of Municipal Solid Waste. (2007a) [Online], Available: http://www.defra.gov.uk/environment/waste/residual/newtech/documents/incineration.pdf [accessed October 2009].

22 DEFRA, Advanced Thermal Treatment of Municipal Solid Waste. (2007b) [Online], Available: http://www.defra.gov.uk/environment/waste/residual/newtech/documents/att.pdf [accessed October 2009]

23 DEFRA, Landfill Directive. (2003) [Online], Available: http://www.defra.gov.uk/environment/waste/strategy/legislation/landfill/index.htm [accessed October 2009]

24 Elliott, P., Eaton, N., Shaddick, G., Carter, R. (2000) Cancer incidence near municipal solid waste incinerators in Great Britain. Part 2: histopathological and case-note review of primary liver cancer cases. British Journal of Cancer, vol. 82, no 5, pp. 1103-1106.

25 Elliott, P., Shaddick, G., Kleinschmidt, I., Jolley, D., Walls, P., Beresford, J., Grundy, C. (1996) Cancer incidence near municipal solid waste incinerators in Great Britain. British Journal of Cancer, vol. 73, no 5, pp. 702-710.

26 Enviros Consulting., University of Birmingham with Risk and Policy Analysts Ltd., Open University., Thurgood, M. (2004) Review of Environmental and health effects of waste management: Municipal Solid Waste and similar wastes. Department for Environment Food and Rural Affairs, [Online], Available: http://www.defra.gov.uk/environment/waste/statistics/documents/health-report.pdf

[accessed October 2009].

27 Ferre-Huguet, N., Nadal, M. Schuhmacher, M., Domingo, J.L. (2006) Environmental impact and human health risks of polychlorinated dibenzo-p-dioxins and dibenzofurans in the vicinity of a new hazardous waste incinerator: A case study. Environmental Science & Technology, vol. 40, no 1, pp. 61-66.

28 Floret, N., Mauny, F., Challier, B., Avereux, P., Cahn, J-Y., Viel, J-F. (2003) Dioxin Emissions from a Solid Waste Incinerator and Risk of Non-Hodgkin Lymphoma. Epidemiology, vol. 14, pp. 392-398.

29 Food Safety Authority of Ireland, (2003) Report on waste incineration and possible contamination of the food supply with dioxins. [Online], Available: http://www.fsai.ie/assets/0/86/204/4154abf8-ca6a-48d2-b4ac-aa1070943881.pdf [accessed October 2009]

30 Franchini, M., Rial, M., Buiatti, E., Bianchi, F. (2004) Health effects of exposure to waste incinerator emissions: a review of epidemiological studies. Ann 1st Super Sanità, vol. 40, no 1 pp. 101-115.

31 Gochfeld, M. (1995) Incineration: health and environmental consequences. Mount Sinai Journal of Medicine, vol. 62, no 5 pp. 365-74.

32 Gonzalez, C.A., Kogevinas, M., Gadea, E., Huici, A., Bosch, A., Bleda, M.J., Päpke, O. (2000) Biomonitoring study of people living near or working at a municipal solid-waste incinerator before and after two years of operation. Archives of Environmental Health, vol. 55, no 4 pp. 259-267.

33 Hazucha, M.J., Rhodes, V., Boehlecke, B.A., Southwick, K., Degnan, D., Shy, C.M. (2002) Characterization of Spirometric Function in Residents of Three Comparison Communities and of Three Communities Located near Waste Incinerators in North Carolina. *[Article].* Archives of Environmental Health March/April, vol. 57, no 2 pp. 103-112.

34 Health Protection Agency (HPA). (2005) Position Statement on Municipal Solid Waste Incineration [Online]. Health Protection Agency. [Online], Available: http://www.hpa.org.uk/webw/HPAweb&HPAwebStandard/HPAweb_C/1195733829068?p=1207293965142 [accessed October 2009].

35 Hu, S.W., ChangChien G.P., Chan, C.C. (2004) PCDD/Fs levels in indoor environments and blood of workers of three municipal waste incinerators in Taiwan. Chemosphere, vol. 55, no 4 pp. 611-620.

36 Hu, S.W., Shy, C.M. (2001) Health effects of waste incineration: a review of epidemiologic studies. Journal of the Air & Waste Management Association, vol. 51, no 7 pp. 1100-1109.

37 Humfrey, C., Taylor, M., Amaning, K. (1997) IEH report on health effects of waste combustion products. Institute for Environment and Health [Online], Available: http://www.cranfield.ac.uk/health/researchareas/environmenthealth/ieh/ieh%20publications/r7.pdf [accessed October 2009]

38 Independent Expert Group on Mobile Phones (IEGMP). (2000) Mobile Phones and Health. Independent Expert Group on Mobile Phones, Chairman Sir William Stewart. ISBN 0-85951-450-1.

39 Kelly, K.E. (1995) Health effects of hazardous waste incineration…more of the rest of the story. International Incineration Conference. Seattle, WA, USA, pp. 21.

40 Kim, M.K., Oh, S., Lee, J.H., Im, H., Ryu, Y.M., Oh, E., Lee, J., Lee, E., Sul, D.

(2004) Evaluation of biological monitoring markers using genomic and proteomic analysis for automobile emission inspectors and waste incinerating workers exposed to polycyclic aromatic hydrocarbons or 2,3,7,8,-tetracholrodedibenzo-p-dioxins. Experimental and Molecular Medicine, vol. 36, no 5. pp. 396-410.

41 Knox, E.G. (2000) Childhood cancers, birthplaces, incinerators and landfill sites. International journal of epidemiology, vol. 29 pp. 391-397.

42 Kumagai, S., Koda, S., Miyakita, T., Ueno, M. (2002) Polychlorinated dibenzo-p-dioxin and dibenzofuran concentrations in serum samples of workers at intermittently burning municipal waste incinerators in Japan. Occupational & Environmental Medicine, vol. 59, pp. 362-368.

43 Kurttio, P.P.J., Alfthan, G., Paunio M., Jaakkola J.J.K., Heinonen, O.P. (1998) Increased mercury exposures in inhabitants living in the vicinity of a hazardous waste incinerator: A 10-year follow-up. Archives of Environmental Health, vol. 53, no 2 pp. 129-137.

44 Last, J.M. (1995) *A dictionary of Epidemiology, 3rd edition,* New York: Oxford University Press.

45 Leem, J.H., Hong, Y.C., Lee, K.H., Kwon, H.J., Chang, Y.S., Jang, J.Y. (2003) Health Survey on Workers and Residents Near the Municipal Waste and Industrial Waste Incinerators in Korea. Industrial Health, vol. 41, no 3 pp. 181-188.

46 Lonati, G., Cernuschi, S., Giugliano M., Grosso, M. (2007) Health risk analysis of PCDD/F emissions from MSW incineration: comparison of probabilistic and deterministic approaches. Chemosphere, vol. 67, no 9 pp. S334-S343.

47 Maître, A., Collot-Fertey, D., Anzivino, L., Marques, M., Hours, M., Stoklov, M. (2003) Municipal waste incinerators: air and biological monitoring of workers for exposure to particles, metals, and organic compounds. [Article]. Occupational & Environmental Medicine, vol. 60, no 8 pp. 563-569.

48 Meneses, M., Schuhmacher, M., Domingo, J.L. (2004) Health risk assessment of emissions of dioxins and furans from a municipal waste incinerator: Comparison with other emission sources. Environment International, vol. 30, no 4 pp. 481-489.

49 Michelozzi, P., Fusco, D., Forastiere, F., Ancona, C., Dell'Orco, V., Perucci, C,A. (1998) Small area study of mortality among people living near multiple sources of air pollution. Occupational and Environmental Medicine, vol. 55 pp. 611-615.

50 Miyake, Y., Yura, A., Misaki, H., Ikeda, Y., Usui, T., Iki, M., Shimizu, T. (2005) Relationship Between Distance of Schools from the Nearest Municipal Waste Incineration Plant and Child Health in Japan. European Journal of Epidemiology, vol. 20, no 12 pp. 1023-1029.

51 Nakayama, O., Ohkuma, K. (2006) Mental Health Status of Municipal Solid Waste Incinerator Workers Compared with Local Government Office Workers. Industrial Health, vol. 44 pp. 613-618.

52 National Research Council (NRC). (2000) *Waste incineration and public health*, Washington DC: National Academy Press.

53 Oppelt, E.T. (1990) Air emissions from the incineration of hazardous waste. Toxicology and Industrial Health, vol. 6, no 5 pp. 23-51.

54 Obi-Osius, N., Misselwitz, B., Karmaus, W., Witten, J. (2004) Twin frequency and industrial pollution in different regions of Hesse, Germany. Occupational and Environmental Medicine, vol. 61 pp. 482-487.

55 Osius, N., Karmaus, W., Kruse, H., Witten, J. (1999) Exposure to Polychlorinated Biphenyls and Levels of Thyroid Hormones in Children. Environmental Health Perspectives, vol. 107, no 10 pp. 843-849.

56 Raemdonck, A., Koppen, G., Bilau, M., Willems, J.L. (2006) Exposure of maintenance workers to dioxin-like contaminants during the temporary shutdown of a municipal domestic solid waste incinerator: a case series. Archives of Environmental & occupational health, vol. 61, no 3 pp. 115-121.

57 Reis, M.F., Sampaio, C., Brantes, A., Aniceto, P., Melim, M., Cardoso, L., Gabriel, C., Simão, F., Segurado, S., Miguel, J.P. (2007a) Human exposure to heavy metals in the vacinity of Portuguese sold waste incinerators - Part 1: Biomonitoring of Pb, Cd and Hg in the blood of the general population. International Journal of Hygiene and Environmental Health, vol. 210 pp. 439-446.

58 Reis, M.F., Sampaio, C., Brantes, A., Aniceto, P., Melim, M., Cardoso, L., Gabriel, C., Simão, F., Segurado, S., Miguel, J.P. (2007b) Human exposure to heavy metals in the vicinity of Portuguese sold waste incinerators - Part 2: Biomonitoring of lead in maternal and umbilical cord blood. International Journal of Hygiene and Environmental Health, vol. 210 pp. 447-454.

59 Reis, M.F., Sampaio, C., Brantes, A., Aniceto, P., Melim, M., Cardoso, L., Gabriel, C., Simão, F., Segurado, S., Miguel, J.P. (2007c) Human exposure to heavy metals in the vicinity of Portuguese sold waste incinerators - Part 3: Biomonitoring of Pb in the blood of children under the age of 6 years. International Journal of Hygiene and Environmental Health, vol. 210 pp. 455-459.

60 Rowat, S.C. (1999) Incinerator toxic emissions: A brief summary of human health effects with a note on regulatory control. Medical Hypotheses, vol. 52, no 5 pp. 389-396.

61 Rushton, L. (2003) Health hazards and waste management. British Medical Bulletin, vol. 68 pp. 183-197.

62 Saffron, L., Giusti, L., Pheby, P. (2003) The human health impact of waste management practices A review of the literature and an evaluation of the evidence. Management of environmental quality, vol. 14, no 2 pp. 191-213.

63 Schuhmacher, M., Domingo, J.L., Agramunt, M.C., Bocio, A., Muller, L. (2002) Biological monitoring of metals and organic substances in hazardous-waste incineration workers. International Archives of Occupational & Environmental Health, vol. 75, no 7 pp. 500-6.

64 Schuhmacher, M., Xifro, A., Llobet, J.M., de Kok, H.A., Domingo, J.L. (1997) PCDD/Fs in soil samples collected in the vicinity of a municipal solid waste incinerator: human health risks. Archives of Environmental Contamination & Toxicology, vol. 33, no 3 pp. 239-46.

65 Scotland & Northern Ireland Forum for Environmental Research (SNIFFER) (2005) Applying the Precautionary Principle – an overview. [Online], Available: http://www.sniffer.org.uk/Webcontrol/Secure/ClientSpecific/ResourceManagement/UploadedFiles/UKCC05.pdf [accessed October 2009].

66 Scottish Environment Protection Agency (SEPA). (2007) Waste Data Digest 7 2005/2006 [Online], Available: www.sepa.org.uk/waste/waste_data_1/idoc.ashx?docid=efee9e72-6a65-4a0b-b260-a69d99370b7e&version=-1 [accessed October 2009].

67 Scottish Environment Protection Agency (SEPA). (2004) SEPA Guidelines for Thermal Treatment of Municipal Solid Waste. [Online], Available: http://www.sepa.org.uk/waste/waste_regulation/energy_from_waste.aspx [accessed October 2009].

68 Scottish Government. Guidance on Landfill Allowance Regulations (Scotland) (2005) [Online], Available: http://www.scotland.gov.uk/Publications/2005/06/08111144/11463 [accessed October 2009].

69 Scottish Intercollegiate Guidelines Network (SIGN), (2008) Guideline Development Process. [Online], Available: http://www.sign.ac.uk/methodology/index.html [accessed October 2009].

70 Sedman, R.M., Esparza, J.R. (1991a) Evaluation of public health risks associated with semi-volatile metal and dioxin emissions from hazardous waste incinerators. Environmental Health Perspectives, vol. 94 pp. 181-187.

71 Shy, C.M., Degnan, D., Fox, D.L., Mukerjee, S., Hazucha, M.J., Boehlecke, B.A., Rothenbacher, D., Briggs, P.M., Devlin, R.B., Wallace, D.D., Stevens, R.K., Bromberg, P.A. (1995) Do Waste Incinerators Induce Adverse Respiratory Effects? An Air Quality and Epidemiological Study of Six Communities. Environmental Health Perspectives, vol. 103, pp. 714-724.

72 Staessen, J., Nawrot, T., Hond, E., Thijs, L., Fagard, R., Hoppenbrouwers, K., Koppen, G., Nelen, V., Schoeters, G., Vanderschueren, D. (2001) Renal function, cytogenetic measurements, and sexual development in adolescents in relation to environmental pollutants: a feasibility study of biomarkers. The Lancet, vol. 357 pp. 1660-1669.

73 Takata, T. (2003) Survey on the Health Effects of Chronic Exposure to Dioxins and Its Accumulation on Workers of a Municipal Solid Waste Incinerator, Rural Part of Osaka Prefecture, and the Results of Extended Survey Afterwards. Industrial Health, vol. 41, no 3 pp. 189-196.

74 Tango, T., Fujita, T., Tanihata, T., Minowa, M., Doi, Y., Kato, N., Kunikane, S., Uchiyama, I., Tanaka, M., Uehata, T. (2004) Risk of adverse reproductive outcomes associated with proximity to municipal solid waste incinerators with high dioxin emission levels in Japan. Journal of Epidemiology, vol. 14, no 3 pp. 83-93.

75 Thompson, J., Anthony, H. (2005) The health effects of waste incinerators. The British Society for Ecological Medicine, vol. 15, pp. 115-156.

76 Viel, J. -F., Clément, M.-C., Hägi, M., Grandjean, S., Challier, B., Danzon, A. (2008) Dioxin emissions from a municipal solid waste incinerator and risk of invasive breast cancer: a population-based case-control study with GIS-derived exposure. International Journal of Health Geographics, vol. 7, no 4 pp. 8.

77 Viel, J.-F., Arveux, P., Baverel J., Cahn, J.-Y. (2000) Soft-Tissue Sarcoma and Non-Hodgkin's Lymphoma Clusters around a Municipal Solid Waste Incinerator with High Dioxin Emission Levels. American Journal of Epidemiology, vol. 152, no 1 pp. 13-19.

78 Williams F. L. R., Lawson A. B., Llyod O. (1992) Low sex ratios of births in areas at risk from air pollution form incinerators, as shown by geographical analysis and 3-dimensional mapping. International Journal of Epidemiology, vol. 21, no 2 pp. 311-319.

79 Wrbitzky, R., Goen, T., Letzel, S., Frank F., Angerer, J. (1995) Internal exposure of waste incineration workers to organic and inorganic substances. International

Archives of Occupational & Environmental Health, vol. 68, no 1 pp. 13-21.

80 Zambon, P., Ricci, P., Bovo, E., Casula, A., Gattolin, M., Fiore, A.R., Chiosi, F., Guzzinati, S. (2007) Sarcoma risk and dioxin emissions from incinerators and industrial plants: a population-based case-control study (Italy). Environmental Health, vol. 6, no 19 pp. 10pp.

# APPENDIX 1 BIBLIOGRAPHY OF PUBLISHED PEER-REVIEWED LITERATURE AND SUMMARY OF KEY FINDINGS

For readers who wish to refer to the primary literature itself, the original papers considered most relevant are summarised in Appendix 1. Papers are grouped by waste stream category: multiple waste streams, municipal solid waste, hazardous, clinical and industrial waste. For each waste stream category, relevant papers are grouped by health outcomes studied: cancer, genetic/congenital malformations, reproductive/birth outcomes, respiratory disease or biochemical markers/ body burden of metabolites. For each paper a brief description is provided with summarised key facts and conclusions. In keeping with SIGN methodology, each sub-section has an evidence table summarising key facts about the study including: the country studied, number of subjects, waste stream studied, outcomes studied and key results (Tables 7 to 11). Two final summary evidence tables provide listings by year of publication for the key data on each study (Table 12) and by health outcomes studied (Table 13).

## A1.1 Multiple Waste Sectors

There were five epidemiological papers identified, published between 1995 and 2007 that dealt with more than one type of waste sector. The findings are summarised in Table 7.

### A1.1.1 Cancer Incidence

Three of the five papers were concerned with cancer incidence and proximity to different types of waste incinerator.

**Knox (2000)** was concerned with the incidence of childhood cancer in relation to proximity with MSWI and a clinical incinerator and toxic landfill. The authors focused on childhood cancers on the premise that children are generally considered to be more susceptible to health effects associated with exposure to environmental hazards. The authors investigated registered cancer deaths of 22,458 children up to the age of 16 in Great Britain between 1953 and 1980. Residence at birth and residence at death were plotted along with proximity to the nearest hazard (MSWI, hospital incinerators or landfill sites). The study was designed to investigate the effect of exposure in early years to environmental hazards for those whose residence at birth were close to a particular hazard and exposure after birth for residence proximity to particular hazards at death due to cancer. This was a complex study using an indirect measure of relative risk based on migration of the case between birth and death to locations where the "exposure" was likely to be different. Relative risks of "about 2:1" within 5km of a potential source were quoted. The results are however, particularly difficult to interpret, especially relating to the migration model as a proxy for differential exposure to hazardous emissions. The authors concluded that they could not distinguish the effect attributable to incinerators alone from that associated with other industrial sources of emissions:

> *"It is difficult to say whether the apparent carcinogenic risks near incinerators might stem from (some of) the plants themselves or from other hazards in the near environments. In favour of the latter, all the most 'toxic' incinerators were close to industrial sources of kinds implicated in earlier studies, as were the few exceptional landfill sites. On the other hand, concordance with hospital incinerators suggests a common direct effect; as does the observed limitations to the operational time spans of the municipal facilities. For the time being we must probably suppose that the effect stems from large-scale combustion process as a whole, of which the incinerators are but one component."*

**Zambon *et al* (2007)** was concerned with soft tissue sarcoma incidence with reference to industrial sources of pollution including 10 MSWI, an industrial incinerator and 12 medical incinerators. The authors found an increased risk of soft tissue sarcoma for residents who had the longest exposure time to the highest level of exposure. It was also found that women seemed to be more at risk for soft tissue sarcoma at the highest level of exposure to dioxins present in emissions from the incinerators within the study area. The authors acknowledge that the dispersion model used wind current data recorded in the vicinity of the local airport located near the centre of the study area. This may mean that estimates of emissions from more distant plants could be less accurate.

#### A1.1.2 Lung Function

Two papers were concerned with lung function as measured by spirometer.

**Shy *et al* (1995)** investigated the effects of particulate emissions in six communities.

- one in proximity to a municipal solid waste incinerator (MSWI) and a comparison unexposed community
- one in proximity to a biomedical waste incinerator (BWI) and a comparison unexposed community

- one in proximity to a liquid hazardous waste incinerator (HWI) and a comparison unexposed community

The authors could not detect differences in particulate concentrations between incinerator and comparison communities. The authors could also find no significant differences in the prevalence of chronic or acute respiratory symptoms between incinerator and comparison communities. These results must be considered in conjunction with a number of limiting factors pertaining to the study.

- Production of individualized air pollution exposure estimates.
- Air quality measurements exist for only 35 successive days in each community.
- Infants younger than 8 years that would be highly susceptible to environmental toxins were excluded from the study.
- The hazardous waste incinerator was burning only coal for this first year of the three year study.
- Spirometric function was the only health impact measured.

**Hazucha *et al* (2002)** is a follow up to the paper by Shy *et al* described above. Here all three years of the study are analysed and reported on. The authors here also found no significant difference in lung function between the incinerator groups and the control groups over the three years of the study.

A1.1.3 PCDD and PCDF (Dioxin) Levels in Blood

**Leem *et al* (2003)** was concerned with the levels of PCDD and PCDFs in blood samples for people living near municipal solid waste incinerator (MSWI) and industrial waste incinerators (IWI). The authors conclude:

> *"There were no differences of PCDD/Fs isomer concentrations between workers at incinerators and residents near the MSW incinerators."*
>
> *"In 1997, WHO recommended 10-30 pg I-TEQ/g lipid as the background level of PCDD/Fs. In this study, the total TEQ concentrations of PCDD/Fs of workers and residents near the MSW incinerator were within the background levels."*

*“Estimated daily intake (EDI) of each person was calculated, and all of workers and residents near MSW incinerator were within the tolerable daily intake range. This means that MSW incinerators now do not affect the level of PCDD/Fs in workers at incinerators and residents near MSW incinerators.”*

*“Total TEQ concentrations of PCDD/F of residents near the industrial waste incinerator were higher than the background levels. The average TEQ concentrations of PCDD/Fs in residents near the industrial waste incinerator were 53.4 pg I-TEQs/g lipid, while those of PCDD/Fs in workers and residents near MSW incinerator were 11.4 pg I-TEQs/g lipid.”*

The authors also found that only 30% of residents living in the vicinity of the IWI had a daily intake within the tolerable daily intake range (1-4 I-TEQ/kg body weight per day) suggested by the World Health Organisation (WHO) in 1998 (http://www.who.int/inf-pr-1998/en/pr98-45.html, accessed October 2009).

**Table 7: Epidemiological papers covering multiple waste sectors**

| Country / Reference (Ref No) | No. of Subjects | Incinerator types | Study Measurements | Outcomes |
|---|---|---|---|---|
| **USA**<br>Shy *et al*., 1995<br>(71) | BWI =1185 cases<br>BCo = 1148 controls<br>MWI = 1414 cases<br>MCo = 1208 controls<br>HWI = 880 cases<br>HCo = 1046 controls<br>Co = control community | Municipal (MWI)<br>biomedical (BWI)<br>Hazardous (HWI) | Spirometry<br>Peak flow<br>Nasal wash | No difference in particulate air pollution between incinerator and comparison communities. Incinerator emissions contributed < 3% to measured particulate concentrations. No consistent difference in prevalence of chronic or acute respiratory symptoms between incinerator and comparison communities. No difference in peak flow. |
| **UK**<br>Knox 2000<br>(41) | 22458 cases | MSW<br>Clinical | Childhood cancer and residence proximity to hazard source including migration | Highly significant excess of migration away from incineration after birth compared to landfill sites. MSW relative risk of cancer within 5.0 km was 2:1; Bio med incinerator gave analogous results. All hazard areas risk ratios exceeded findings for non combustion urban sites |
| **USA**<br>Hazucha *et al*., 2002<br>(33) | 358 residents in the vicinity of incinerators for 3 years | Clinical<br>Hazardous<br>MSW | Spirometric lung function | No difference in lung function between the 3 communities round the different incinerators and no adverse effect on spirometric function |
| **Korea**<br>Leem *et al*., 2003<br>(45) | 13 MSWI workers<br>16 MSWI residents<br>10 Industrial waste incinerator residents | Industrial<br>MSW | PCDDs and PCDFs in 150 cc blood samples | Higher toxic equivalency in workers and residents of industrial than MSW (53.4 pg I-TEQs/g lipid and 11.4 pg I-TEQs/g lipid respectively) Only 30% of 10 cases living near the industrial incinerator were within tolerable daily intake range (taken as (1–4 pg I-TEQ/kg bw/day) |
| **Italy**<br>Zambon *et al.,* 2007<br>(80) | 172 cases<br>405 controls | Industrial<br>MSW<br>Clinical | Soft tissue sarcoma case and residence with reference to industrial sources including incinerators | Sarcoma risk 3.3 times for both sexes for cases exposed for greatest time at highest exposure (Odds Ratio OR = 3.30, 95% CI: 1.24 – 8.76) and a significant excess of risk sarcoma for women (Odds Ratio OR = 2.41, 95% CI: 1.04 – 5.59) |

## A1.2 Municipal Solid Waste Incineration

There were 27 papers identified that concentrated on MSW incineration. The papers were published between 1992 and 2008. The findings of these papers are summarised in Table 8.

### A1.2.1 Cancer Incidence

Five papers dealt with cancer incidence in association with Municipal Solid Waste Incinerators. All five papers reported an excess risk for cancer for communities resident in close proximity to MSWI.

**Elliott *et al* (1996 and 2000)** both show an excess risk for liver cancer for residents living between 0 and 1 km from a MSWI. Elliott *et al* (1996) showed a significant decline in risk with increasing distance from the incinerator. In 2000, following re-classification of cases based on a historical review, a revised estimate of between 0.53 and 0.73 excess cases per 100,000 per year within 1Km of an incinerator.

**Michelozzi *et al* (1998)** investigated the potential health risk from airborne pollution in the vicinity of a waste disposal site, a waste incinerator and an oil refinery in the Malagrotta area of Rome, Italy. The health risk was quantified by the mortality risk from cancers were the particular focus of this study. The authors conclude:

> *"In conclusion, our study did not show any increase in mortality in the resident population for any of the analysed causes. We focused on the decrease in mortality risk for laryngeal cancer as a function of distance from the sources of emissions; these results are based on a limited number of cases, and further studies will be necessary to clarify whether the presence of refineries or waste incinerators does represent a risk factor for this disease in resident populations."*

**Viel *et al* (2000)** focused on soft tissue sarcoma and non-Hodgkin's lymphoma incidence for residents leaving near MSWI. The authors report a highly significant incidence ratio of 1.44 (p = 0.004) for soft tissue sarcoma in the vicinity of a MSWI for a study conducted over 16 years. In the same study the incidence ratio around the incinerator for non-Hodgkin's lymphoma was 1.27 (p = 0.00003). The rates of Hodgkin's disease, which was used here as a control condition, showed no significant clustering or association with the MSWI.

**Floret *et al* (2003)** focused on the findings in terms of risk of non-Hodgkin's lymphoma and residential exposure to dioxin emissions from a municipal waste incinerator (MSWI). The authors report levels of dioxins measured from the MSWI in 1997 were high (16.3 ng I-TEQ $m^{-3}$) well above the European guideline (0.1 ng I-TEQ $m^{-3}$). The study attempted to identify the point source of the dioxin emissions in the area by analysis of the dioxin congener profiles in soil samples of the surrounding area. The authors conclude:

> *"Distinguishing between PCDD/F emission sources according to their finger-prints might be difficult (Atkinson, 1991) and still represents an open area of research. Nevertheless, the sampling site selection process, the high similarities in the congener profiles, and the absence of other polluting industries allow us to conclude that the presence of PCDD/Fs in the area under the influence of the MSWI is not subject to other point sources of PCDD/Fs. Therefore since the most polluting combustion chambers were recently shut down, and replaced by a new one with up-to-date pollution controls, slowly decreasing dioxin concentration in soil are to be expected in the study area."*

**Viel et al (2008)** reported on dioxin emissions from a MSWI and risk of breast cancer, the authors concluded:

> *"Before speculating that dioxin anti-estrogenic activity has greater effect on late-onset acquired breast cancer, we must envisage some residual confounding. Considering the inconclusive evidence from studies undertaken so far, future large-scale population based studies that include assessment of family history, breast cancer risk factors, environmental exposures, standardized histopathology reviews and molecular characterization are needed to lead to new insights into the association between environmental dioxin exposure and breast cancer risk."*

### A1.2.2 Dioxins and Heavy Metals in Blood

14 papers in total published between 1997 and 2007 study exposure assessments through levels of dioxins and heavy metals in blood samples of residents living near MSWI.

*Dioxins*

**Bresnitz *et al* (1992)** investigated morbidity among Municipal Waste Incinerator workers. For heavy metals in blood and urine the study discovered less than 2% of 471 tests showed levels elevated above the expected range of the general population.

**Schuhmacher *et al* (1997)** investigated human health risk associated with PCDD/Fs in soil samples collected in the vicinity of a municipal solid waste incinerator. The authors conclude:

> *"The highest and lowest PCDD/F concentrations were found at 750 m (44.6 ng TEQ/kg) and 3000 m (0.3 ng TEQ/kg) from the stack, while the PCDD/PCDF ratio was 1.78. The health risk analysis of the data shows that the PCDD/F intake from soils is substantially lower than the tolerable daily intake for toxicological (other than cancer) effects of PCDD/Fs."*

**Gonzalez *et al* (2000)** investigated dioxins, furans and PCBs in blood samples of residents and workers of a municipal waste incinerator. The authors conclude:

> *"In conclusion, results from this bio-monitoring study indicate that blood levels of PCDDs/PCDFs in the population of Mataro are low, but they do not appear to follow the general decreasing trends observed in other industrialized countries. During the 2 y the MSWI functioned, there was a small increase in PCDD/PCDF blood levels in the general population of Mataro that did not depend on distance of residence from the incinerator. Given the low reported stack emissions from this plant, it is unlikely that we could attribute the aforementioned increase to the emissions from the incinerator. However, apart from the functioning of the incinerator, no other major changes in sources of dioxin exposure could be identified in this population."*

**Staessen *et al* (2001)** reported on the renal function, cytogenetic measurements, and sexual development in adolescents from two exposed suburbs living near a MSWI and a control suburb. The authors concluded:

> *"Concentrations of lead and cadmium in blood, PCBs (polychlorinated biphenyls) and dioxin-like compounds in serum samples, and metabolites of VOCs (volatile organic compounds) in urine were higher in one or both suburbs than in the control area. Children who lived near the waste incinerators matured sexually at an older age than others, and testicular volume was smaller in boys from the suburbs than in controls. Biomarkers of glomerular or tubular renal dysfunction in individuals were positively correlated with blood lead. Biomarkers of DNA damage were positively correlated with urinary metabolites of PAHs (polycyclic aromatic hydrocarbons) and VOCs."*

**Kumagai *et al* (2002)** was a study of workers in three MSWI that burned on an intermittent basis. The toxic equivalency levels of PCDD and PCDF in lipids of workers showed no significant difference when comparing TEQ of PCDD and PCDF between workers and controls (PCDD and PCDF TEQ in serum of workers 22.8 and controls 16.4 pg TEQ/g lipid for incinerator I, workers 29.4 and controls 19.3 pg TEQ/g lipid for incinerator II, workers 22.8 and controls 24.9 pg TEQ/g lipid for incinerator III).

The authors conclude:

> *"The serum TEQs of PCDDs and PCDFs in all of the incinerator workers and controls were almost the same as in other industrialised countries. The comparison between the incinerator workers and controls did not show differences in the serum TEQs of PCDDs and PCDFs, but the concentration of 1,2,3,4,6,7,8-HpCDF was higher among the incinerator workers in all three areas although the workers wore respiratory protection during the repair work. This suggests that the incinerator workers inhaled dust containing PCDDs and PCDFs during their work."*

**Takata (2003)** investigated the chronic exposure of workers in a MSWI to dioxins. The paper showed that exposure duration is an important factor in determining the level of dioxins in the blood. This is highlighted by significantly higher dioxin levels in blood when comparing workers that spent little time exposed to the waste ash produced by the incinerator to those that were directly exposed to the waste ash (34.2 and 323.3 pg I-TEQ/g-fat respectively). The appendix of the paper reports the findings of a further 3 year study of workers measured dioxin levels from 104 workers at six incineration plants. The study conclusion was:

> *"Using the data of 412 persons, who had all results of tests and measurements and excluding women because of inducing difference by sex, the relation between blood dioxins concentration and results of tests and measurements were statistically analysed. As a result, there were no observable health effects due to dioxins exposure during operations in incinerator related facilities."*

**Hu *et al* (2004)** reported PCDD/F levels in indoor environments and blood from workers of three municipal waste incinerators in Taiwan. The authors conclude:

> *"The Three municipal waste incineration plants in Taiwan had average air PCDD/Fs concentrations between 0.08 and 3.01 pg I-TEQ/m3. Workers from these plants had geometric mean blood PCDD/Fs level of 14.6-19.1 pg WHO-TEQ/g lipid. Blood concentrations of 2,3,7,8-TeCDD, 1,2,3,7,8-PeCDD, 2,3,7,8-TeCDF, 1,2,3,7,8-PeCDF, 1,2,3,4,7,8,9-HpCDF, and OCDF, respectively, were significantly different among plants. The differences were not explained by the discrepancy in job contents, duration of employment and time activity among these plants."*

**Meneses *et al* (2004)** reported on an update to a long term study of PCDD/F concentrations in herbage and soil samples in the vicinity of a MSWI in Spain. The authors conclude:

> *"In summary, the present results show that although in general terms, PCDD/F health risks decreased during the examining period (before and after the installation of the new cleaning gas system), this reduction has not been*

*as great as it could have been expected according to the very pronounced decreases in PCDD/Fs emissions from the stack. It should be taken into account that these emissions diminished, on average, from 111.39 ng I-TEQ $m^{-3}$ (before) to 0.036 ng I-TEQ $m^{-3}$ (after). It clearly indicates that other sources of PCDD/Fs (traffic, industrial activities, local fires, etc) also have a notable impact on the area under direct influence of the MSWI. Similar conclusions were also reached following a comparison of the congener profile of PCDD/Fs in soil and herbage samples collected near the MSWI with those from samples collected in a close area, which is outside the direct influence of the plant. According to the above, it can be concluded that the health risks due to the current PCDD/F emissions from the MSWI would be of relatively small significance for the population living in the neighbourhood of the facility. "*

**Raemdonck *et al* (2006)** reported on a focused study of MSWI workers exposure to dioxin contaminants during cleaning procedures. The dioxin chemical-activated luciferase gene expression (CALUX) assay results showed that after cleaning operations the workers could be exposed to dioxin-like substances. The authors conclude:

*"The workers' mean serum concentration of dioxin-like substances before the first cleaning operation, shown as a weighted value of toxic equivalents (or TEQs) according to the CALUX test, was 17.2 pg CALUX TEQ/g fat (range = 12-22), which is comparable with concentrations found in similarly aged men in a Flemish environmental health pilot study. After cleaning work, the workers' mean serum concentration was 28.5 pg CALUX TEQ/g fat (range = 18-31). At the second plant stoppage, the workers' mean dioxin-like activity was 15.4 pg CALUX TEQ/g fat (range = 12-21) before and 16.4 pg CALUX TEQ/g fat (range = < 10-32, where 10pg is the limit of determination) after the cleaning operation. These results indicate that workers may be exposed to dioxin-like substances during their performance of cleaning operations in a municipal domestic solid-waste incinerator."*

**Lonati *et al* (2007)** reported on a health risk analysis of PCDD/F emissions from MSW incineration. The stack emission concentrations of PCDD/Fs are compared between the older incinerators and the newer incinerators that have PCDD/F removal technologies. The values reported are geometric mean values for old incinerator (2 nano grams I-TEQ $m_n^{-3}$) and new incinerator (4.7 pico grams I-TEQ $m_n^{-3}$) respectively.

The older incinerators have considerably higher PCDD/F emissions, bearing in mind the current regulatory standard for emissions is 0.1 ng I-TEQ $m_n^{-3}$. The authors also report calculated mean individual risk values of developing cancer due to emissions measured from the old MSWI being much greater than the newer incinerators with PCDD/F abatement technology installed (mean $1.1 \times 10^{-7}$ and mean $6.7 \times 10^{-10}$) respectively.

*Heavy Metals*

**Gonzalez *et al* (2000)** which has been discussed earlier with respect to dioxins and furans also investigated lead (Pb), chromium (Cr), cadmium (Cd) and mercury (Hg) in blood and urine (U-Hg, U-Cr). The authors conclude:

> *"A decrease in blood Pb was found in both groups of residents, and this decrease was statistically significant in residents "far" from the incinerator. Blood levels of Cd and U-Hg and U-Cr were very similar in all groups, both before and after the 2-y period; the only exception was that a reduction in Cr levels was noted in incinerator workers."*

**Maître *et al* (2003)** reported on an occupational exposure study of toxic pollutants at two municipal incineration plants. Levels of metals (Cadmium, Chromium and Nickel) were measured in 29 male workers and 17 male controls. The authors conclude:

> *"Concentrations of VOCs and aldehydes in the air were low and do not appear to pose a significant threat to human health. Only the measurement of chlorinated hydrocarbon levels (which are a good marker for the products of the combustion of plastics) would seem to be of use in this context. When it comes to particulate pollution, MWI workers are not more highly exposed to PAHs than any other workers who are regularly in contact with vehicle exhaust. The only times MWI workers are exposed to levels of pollutants which are 10–100 times higher than controls concern exposure to particles during cleaning operations and to metals during residue transfer and disposal operations. These levels might be higher in incinerators which fail to meet current norms and also during certain special operations such as furnace maintenance; respiratory protection ought to be worn when carrying out any of these high risk activities in order to cut down exposure and thereby reduce the incidence of respiratory disease, and in the longer term and even more importantly, the risk of cancer. Recent incinerators in which the effluent treatment systems are efficient should be considered as a good alternative waste management practice to landfills."*

**Reis *et al* (2007a & 2007b& 2007c)** investigate heavy metal concentrations in blood in the vicinity of two Portuguese solid waste incinerators, one near Lisbon and the other on Madeira Island. The first paper Reis *et al* (2007a) focuses on bio-monitoring of Pb, Cd and Hg in blood of the general population around a waste incinerator. The authors conclude:

> *"Individuals from Lisbon seem to have a significantly higher body burden of the studied metals than those living in Madeira and, in general, metal*

*exposure in men is significantly higher than in women, with the most relevant exception being the case of higher mercury levels in women, at the baseline and for both communities."*

The second report Reis *et al* (2007b) focuses on lead levels in maternal and umbilical cord blood. The authors conclude:

*"For Lisbon, lead levels determined at the baseline period (T0), as well as three subsequent evaluations of potential specific impacts of the incinerator (T1,T2 and T3) are described in order to investigate special and temporal trends of human exposure to lead. Available data for Madeira, namely lead levels in blood from the study population before the incinerator started operation, is also described. For Lisbon, analyses showed a statistically significant decrease of lead concentrations in maternal (p<0.001) and umbilical cord blood (p<0.001) during the whole monitoring period. Baseline levels for Madeira were the lowest found in all observations already performed in both programs (maternal and umbilical cord mean lead levels of 0.4 μg/dl and 0.3 μg/dl, respectively). No statistical associations have been found between lead levels in blood and age neither for global populations from Lisbon and Madeira nor for specific groups included in the different observational periods."*

The third paper Reis *et al* (2007c) focused on lead levels in children under the age of 6 years. The authors draw the following conclusions:

*"From analysis of all results obtained in the study it is possible to conclude that lead levels in the blood of the study children are relatively low and that only 14 cases (13 in Lisbon and 1 in Madeira), corresponding to 2.8% of the whole studied group, had blood lead levels equal to or higher than the action level of 10μg/dl"*

A1.2.3 Reproductive and Genetic Effects

**Williams *et al* (1992)** reports the findings of a study of 3 exposed and 4 comparison areas round two MSWI plants in the Falkirk area. The focus of the study was to investigate the influence of emissions from the MSWIs and sex ratio of births. The authors concluded:

*"Many factors can alter the sex ratios of births, and it would of course be premature to attribute causality to the association presented in this paper. Further work is required to establish the extent, significance and implications of this association between environmental air pollution from incineration plants and abnormal sex ratios of births. However, if sex ratios are affected through residential exposure to airborne pollution, the simple screening procedure to alert medical and environmental health authorities against insidious hazards to health"*

**Cresswell *et al* (2003)** reported the risk of congenital anomalies near a MSWI plant. The risk of congenital anomalies was compared between residents living within 3 km of the incinerator and between 3 km and 7 km of the incinerator. The overall risk of congenital anomalies in the 3 km inner zone before and after the start-up of the plant was greater than the outer zone but not significantly so.

**Cordier *et al* (2004)** investigated the risk of congenital anomalies in the vicinity of municipal solid waste incinerators (MSWIs) in France. In general the rate of congenital anomalies was not significantly higher in areas close to MSWI compared to areas with no MSWI. The authors conclude:

> *"Although both incinerator emissions and road traffic may plausibly explain some of the excess risks observed, several alternative explanations, including exposure misclassification, ascertainment bias, and residual confounding cannot be excluded. Some of the effects observed, if real, might be attributable to old-technology MSWIs and the persistent pollution they have generated."*

**Kim *et al* (2004)** presents a study of the effects of PAHs and dioxins on mRNA and plasma protein expression. The authors report that the concentration of carcinogenic PAHs in waste incineration work sites was 10 times higher than those levels found in the automobile emission inspection offices. The DNA damage analysis showed a significant difference between incineration workers, automobile emission inspection officers and control subjects.

**Tango *et al* (2004)** reported on the risk of adverse reproductive outcomes associated with proximity to MSWI that exhibit high dioxin emissions. The authors conclude:

> *"Our study shows a peak-decline in risk with distance from the municipal solid waste incinerators for infant deaths and infant deaths with all congenital malformations combined. However, due to the lack of detailed exposure information to dioxins around the incinerators, the observed trend in risk should be interpreted cautiously and there is a need for further investigation to accumulate good evidence regarding the reproductive health effects of waste incinerator exposure."*

### A1.2.4 Miscellaneous Health Effects Associated with Emissions

**Miyake *et al* (2005)** investigated the relationship between the distance of schools from the nearest municipal waste incineration plant and child health in Japan. The Authors concluded:

> *"The findings suggest that proximity of schools to municipal waste incineration plants may be associated with an increased prevalence of wheeze, headache, stomach ache, and fatigue in Japanese children."*

**Nakayama & Ohkuma (2006)** compared the mental health status of municipal solid waste incinerator workers compared with local government office workers. The authors concluded:

> *"Our results showed that mental health status of health administration workers was less healthy compared with MSWI workers. This meant that the stress of MSWI workers enhanced by the fear that they might have been exposed to dioxin did not exceed the stress the health administration workers usually had suffered from."*

**Table 8: Epidemiological papers on municipal solid waste incineration**

| Country / Reference (Ref No) | No. of Subjects / sampling | Study Measurements | Outcomes |
|---|---|---|---|
| **4.3.1 Cancer Incidence** | | | |
| **UK**<br>Elliott *et al.*, 1996 (25) | 14000000 living near 72 MSWI in the UK | Cancer incidence | Statistically significant decline of risk as residence distance from the MSWI increases ($p < 0.05$). Excess liver cancer risk 0.95 excess cases per 105 per year living between 0 and 1km from the MSWI |
| **Italy**<br>Michelozzi *et al* 1998<br>(49) | 2020<br>Male 1451<br>Female 569 | Cancer Incidence and distance from MSW incinerator | No overall excess or decline in risk with distance found for liver, lung and lympho-haematopoietic cancer in either sex. Laryngeal cancer increased but not significant risk found 0 – 3 km & 3 – 8 km for all cases. Significant decline with distance in mortality of laryngeal cancer for men before adjusting for socioeconomic index ( $P = 0.03$) and similar though not significant trend after adjustment ($P = 0.06$) |
| **France**<br>Viel *et al*., 2000<br>(77) | 913 cases of non-Hodgkin's and soft tissue sarcoma plus 176 cases of Hodgkin's disease | Cancer incidence and distance from MSW incinerator | Soft tissue sarcoma incidence ratio around the incinerator = 1.44 ($p = 0.004$).<br>Non-Hodgkin's lymphoma incidence ratio around the incinerator = 1.27 ($p = 0.00003$)<br>Control cancer Hodgkin's disease showed no special distribution |
| **UK**<br>Elliott *et al*., 2000 (24) | 235 cases | Validation of cancer incidence from a previous study. | Revised excess liver cancer risk between 0.53 and 0.78 cases per 105 per year living within 1 km of the incinerator. |
| **France**<br>Floret *et al*., 2003<br>(28) | 222 cases<br>2220 controls | Non-Hodgkin's lymphoma incidence and distance from MSW incinerator with consideration to dioxin ground-level concentrations | Risk of developing non-Hodgkin's lymphoma was 2.3 times higher (95% confidence interval = 1.4 – 3.8) for individuals living in the area with the highest dioxin concentration. |
| **France**<br>Viel *et al*., 2008<br>(76) | 434 cases<br>2170 controls | Cases of invasive breast cancer in residents living in the vicinity of a MSWI. Dioxin exposure was modelled i.e. not measured directly | Among women younger than 60 years old, no increased or decreased risk was found for any dioxin exposure category. Conversely, women over 60 years old living in the highest exposed zone were 0.31 time less likely (95% confidence interval, 0.08–0.89) to develop invasive breast cancer. |
| **4.3.2 Dioxins and heavy metals in blood** | | | |
| **USA**<br>Bresnitz *et al.*, 1992 (91) | 86 MSWI workers | Heavy metals in blood and urine<br>Forced expiratory volume | No clinically significant mean blood or serum measurements were noted. |

**Table 8: Continued**

| Country / Reference (Ref No) | No. of Subjects / sampling | Study Measurements | Outcomes |
|---|---|---|---|
| **Spain** Schuhmacher *et al*., 1997 (64) | Soil samples in vicinity of municipal waste incinerator | PCDD and PCDF concentrations and congeners relating them to TEQ levels | PCDD/F levels range from 0.30 to 44.26 TEQ/kg (dry matter). Highest and lowest PCDD/F concentrations were found at 750 m and 3000 m from the stack (44.26 ng TEQ/kg and 0.30 ng TEQ/kg respectively) |
| **Spain** Gonzalez *et al*., 2000 (32) | 104 residents within 0.5 – 1.5 km proximity to the incinerator<br>97 residents within 3.5 – 4.0 km proximity to the incinerator<br>17 workers in the MSW incinerator | Blood– testing for dioxins PCB, lead, cadmium. In urine testing for Hg + Cr | Dioxin and PCB levels in blood increased over two years after the incinerator was brought online 25% and 12% for both the respectively. Blood lead decreased, no difference for Cadmium, mercury or chromium. Minimal changes exhibited among workers. |
| **Belgium** Staessen et al., 2001 (72) | 200 17 year old residents | Biomarkers in blood and urine | For biomarkers of exposure the Wilrijk study group showed significant levels of lead and PCBs in blood samples and significant for toluene and benzene biomarkers in urine. The Hoboken study group showed significant levels of lead and cadmium and dioxins in blood but no significant levels in urine. For biomarkers of effect the Wilrijk study group showed significant levels of bio-markers showing cytogenetic effects and sexual development in male and female subjects. The Hoboken study group showed significant effects for renal function and testicular volume. |
| **Japan** Kumagai *et al*., 2002 (42) | 20 workers of MSWI<br>20 controls | PCDDs and PCDFs in serum samples | PCDD and PCDF TEQ in dust 0.91, 33 and 11 ng TEQ/g for plants I, II and III respectively. PCDD and PCDF TEQ in serum 22.8 and 16.4 pg TEQ/g lipid for area I, 29.4 and 19.3 pg TEQ/g lipid area II, 22.8 and 24.9 pg TEQ/g lipid for area III. |
| **France** Maître *et al*., 2003 (47) | 29 MSWI workers and 19 controls | Levels of heavy metals in urine | Cadmium plant 1 vs. plant 2 $p<0.005$, plant 1 vs. control $p<0.005$, plant 2 vs. control NS. Chromium plant 1 vs. plant 2 $p<0.001$, plant 1 vs. control $p<0.001$, plant 2 vs. control NS. Nickel plant 1 vs. plant 2 $p<0.001$, plant 1 vs. control $p<0.001$, plant 2 vs. control NS. Arsenic plant 2 vs. control before shift $p<0.001$ after shift $p<0.005$. Manganese plant 2 vs. control NS. |
| **Japan** Takata 2003 (73) | 96 MSWI workers | Survey and blood dioxin level to determine health effects of dioxin exposure | Blood dioxin levels ranged from 13.4 to 805.8 pgI-TEQ/g-fat. Exposure to dioxin and levels in blood showed 34.2, 66.8, 93.3 and 323.3 pgI-TEQ/g-fat for groups I to IV respectively. |

**Table 8: Continued**

| Country / Reference (Ref No) | No. of Subjects / sampling | Study Measurements | Outcomes |
|---|---|---|---|
| **Taiwan** Hu *et al*., 2004 (35) | 133 male workers of MSWI | Dioxin/Furan exposure association with liver function and blood lipid | Average total cholesterol 13.5 mg/dl higher in high-exposure workers (dioxin/furan blood levels 15.4–59.0pg TEQ/g lipid) compared to low-exposure workers (dioxin/furan blood levels 5.5-15.3pg TEQ/g lipid) |
| **Spain** Meneses *et al*., 2004 (48) | Air, herbage and soil samples were taken from 24 sample sites | Health risk of dioxin and furan emissions from a MSWI | Cancer risk of MSWI before and after air cleaning system installed was 1.07E-07 and 3.08E-09 respectively. Cancer risks from other PCDD/F sources for similar sample years in the area were 5.54E-06 and 1.86E-06 respectively. Total PCDD/F cancer risk (including diet) for residents in the vicinity of the MSWI before and after air cleaning was installed were 1.3E-04 and 4.25E-05 respectively. |
| **Belgium** Raemdonck *et al*., 2006 (56) | 4 workers in a MSWI | Dioxin levels in blood | Worker's serum TEQ for dioxin before the first cleaning was 17.2 pg CALUX TEQ/g fat (range=12-22). After first cleaning TEQ was 28.5 pg CALUX TEQ/g fat (range=18-31). The TEQs before and after the second cleaning followed a similar pattern (15.4 pg CALUX TEQ/g fat and 16.4 pg CALUX TEQ/g fat respectively). |
| **Italy** Lonati *et al*., 2007 (46) | Emissions data sets for older and modern MSWI in Italy | Dioxin concentration in emissions | The TEQs reported for newer plants using BAT were considerably lower than those for older plants (geometric mean values 4.7 pg **I**-TEQ $m_n^{-3}$ and 2 ng **I**-TEQ $m_n^{-3}$ respectively). Mean individual risk of cancer development from emissions of newer and older MSWI were $6.7x10^{-10}$ and $1.1x10^{-7}$ respectively. |
| **Portugal** Reis *et al*., 2007a (57) | 260 residents living in the vicinity of two MSWI | Heavy metals in blood | Lisbon baseline levels exposed versus control (Lead = NS, Cadmium = NS, Mercury = p<0.001). Lisbon after 1st potential impact of the incinerator (Lead = p<0.001, Cadmium = NS, Mercury = NS). |
| **Portugal** Reis *et al*., 2007b (58) | 479 pregnant women 400 Lisbon, 79 Madeira | Monitoring Lead in maternal and umbilical cord blood. Comparing baseline and time periods when incinerator operational. | In Lisbon a significant decrease in Lead concentrations in maternal (p<0.001) and umbilical cord blood (p<0.001) over the whole monitoring period. No statistical associations were found for Lead levels in blood and age at either site. |
| **Portugal** Reis *et al*., 2007c (59) | 497 children, 250 Lisbon, 249 Madeira | Monitoring of Lead in blood of children less than 6 years of age. | Time trends of Lead exposure in blood do not show any clear pattern. Only about 3% of children from the whole group had blood Lead levels of ≥ 10 μg/dl, which warrants further investigation. |
| **UK** Wiliams *et al.*, 1992 (78) | 1,605 births at risk area 1,972 births in comparison area | Sex ratios | Only one area showed significantly low sex ratios in both analysis periods 1981-1983 and 1975-1979 (1975-1979 – male 245, female 274, sex ratio 89, Z statistic 2.1636 (p<0.05)) (1981-1983 - Male 240, female 266, sex ratio 90, Z statistic 2.0370 (p<0.05)) |

**Table 8: Continued**

| Country / Reference (Ref No) | No. of Subjects / sampling | Study Measurements | Outcomes |
|---|---|---|---|
| **4.3.3 Reproductive and genetic disorders** | | | |
| **UK** Cresswell *et al.,* 2003 (19) | 81,255 live births of which 1,508 cases of congenital anomalies | Prevalence of congenital anomalies around a MSWI | No significant overall association with proximity to the MSWI at birth and number of congenital anomalies. Possible increase of risk in the later years of the study. |
| **Korea** Kim *et al.,* 2004 (40) | 31 MSWI workers, 54 automobile emission officers, 84 controls | Comet assay of blood | Significant difference in Olive tail moments in mononuclear cells was observed between exposed and control subjects (P < 0.0001). |
| **France** Cordier et al., 2004 (12) | 94239 exposed individuals from communities<br>470369 not exposed | Assessment of the effects of MSWI emissions on birth defects of surrounding communities of a MSWI | Rate of congenital anomalies was not different between exposed and unexposed communities. For some anomalies, specifically facial clefts and renal dysplasia were more frequent in the exposed communities. Road traffic identified as a serious confounder and may be a significant contributor to the occurrence of some anomalies. |
| **4.4.5 Miscellaneous health effects associated with emissions** | | | |
| **Japan** Tango *et al*., 2004 (74) | 229437 study population, 225,215 live births, 3,387 foetal deaths, and 835 infant deaths | Adverse reproductive outcomes associated with proximity to MSWI with high dioxin emissions | Peak decline of risk with distance away from the incinerator for infant deaths and infant deaths with all congenital malformations combined. |
| **Japan** Miyake *et al*., 2005 (50) | 450,807children 6–12 years | Distance of schools from municipal waste<br>incineration plants and the prevalence of allergic disorders and general symptoms in Japanese children | The closer a school was to a MSWI the prevalence of the following increased wheeze, headache, stomach ache, and fatigue (adjusted odds ratios [95% confidence intervals] for<br>shortest vs. longest distance categories =1.08 [1.01–1.15], 1.05 [1.00–1.11], 1.06 [1.01–1.11], and 1.12<br>[1.08–1.17], respectively). Fatigue showed a positive association in schools within 4 km of the second nearest municipal waste incineration plant.<br>There was no evidence between the distance of schools from a MSWI and the prevalence of atopic dermatitis or allergic rhinitis. |
| **Japan** Nakayama & Ohkuma 2006 (51) | 20 office workers, 55 MSWI workers | Metal health status compared between the two groups | Mental health status of the office workers was found to be worse than for the MSWI workers. Even taking into account the stress of being potentially exposed to dioxins for the MSWI workers. |

## A1.3 Hazardous Waste Incineration

### A1.3.1 Dioxins and Heavy Metals in Blood

In total six studies are summarised in Table 9 and discussed in the text below.

**Sedman & Esparza (1991)** reported on the evaluation of the public health risks associated with semi-volatile metal and dioxin emissions from hazardous waste incinerators. The authors concluded:

> *"The results of 20 trial burns at hazardous waste incinerators were assembled in an attempt to determine which compounds may pose a significant threat to the public health. The risks associated with semi-volatile emissions were found to be inconsequential, although further study of dioxins and dibenzofurans emissions appears to be warranted. The risk associated with the emission of cadmium and perhaps chromium (VI) may pose a significant risk to public health at certain facilities. Controls on waste feed or air pollution control devices should be employed to reduce the emission of these metals. Any monitoring of metal emissions from hazardous waste incinerators should focus on cadmium and chromium (VI)."*

**Kurttio *et al* (1998)** investigated mercury exposure in inhabitants living in the vicinity of a hazardous waste incinerator over a 10 year period. The authors concluded:

> *"In summary, mercury exposure increased as distance from the plant decreased; however, the increase in exposure was minimal and, on the basis of current knowledge, did not pose a health risk."*

**Osius *et al* (1999)** investigated the exposure to polychlorinated biphenyls and levels of thyroid hormones in children in the vicinity of a toxic (hazardous) waste incinerator. The authors conclude:

> *"Blood concentrations and information on questionnaire data were available for 320 children 7-10 years of age. We found a statistically significant positive association between the mono-ortho congener PCB 118 and TSH as well as statistically significant negative relationships of PCBs 138, 153, 180, 183, and 187 to FT3. There was no association for the PCB congeners and FT4. Blood cadmium concentration was associated with increasing TSH and diminishing FT4. Blood lead and urine concentration of mercury were of no importance to thyroid hormone levels."*

**Schuhmacher *et al* (2002)** investigated levels of heavy metals and organic substances in workers of a hazardous waste incinerator. The investigation showed that plasma levels of hexachlorobenzene, polychlorinated biphenyls and poly-chlorinated dibenzo-*p*-dioxins and dibenzofurans along with chlorophenol and 1-

hydroxypyrene levels in urine showed no significant difference between different areas of the workplace or even baseline concentrations. No significant difference was observed for heavy metals between different areas of the workplace.

**Agramunt *et al* (2005)** reported on a study of levels of dioxins and furans in plasma of residents living near a hazardous waste incinerator. The mean PCDD/F concentration in plasma for residents after 3 years was found to be significantly lower than the baseline values (15.70 pg I-TEQ/g lipid and 27.01 pg I-TEQ/g lipid. Reductions were noted for both sexes and all age groups.

**Ferré-Huget *et al* (2006)** reported on an epidemiological survey and risk assessment study of residents living in the vicinity of a hazardous waste incinerator. The air sampling results revealed PCDD/F concentrations of 0.025 ng I-TEQ/$m^3$ which is lower than the quoted 0.1 ng I-TEQ/$m^3$ (European Union Directive limit). There was no significant difference between baseline concentrations in soil and those taken at the end of the four year study 1.59 and 0.77 ng ITEQ/kg dry matter respectively. No difference was found for concentration in soils relating to either distance from the incinerator or wind direction. Herbage levels appeared to increase in samples taken more than 4km away from the incinerator. PCDD/F levels in plasma for potentially exposed areas was shown to decrease from the baseline to the end of the four year study 27.01 pg I-TEQ/g lipid and 15.70 pg I-TEQ/g lipid respectively.

### A1.3.2 Reproductive and Genetic Disorders

**Obi-Osius *et al* (2004)** described the effect of pollution from industrial sources specifically a toxic waste incinerator on the frequency of twins. The environmental study conducted by the authors showed twinning reported as 5.3% in the toxic waste incinerator region compared to 1.6% and 2.3% in comparison regions. Figures derived from analysis of the Hessian Perinatal Study data showed that for areas surrounding the toxic waste incinerator and other industries twinning rates were 1.4 – 1.6 per 100 births compared to 0.8 per 100 births for reference areas.

**Table 9: Epidemiological papers on hazardous (toxic) waste incinerators**

| Country / Reference (Ref No) | No. of Subjects | Study Measurements | Outcomes |
|---|---|---|---|
| **Dioxins and heavy metals in blood** | | | |
| **USA** Sedman & Esparza 1991 (70) | Stack emissions sampling from 20 trial burns | SVOCs, dioxins and furans, heavy metals. | For dioxins / dibenzofurans and SVOCs no significant exposure was determined. For heavy metals cadmium and chromium may pose a cumulative risk to communities surrounding a hazardous waste incinerator. |
| **Finland** Kurttio *et al*., 1998 (43) | 179 workers and residents | Mercury measured in hair and blood samples | Over the 10 year period median mercury levels in hair increased by 0.35 mg/kg for workers, 0.16 mg/kg, 0.13 mg/kg and 0.03 mg/kg for residents living 2km, 2-4km and 5km respectively and 0.02 mg/kg for a reference group comprised of a random sample of 2% of a population of 40,000. |
| **Germany** Osius *et al*., 1999 (55) | 320 children between 7 and 10 years | PCBs, lead, cadmium, mercury in blood and mercury in urine and affect on thyroid hormone. | For PCBs there were varying associations depending on congener (type). PCB 118 showed a significantly positive association with thyroid stimulating hormone (TSH). Significantly negative relationships were found for PCBs 138, 153, 180, 183 and 187 to free triiodothyronine. No association was found for PCBs and free thyroxine ($FT_4$). Of the metals only blood cadmium levels had an association with increasing TSH and diminishing $FT_4$. |
| **Spain** Schuhmacher *et al*., 2002 (63) | 23 workers of the HWI plant | Hexachlorobenzene, PCBs, PCDD/Fs, chlorophenols and heavy metals. | No significant differences could be found for any of the compounds between workplace groups and baseline concentrations. |
| **Spain** Agramunt *et al*., 2005 (1) | 20 subjects | PCDD/Fs in blood samples. | Mean PCDD/F concentration in blood plasma was significantly lower than the concentration found in the baseline study. Reductions were recorded for both sexes and all age groups. |
| **Spain** Ferré-Huguet *et al*., 2006 (27) | 20 residents | PCDD/Fs in blood samples. Also 40 soil and herbage samples taken and analysed for PCDD/Fs. | The PCDD/F levels were monitored before the plant started operating and over 4 years after it became operational. Comparisons of the baseline and subsequent surveys found that the HWI does not cause additional risks to the surrounding populations |
| **Reproductive and genetic disorders** | | | |
| **Germany** Obi-Osius *et al*., 2004 (54) | 1091 school children | Fertility and twinning rates in relation to a TWI | Twinning was recorded at 5.3% in the vicinity of the TWI compared to 1.6% and 2.3% in the comparison regions. Mothers that received fertility treatment was recorded as 5.7% in the vicinity of the TWI and 8.3% and 0% in the reference areas. |

## A1.4 Clinical Waste Incineration

### A1.4.1 Gaseous Emissions, Particulate Matter and Heavy Metals

Three published reports studied incineration of clinical wastes and how the composition of the waste can affect the gaseous emissions. These are summarised in Table 10.

**Alvim-Ferraz & Afonso (2003a)** reported that emission factors are directly affected by the composition of the waste feeding into the incinerator. The levels of four gases ($No_x$, CO, $So_2$ and HCl) in the emissions were monitored through this study. During the study levels of $No_x$ were within legal limits. The levels for CO, $So_2$ and HCl were all over the legal limit for samples taken (11-24 times, 2-5 times and 9-200 times respectively). The addition of fuel to assist the incineration process was reported to contribute significantly to the levels of CO, $No_x$ and $So_2$ by 28, 20 and almost 100% respectively.

**Alvim-Ferraz & Afonso (2003b)** reiterated the findings for gaseous emissions reported in the other paper by the authors (2003a) and reported on metal emissions. It was noted that during the study mercury levels were detected 1.3-226 times those of legal limits. The segregation and consequent reduction of waste entering the incinerator gives rise to significant reductions of emissions. The authors quote a 98% reduction in particulate matter and 99.5% reduction in dioxin emissions. Values quoted for metals were for As, Cd, Cr, Mn, and Ni was 90%, 92%, 84%, 77% and 92% respectively. The authors also suggest that with segregation in place that mercury and lead would be practically eliminated.

**Alvim-Ferraz & Afonso (2005)** reported on the management of atmospheric emissions through waste segregation of incineration of healthcare (clinical) waste. The authors conclude:

> *"It was concluded that: (i) when emission factors are not associated with the type of incinerated mixture, the utility of the emission factors is highly doubtful; (ii) without appropriate equipment to control atmospheric pollution, incineration emissions exceed legal limits, neglecting the protection of human health (the legal limit for pollutant concentrations could only be met for NOx, all other concentrations were higher than the maximum allowed: dioxins, 93–710 times; Hg, 1.3–226 times; CO, 11–24 times; SO2, 2–5 times; and HCl, 9–200 times); (iii) rigorous segregation methodologies must be used to minimize atmospheric emissions, and incinerate only those wastes that should be incinerated according to the law."*

**Table 10: Epidemiological papers on clinical waste incineration**

| Country / Reference (Ref No) | Study Measurements | Outcomes |
|---|---|---|
| **Gaseous emissions, particle matter and heavy metals** | | |
| **Portugal** Alvim-Ferraz & Afonso 2003a & 2003b (4) + (5) | Emissions of CO, $NO_x$, $SO_2$ and HCl | CO 11-24 times greater than legal limits, $SO_2$ 2-5 times greater than legal limit, HCl 9-200 times greater than legal limit. |
| **Portugal** Alvim-Ferraz & Afonso 2005 (3) | Emissions of CO, $NO_x$, $SO_2$, HCl, dioxins and heavy metals | CO 11-24 times greater than legal limits, $SO_2$ 2-5 times greater than legal limit, HCl 9-200 times greater than legal limit, dioxins 93-710 times legal limit, Hg 1.3-226 times greater than legal limit. |

## A1.5 Industrial Waste Incineration

Two papers associated with industrial waste incineration were identified, and are summarised in Table 11.

### A1.5.1 Cancer Incidence

**Comba *et al* (2007)** investigates the risk of soft tissue sarcomas for residents in the vicinity of an industrial waste incinerator. The study showed soft tissue sarcoma incidence of 8.8 per 100000 for men and 5.6 per 100000 for women. There was also a higher observed risk within 2 km distance from the incinerator (Odds ratio 31.4 95%CI 5.6 to 176.1). Risk rapidly decreased with distance from the incinerator.

### A1.5.2 Dioxins and Heavy Metals in Blood

**Wrbitzky *et al* (1995)** investigated exposure to inorganic and organic substances in workers of an industrial waste incinerator. None of the waste incineration workers showed exposure values greater than threshold limit values for date of publication. Significantly higher levels were found in the waste incinerator workers for toluene when comparing the periphery and office workers (median 1.1 vs. 0.9 vs. 0.6 μg/l respectively).

**Table 11: Epidemiological studies on industrial waste incineration**

| Country / Reference (Ref No) | No. of Subjects | Study Measurements | Outcomes |
|---|---|---|---|
| **Cancer Incidence** | | | |
| **Italy** Comba *et al*., 2007 (10) | 37 cases 171 controls | Soft tissue sarcoma | Odds ratio for residence within 2 km proximity to the incinerator was 31.4% (95% CI 5.6 to 176.1) which was based on 5 cases. Risk decreased rapidly with distance. |
| **Dioxins and heavy metals in blood** | | | |
| **Germany** Wrbitzky *et al*., 1995 (79) | 45 incinerator workers<br>54 periphery workers<br>23 managerial workers | Lead, cadmium, mercury, benzene, toluene, ethyl-benzene and m-xylene in blood. Chromium in erythrocytes. Polychlorinated biphenyls, hexachloro-benzene and pentachloro-phenol in plasma. Arsenic, chromium, nickel, vanadium, chlorophenol and hydro-xypyrene in urine. | There were 3 groups of employees, incineration workers, periphery workers and management. Incineration workers had significantly higher levels of toluene in blood. Lead and cadmium levels in blood along with arsenic, 2, 4-dichloro-phenol and tetrachlorophenols in urine showed differences between at least one other group though the elevations were small. |

**Tabular overview of findings from the primary literature**

The overview of the findings for relevant papers is presented in Table 12.

A summary of health outcomes used in these studies is presented in Table 13.

**Table 12: Summary of key features from primary papers**

| Date | Ref | Incinerator types | | | | | Population studied | Population type | | | Study period | Outcome measures | | | | Process specific results | | | Multiple category results | | | In Review |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | M | I | C | H | U | | O | R | M | | E | B | MB | MT | Y | N | I | Y | N | I | |
| 1995 | 71 | X | | X | X | | CWI = 1185 cases<br>CCo = 1148 controls<br>MWI – 1414 cases<br>MCo = 1208 controls<br>HWI = 880 cases<br>HCo = 1046 controls<br>(Co = control community) | | X | | 1992-1994 | | | X | | | | | | X | | D, F |
| 1995 | 79 | | X | | | | 122 IWI workers (45 exposed, 54 periphery, 23 management) | X | | | N/A | | X | | | | X | | | | | D, G |
| 1996 | 25 | X | | | | | 14,000,000 residents | | X | | 1974-1987 | | | X | | X | | | | | | D, E, G |
| 1998 | 49 | X | | | | | 2020 residents | | X | | 1987-1993 | | | | X | | | X | | | | D, G |
| 1999 | 55 | | | | X | | 320 children 7-10 years | | X | | N/A | | X | | | | | X | | | | G |
| 2000 | 24 | X | | | | | 235 cancer cases | | X | | 1974-1986 | | | X | | | | X | | | | E, G |
| 2000 | 32 | X | | | | | 104 living 0.5-1.5 km; 97 living 3.5-4 km; 17 workers | | | X | 1995-1997 | | X | | | | X | | | | | G |
| 2000 | 41 | X | | X | | | 22,458 cancer deaths | | X | | 1953-1980 | | | | X | | | | | | X | G |

**Incinerator types:** M=Municipal solid waste, I=Industrial waste, C=Clinical waste, H=Hazardous waste, U=Unspecified.

**Population Type:** O=Occupational, R=Residential, M=Mixed.

**Outcome measures:** E=Environmental monitoring, B=Biological monitoring, MB= Morbidity, MT=Mortality.

**Results:** Y=Yes there is evidence of association with health effects, N=No there is no evidence of association with health effects, I=Inconclusive; the evidence was inconsistent or inconclusive

**In Review:** (These papers have been reviewed by other authors in one or more of 8 scientific reviews. A=ref no 53, B=ref no 31, C=ref no 60, D=ref no 36, E=ref no 61, F=ref no 62, G=ref no 30, H=ref no 13).

**Table 12 continued**

| Date | Ref | Incinerator types | | | | | Population studied | Population type | | | Study period | Outcome measures | | | | Process specific results | | | Multiple category results | | | In Review |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | M | I | C | H | U | | O | R | M | | E | B | MB | MT | Y | N | I | Y | N | I | |
| 2000 | 77 | X | | | | | 913 cases NHL + STS 176 cases HD | | X | | 1980-1995 | | | X | | X | | | | | | – |
| 2002 | 33 | X | | X | X | | 358 residents | | X | | 3 years | | | X | | | | | | X | | – |
| 2002 | 42 | X | | | | | 20 workers; 20 controls | | | X | N/A | | X | | | | | X | | | | – |
| 2002 | 63 | | | | X | | 23 workers | X | | | 1999-2000 | | X | | | | X | | | | | – |
| 2003 | 19 | X | | | | | 1508 residents | | X | | 1985-1999 | | | X | | | | X | | | | – |
| 2003 | 28 | X | | | | | 222 cases; 2220 controls | | X | | 1980-1995 | | | X | | X | | | | | | G |
| 2003 | 47 | X | | | | | 29 workers; 19 controls | | | X | N/A | | X | | | | | X | | | | – |
| 2003 | 45 | X | X | | | | 13 M workers; 16 M residents; 10 I residents | | | X | N/A | | X | | | | | | | | X | – |
| 2003 | 73 | X | | | | | 96 workers | X | | | 1998 + 1999-2002 | | X | | | | X | | | | | – |
| 2004 | 12 | X | | | | | 94,239 exposed 470,369 not exposed | | X | | 1988-1997 | | X | | | | | X | | | | – |

**Incinerator types:** M=Municipal solid waste, I=Industrial waste, C=Clinical waste, H=Hazardous waste, U=Unspecified.

**Population Type:** O=Occupational, R=Residential, M=Mixed.

**Outcome measures:** E=Environmental monitoring, B=Biological monitoring, MB= Morbidity, MT=Mortality.

**Results:** Y=Yes there is evidence of association with health effects, N=No there is no evidence of association with health effects, I=Inconclusive; the evidence was inconsistent or inconclusive

**In Review:** (These papers have been reviewed by other authors in one or more of 8 scientific reviews. A=ref no 53, B=ref no 31, C=ref no 60, D=ref no 36, E=ref no 61, F=ref no 62, G=ref no 30, H=ref no 13).

**Table 12 continued**

| Date | Ref | Incinerator types | | | | | Population studied | Population type | | | Study period | Outcome measures | | | | Process specific results | | | Multiple category results | | | In Review |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | M | I | C | H | U | | O | R | M | | E | B | MB | MT | Y | N | I | Y | N | I | – |
| 2004 | 35 | X | | | | | 133 workers | X | | | N/A | | X | | | | | X | | | | – |
| 2004 | 40 | X | | | | | 31 M workers; 54 car emissions workers; 84 controls | X | | | Short term study 2002 | | | X | | | | X | | | | – |
| 2004 | 54 | | | | X | | 1091 school children | | X | | 1994-1997 | | | X | | | | X | | | | – |
| 2004 | 74 | X | | | | | 229,437 residents | | X | | 1997-1998 | | | X | | | | X | | | | – |
| 2005 | 1 | | | | X | | 20 residents | | X | | 1998-2002 | | X | | | | X | | | | | – |
| 2006 | 27 | | | | X | | 20 residents | | X | | 1999-2003 | X | X | | | | | X | | | | – |
| 2006 | 56 | X | | | | | 4 workers | X | | | Short term study 2004 | | X | | | | | X | | | | – |
| 2007 | 10 | | X | | | | 37 cases; 171 controls | | X | | 1989-1998 | | | X | | X | | | | | | – |
| 2007 | 57 | X | | X | | | 260 residents | | X | | N/A | | X | | | | | X | | | | – |
| 2007 | 58 | X | | X | | | 479 pregnant women | | X | | N/A | | X | | | | | X | | | | – |
| 2007 | 59 | X | | X | | | 497 children under 6 years | | X | | N/A | | X | | | | | X | | | | – |
| 2007 | 80 | X | X | X | | | 172 cases; 405 controls | | X | | 1990-1996 | | | X | | | | | X | | | – |

**Incinerator types:** M=Municipal solid waste, I=Industrial waste, C=Clinical waste, H=Hazardous waste, U=Unspecified.

**Population Type:** O=Occupational, R=Residential, M=Mixed.

**Outcome measures:** E=Environmental monitoring, B=Biological monitoring, MB= Morbidity, MT=Mortality.

**Results:** Y=Yes there is evidence of association with health effects, N=No there is no evidence of association with health effects, I=Inconclusive; the evidence was inconsistent or inconclusive

**In Review:** (These papers have been reviewed by other authors in one or more of 8 scientific reviews. A=ref no 53, B=ref no 31, C=ref no 60, D=ref no 36, E=ref no 61, **F=ref no 62, G=ref no 30, H=ref no 13).**

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**Table 13: Summary of health outcomes considered in primary papers**

| Date | Reference No. | Authors | Country | Cancer | Reproductive | Genetic Congenital | Respiratory | Body Burden |
|---|---|---|---|---|---|---|---|---|
| 1995 | 79 | Wrbitzky *et al*., | Germany | | | | | X |
| 1995 | 71 | Shy *et al*. | USA | | | | X | |
| 1996 | 25 | Elliott *et al*., | UK | X | | | | |
| 1998 | 49 | Michelozzi *et al* | Italy | X | | | | |
| 1999 | 55 | Osius *et al*., | Germany | | | | | X |
| 2000 | 24 | Elliott *et al*., | UK | X | | | | |
| 2000 | 41 | Knox | UK | X | | | | |
| 2000 | 32 | Gonzalez *et al*., | Spain | | | | | X |
| 2000 | 77 | Viel *et al*., | France | X | | | | |
| 2002 | 33 | Hazucha *et al.* | USA | | | | X | |
| 2002 | 42 | Kumagai *et al*., | Japan | | | | | X |
| 2002 | 63 | Schuhmacher *et al*. | Spain | | | | | X |
| 2003 | 19 | Cresswell *et al*. | UK | | | X | | |
| 2003 | 28 | Floret *et al*., | France | X | | | | |
| 2003 | 45 | Leem *et al.* | Korea | | | | | X |
| | | | **Table Total** | **6** | **0** | **1** | **2** | **6** |

**Table 13 continued**

| Date | Reference No. | Authors | Country | Cancer | Reproductive | Genetic Congenital | Respiratory | Body Burden |
|---|---|---|---|---|---|---|---|---|
| 2003 | 47 | Maître *et al.*, | France | | | | | X |
| 2003 | 73 | Takata | Japan | | | | | X |
| 2004 | 12 | Cordier *et al.*, | France | | | X | | |
| 2004 | 35 | Hu *et al.*, | Taiwan | | | | | X |
| 2004 | 40 | Kim *et al.*, | Korea | | | X | | |
| 2004 | 54 | Obi-Osius *et al.*, | Germany | | X | | | |
| 2004 | 74 | Tango *et al.*, | Japan | | X | | | |
| 2005 | 1 | Agramunt *et al.*, | Spain | | | | | X |
| 2006 | 27 | Ferré-Huguet *et al.*, | Spain | | | | | X |
| 2006 | 56 | Raemdonck *et al.*, | Belgium | | | | | X |
| 2007 | 10 | Comba *et al.*, | Italy | X | | | | |
| 2007a | 57 | Reis *et al.*, | Portugal | | | | | X |
| 2007b | 58 | Reis *et al.*, | Portugal | | | | | X |
| 2007c | 59 | Reis *et al.*, | Portugal | | | | | X |
| 2007 | 80 | Zambon *et al.* | Italy | X | | | | |
| | | | **Table Total** | **2** | **2** | **2** | **0** | **9** |
| | | | **FINAL TOTAL** | **8** | **2** | **3** | **2** | **15** |

## APPENDIX 2 METHODOLOGICAL WEAKNESSES IN THE PUBLISHED LITERATURE ON INCINERATION AND HEALTH

The following are the main categories of methodological problem associated with this body of research.

i. Inadequate definitions of research questions and study parameters.

ii. Non-uniformity of subject matter and failure to use recognised epidemiological and toxicological paradigms (e.g. agent/host/environment and source/pathway/exposure models).

iii. Inadequate data on emissions and actual exposures; uncertainty as to its accuracy, representativeness and biological significance.

iv. Incomplete scientific knowledge base, particularly the toxicology of chemicals and mixtures at low exposure levels.

v. Use of limited and unreliable data on health status, including morbidity measures and mortality.

vi. Limitations of study designs used to detect correctly those associations that do or do not exist (Type 1 and Type 11 errors).

vii. Limitations of data analysis, interpretation and statistical inference techniques.

viii. Over-interpretation of apparent associations between illness and incinerators due to failure to consider recognised criteria of causality and the relative magnitude of detected effects.

ix. Over-attribution of detected effects to *'incineration'* due to inadequate control for multi-factorial risk factors, including the contribution to total pollutant exposures from other sources of environmental contaminants in any locality.

x. Failure to consider incinerator emissions as part of an inclusive *'health impact assessment model'* and failure to consider pollutants from a *'life-cycle'* concept of waste management.

i. **Inadequate definitions of research questions and study parameters**

The *'question'* if described in published work, is rarely framed as a clearly stated hypothesis. The objectives of many studies are ill defined and appear to rely on an implicit view that incinerators may be linked to the health status of people, without specifying what the agents (chemical or other) of interest are, what the relevant mechanisms of exposure is or what the pathological processes thought to be involved is. The time periods studied sometimes appear to be influenced by the availability of data rather than by a need to ensure consistency in potential exposures or population attributes. Study populations sometimes appear to have been selected by the availability of data rather than a need to ensure sufficient numbers for reliable detection of a pre-determined effect size. The study methods have therefore often appeared to lack rigour, thereby limiting the robustness of their conclusions.

ii. **Non-uniformity of subject matter and failure to use recognised epidemiological and toxicological paradigms (e.g. agent /host /environment and source /pathway /exposure models)**

***Agent /Host /Environment Model***

*Agents*

The agents (if actually described) range from individual chemicals to mixtures of pollutants (e.g. dioxins and related chemicals). Studies sometimes consider the gaseous products emissions and particulate matter (e.g. $PM_{10}$ or $PM_{2.5}$, ultrafine particles) but rarely include the solid outputs (bottom and fly ash) or waste water emissions in their analyses.

Very few studies consider the pollutants and toxic emissions in the context of the total daily exposure of the study populations from these agents and from all sources including incineration emissions. The relative importance of the airborne emission fraction is rarely considered in the health risk assessment; e.g. dioxin exposure occurs mainly via ingestion from foods.

*Host*

Host factors among the study population are often poorly described. Relative sensitivities of individuals within the study population may alter the probability of a health effect occurring. Differences between risk factors (e.g. age, sex, occupation, life-style, smoking history, diet and general health status) may act as confounding variables. Some studies deliberately restrict the subjects using age or occupation to try to overcome such problems. However, populations are often treated as having a uniform risk by simply living near an incinerator. Studies often rely on past home addresses over varying time periods to estimate potential exposure; effectively treating geographic locations as the *'hosts'*, rather than individuals. Proximity is often crudely defined using simple concentric circles around an incinerator site. This method assumes that equidistant locations are at equal risk of exposure to contaminants ignoring the influence of individual *'host'* factors in determining the variation in opportunity for actual exposure.

*Environment*

Environmental factors may influence the dispersion of emissions from incinerator stacks; e.g. ambient temperature, prevailing wind direction and strength, precipitation, altitude and weather events such as temperature inversions may all affect dispersal of airborne contamination. Local geography and topography may also create additional variation. Studies have been conducted in various countries with widely differing environmental conditions. Studies rarely considered such issues or allowed for them in risk-estimate calculations. The emissions from incinerators studied are rarely considered in relation to the background environmental levels of similar agents and pollutants; e.g. industrial or traffic sourced pollution.

***Source /Pathway /Exposure Model***

*Sources*

The types of incinerator (sources) studied vary. Papers rarely describe the inputs, process technology and outputs in any depth. A range of terminology is used to describe the waste streams providing the input including *'controlled'* waste. More detailed descriptions used include: municipal, urban, industrial, hazardous, medical, biomedical, toxic and mixed waste, usually without reference to standard definitions. Some studies investigated single process types (e.g. MSW); others investigated a mixture of incinerator types analysed together. These, and variations in *inputs*, *process technology* and *outputs* make comparison of studies problematic.

### Inputs

The raw materials for thermal treatment may vary considerably; from routine domestic type waste, generated by households, to hazardous waste by products from industrial, commercial and agricultural processes. There is no uniformity in the inputs and potentially considerable variability in the mixtures of materials submitted as inputs. These will inevitable affect the potential for generating emissions and the composition of these emissions; hence not all incinerators (even those processing the same nominal waste stream) are the same in terms of their potential hazardous emissions.

### Process Technology

The basis of thermal treatment of waste is the use of high temperature combustion of materials to destroy potentially toxic compounds and reduce the bulk of residual waste. The overall objective is to produce a more limited quantity of ash while minimising the potential for hazardous by-products in the form of emissions via air and water.

Considerable changes in process technologies have occurred over time with progressively increasing emphasis on improving the efficiency of thermal treatment processes, to reduce the toxicity of the end products particularly the gaseous emissions but also the nature of the solids produced. There has a progressive shift to improve process technology with more stringent process regulation by government bodies which has in general resulted in cleaner processes. However variations may still occur in operational control efficiency, hence not all incinerators can be considered as being equally effective in terms of their process control and therefore their potential for hazardous emissions. Also processes are not equally effective over the entire process cycle with potential for increased emissions at start up and shut down phases.

### Outputs

The end products of thermal treatment vary depending on the inputs and the efficiency of the process. There is therefore considerable scope for variation in the nature and toxicity of the end products, even if the process is being operated within regulatory parameters.

Hence, there is scope for variation at all stages of the thermal treatment process and consequently any study considering the potential association between a particular incinerator and health effects in the surrounding community should be generalised with caution.

Other significant variation is due to differences over time in the regulation of waste inputs, incineration process efficiency and emissions standards in different countries. These all add to the variation in exposures to incinerator emissions that is not usually controlled for in study analyses. In the UK the most recent changes in the regulation of incinerator emissions (Council of the European Union 2000) have had a significant impact on the type of thermal treatment technology in use and the resulting mass of material emitted to air. However, rather than eliminating them completely, some emission control improvements have transferred certain pollutants to other parts of the residual waste stream, which are generally less well investigated; e.g. dioxin abatement of exhaust gasses can result in dioxins being concentrated in the fly ash. Given these inconsistencies and variations in the sources studied, it is difficult to make meaningful comparisons between many studies.

*Pathways*

The pathways of exposure to emissions (airborne, food borne, waterborne, physical contact, radiation) are often restricted in studies to one category (usually airborne, rarely food or waterborne) or are poorly defined. Geographic *'proximity'* may be the only measure of *'exposure'* used, with no consideration of a plausible pathway. Given that ecological-type studies provide amongst the weakest type of evidence of association, of any epidemiological method, the reliance on geographic proximity in many studies is a major weakness in the evidence base.

The *'receptors'* (people at risk of exposure) in the source/pathway/receptor model are analogous to the *'hosts'* in the agent/host/environment model. Factors associated with individual variation have already been discussed. Studies are highly variable in their treatment of the receptor populations but generally focus on a mixed age range of adults in a given area, sometimes including or excluding people who might be expected to have very different levels of exposure to toxic pollutants; e.g. those who worked at an incinerator or other local industries. Studies rarely allow for the range of variation in exposure to be expected within groups in different countries and population sub-groups, particularly in terms of their physical likelihood of exposure via defined pathways such as inhalation. People who spend more time in a locality during working hours (mothers and young children, the elderly and infirm) are at relatively increased risk of airborne exposure compared to school children or the working population (who potentially spend daytime elsewhere) yet this is rarely considered as a factor determining variation in exposure. Similarly, variation in risk associated with time spent indoors versus outdoors is not usually discussed.

**iii. Inadequate data on emissions and actual exposures and uncertainty as to its accuracy, representativeness and biological significance**

***Emissions***

Studies sometimes attempt to quantify the composition and levels of incinerator emissions using actual measurement data. Where actual emissions are studied, data are likely to be very limited and likely to only affect a partial inventory of the total emissions possible from any given incinerator. More often emissions are estimated using historical assumptions on outputs and knowledge of the thermal process efficiency. Some studies use modelling techniques to estimate emission levels at precise geographic locations down to individual home addresses, or use aggregated locations to generate zones with a range of likely pollutant levels to enable comparison between high and low emission areas.

***Exposures***

Studies often appear to rely on supposition about the nature and quantity of emissions; occasionally use actual data on emissions and very occasionally use a combination of modelling and validated data to assess the quantities of pollutant agents involved. Very few studies actually use objective measures to verify the estimates of exposure experienced by the target (host) populations. These limitations generate doubts regarding the accuracy of *'exposure'* and highlight the potential for error in classifying subjects as exposed or not. Geographic (ecological studies) often have no evidence of efforts to estimate exposure but rely instead on distance from the *'source'* as a proxy for exposure.

Some studies address exposure measurement by indirect measures (e.g. using emission data from selected incinerators). Others use measurement of blood or body tissue burden of selected chemicals (e.g. dioxins) in a sample of individuals as indicators of exposure. Other studies use biochemical or physiological parameters as bio-markers or proxies of exposure (e.g. liver enzyme activity). Inconsistency in the methods used makes meaningful comparison of these measurements problematic.

Ideally exposure assessment should determine the relationship between exposure levels and the physiologically active dose of the chemical received. Such detailed study is very rarely undertaken in the TTW subject area. In most studies exposure assessment, if attempted at all, is conducted at a relatively crude level.

***Biological Significance of Exposures***

Few studies consider detailed issues of variation in absorbed dose and bioavailability, as factors influencing the risk estimation. Studies often rely on relatively simplistic models of dose absorption, bioavailability, dispersion and metabolism in humans. In vitro studies and animal toxicology data have sometimes been used to estimate variation.

### iv. Incomplete scientific knowledge base, particularly the toxicology of chemicals and mixtures at low exposure levels

Knowledge on the toxicology of incinerator emissions has improved in recent years. Some incinerator combustion products (e.g. $PM_{10}$, $PM_{2.5}$, ultra fine particles and gaseous emissions; $NO_x$, $SO_2$), have been extensively studied in relation to external air quality and their effects on health. There is increasing evidence on the adverse effects on respiratory and cardiovascular health associated with exposure to combustion products, ozone and certain hydrocarbons, such as benzene, benzo-a-pyrene and other organic chemicals including dioxins and analogues. The significance of traffic related combustion emissions and their effects are becoming clearer. Such work has been used to extrapolate the likely effects of emissions associated with incinerators. However, the toxicology of relevant chemicals and combustion products at the low levels normally associated with thermal treatment plants is less complete. There is often a reliance on data from studies of relatively highly exposed workers. Compared to thermal waste treatment plants, traffic emissions are likely to have been relatively important sources of pollutant exposure even in the past, yet these are rarely allowed for as confounding factors in incineration studies.

The toxicology of the complex chemical mixtures likely to be emitted from incinerators is poorly understood. Similarly epidemiological data covering this aspect is very limited.

**v. Use of limited and unreliable data on health status, including morbidity measures and mortality**

Studies have considered a wide range of health effect end-points. There is little consistency in how these are defined in terms of the specificity and range of health outcomes. Effects studied range from measurement of physical functions associated with health impairment (e.g. lung function tests, FEV-1 etc.) to routinely collected morbidity and mortality data. The range of end-points has been wide, including data on specific cancers (e.g. soft tissue sarcoma), cancer groups (e.g. leukaemias), all cancers, other disease categories using ICD codes, birth outcomes (including birth weight, infant deaths, stillbirths), congenital anomalies and (very) occasionally measures of psychological or mental illness. The variation in the outcomes used and lack of standardised approaches to data quality assurance makes comparisons between studies difficult. There are particular problems when rare health outcomes are studied, due to the difficulty of interpreting variation in small numbers of cases and the risks of false identification of clusters due to random variation. There are also problems in relation to the long latency of some health outcomes, especially cancers and chronic diseases, which may make detection and attribution of any association to a hazardous environmental exposure particularly difficult.

Health outcomes have generally focussed on objective measurable end-points, rather than more subjective (but difficult to measure accurately) assessments of self reported or perceived health status. These other measures might be considered relevant depending on views on how widely defined *‘health’* status should be. Broader definitions of health, incorporating measures of *‘well being’*, might be considered appropriate given the likely contribution of psychological factors in determining health status, especially in locations perceived to have poor environmental quality by the residents. This issue is very rarely considered or discussed in the studies on incinerators.

### vi. The ability of study designs to detect correctly those effects that do or do not exist (Type 1 and Type 11 errors)

A wide range of epidemiological study types have been used including descriptive and analytical methods. Ecological (or geographic studies), relying on detecting association by location, are particularly popular but problematic due to their inherent weakness. Variants of cross sectional, case-control and cohort methods have been used though it is not always immediately obvious what category of study applies. The size of the populations studied ranges from very small numbers to millions, making comparisons difficult. Large scale prospective cohort studies, of the type that has provided definitive epidemiological data in other areas (e.g. smoking and lung cancer), are notably absent. Such studies are difficult and costly.

The published studies are prone to bias including case and control selection bias, recall bias and misclassification of exposure bias. Due to the limitations of the study designs and the difficulty of acquiring suitable data, potential confounding factors are rarely considered in any depth. The impact of social determinants, including deprivation and poverty, in terms of influencing people's *'choice'* of home location near incinerators, is a major confounding issue rarely discussed. Some studies corrected for such factors and still found positive evidence of associations with ill health. Diet, smoking and other lifestyle related variables are generally poorly corrected for, if at all. Hence, interpretation of positive findings often has to be highly qualified.

The consequence of these limitations is to limit the power of the published studies in terms of classical Type 1 and 11 errors (Last 1995). Studies rarely discuss the limitations of their own methods in relation to their power to detect positive associations. Some studies have involved large populations in an effort to overcome problems associated with small numbers of rare health outcomes. However, formal power calculations are rarely in evidence.

### vii. The limitations of techniques for data analysis, interpretation and statistical inference

The range of risk values determined by different studies, expressed (sometimes incorrectly) as odds ratios or relative risks, is wide as is the range of confidence intervals. The magnitude of increased risk of health effects, when identified as being statistically significant, is usually small, often marginally above unity (1) and rarely greater than 2. The implication being, that the actual impact of such effects at population level is generally likely to be small. Studies generally consider the absolute risk of a health effect but less commonly report measures of attributable risk associated solely with exposure to incinerators.

**viii. Over-interpretation of apparent associations between illness and incinerators due to failure to consider recognised criteria of causality and the relative magnitude of detected effects**

There is a reliance on study methods that cannot provide evidence of *'causality'*. The better epidemiological studies can only provide evidence of *'association'* and often, even this is weak. Taking the body of work as a whole, it performs poorly against standard criteria of causality, such as those attributed to Bradford Hill (1965).

*Consistency* – there is little consistency in the magnitude of increased health risk, even where positive associations have been detected in comparable studies; e.g. those that considered similar health outcomes in comparable populations, exposed under similar circumstances to broadly comparable pollutants.

*Strength of association* – when detected, significant effects are often of low magnitude and often have wide confidence intervals.

*Specificity* – the study methods limit the researchers' ability to detect specificity in terms of a single effect associated with exposure to a single incinerator type, process, or chemical pollutant. This is compounded by the variation in composition of chemical mixtures in incinerator emissions, in turn determined by differences in the inputs, processes and outputs and multiple other factors discussed earlier.

*Temporality* – the published work usually considers exposures which predate the onset of the health effects studied; hence this criterion is normally satisfied. However, the time period considered varies considerably between studies. Some health outcomes studied have long latencies, especially cancers. Studies may not allow an adequate period of exposure making it unlikely that a real effect would be detected; conversely too long a period may mean that any clustering of cases of a rare outcome might be obscured within the overall measured risk.

*Dose response* – efforts have been made in some studies to create a proxy for differing exposure *'dose'* by creating zones of different pollutant emission levels. This may be in the form of simple concentric circles round a plant or more sophisticated exposure level contours based on environmental sampling or modelling work. Where there are positive findings relating to incinerators, the evidence is inconsistent using such proxy measures; e.g. distance from an incinerator plant. Studies are rarely comparable in the size and populations mix. Risk estimates based on proximity to incinerators or proxies for *'dose'* vary considerable between studies. There is therefore little consistency in relation to this criterion.

*Biological plausibility* – much of the published work fails to consider this criterion. A plausible *'source-pathway-receptor'* linkage is not always identified. Even less frequently discussed, is a plausible pathological mechanism to explain how any detected effects might occur. However, there are some positive findings that are considered by reviewers to be consistent with known pathological processes, based on animal toxicological work.

*Experimental evidence* – *'natural'* experiments, where increases in exposures occurred by chance; e.g. incidents such as the Seveso (dioxins) accident involving unplanned exposure to high pollutant levels, provide some evidence in this category. Otherwise there is little data that could be used to satisfy this criterion.

*Analogous explanation* - evidence of adverse health effects attributable to motor vehicle combustion emissions could satisfy this criterion. The growing body of evidence on respiratory and cardiovascular effects associated with traffic emissions suggests a plausible mechanism for a potential association between combustion products from thermal waste treatment and adverse health effects.

**ix. Over-attribution of detected effects to *'incineration'* due to inadequate control for multi-factorial risk factors, including the contribution to total pollutant exposures from other sources of environmental contaminants in any locality**

Many of the health effects studied in relation to incinerators have unknown aetiology, cancers and congenital anomalies being typical of this category. They are likely to have multi-factorial causes and complex inter-relationships between genetic and environmental factors, including exposure to toxic pollutants from many sources. The likelihood that incinerator emissions constitute a major contributor to the other pre-existing risk factors, has to be considered to be low, especially at the very low levels of pollutants now being emitted. The lack of consistency and the low magnitude of effects found, even in studies where exposures have been assessed as relatively high, suggest that any directly attributable effect from incineration is likely to be small compared to all other causal factors. If there was any significant contribution from incinerator activities to the multi-factorial origin of disease conditions, it is likely to have decreased over time as emission control standards have progressively increased.

This assumption regarding the reduction over time in the additional risk attributable to incinerator emissions, must be qualified however on the basis that the total mass of emissions products to air, would have had to reduce, not just that the emissions from each individual incinerator had fallen. Improvements in air quality due to reductions in individual incinerator plant emissions could be cancelled out if the total number of incinerators actually increased over time. There is little discussion of this issue in the existing literature. Proposed increases in the number of incinerators in future may therefore result in an increase in the total mass of pollutants, negating the benefit of improved emission standards.

**x. Failure to consider incinerator emissions as part of an inclusive *'health impact assessment model'* and failure to consider pollutants in form a *'life-cycle'* concept of waste management**

Studies of health outcomes related to incinerator facilities usually focus on the emissions, rather than considering a complete hazard exposure assessment model, incorporating the full *'life-cycle'* of the waste from creation to final incineration. This was commented on for example, in the Royal Society critique of the initial DEFRA (2004) report.

The method of transporting waste to any incinerator affects the total burden of pollutants associated with any individual site; e.g. sites receiving waste by diesel powered transport would have an additional particulate burden. Comprehensive hazard assessment of this type is rarely found in the published literature on incineration. Consideration of only the known incinerator emissions inventory provides only a partial picture of the environmental pollution burden which might be contributing to adverse health outcomes in any locality. Paradoxically, studies that have detected health effects may be detecting impacts attributable to these other sources of environmental pollution, rather than to incinerators. Incinerators may therefore be acting as proxy indicators for other confounding environmental factors. The study methodologies used rarely allow an adequate analysis of such issues.

Full scale *'health impact assessments'* of the type incorporating a comprehensive environmental exposure assessment are probably beyond the scope of most of the published research work in this field. This would therefore a very high standard against which to judge them.

## APPENDIX 3 GLOSSARY

| | |
|---|---|
| BAT | Best Available Techniques |
| DEFRA | Department for Environment Food and Rural Affairs |
| DNA | Deoxyribonucleic Acid |
| HPS | Health Protection Scotland |
| mRNA | Messenger Ribonucleic Acid |
| MSWI | Municipal Solid Waste Incineration |
| PAH | Polycyclic Aromatic Hydrocarbons |
| PCB | Polychlorinated Biphenyls |
| PCDD | Polychlorinated Dibenzo-p-dioxins |
| PCDF | Polychlorinated Dibenzofurans |
| SEPA | Scottish Environment Protection Agency |
| SVOC | Semi-Volatile Organic Compounds |
| TEQ | Toxic Equivalent |
| VOC | Volatile Organic Compounds |

## APPENDIX 4 SEARCH TERMS USED IN THE SEARCH STRATEGY

| Reference Number | Search term | Number of papers |
|---|---|---|
| 1 | waste incineration | 893 |
| 2 | thermal treatment | 2851 |
| 3 | waste to energy | 213 |
| 4 | human health | 26082 |
| 5 | health complaints | 2891 |
| 6 | Pollution | 135845 |
| 7 | Emissions | 35975 |
| 8 | ischemic heart disease | 64376 |
| 9 | Cancer | 1629953 |
| 10 | Respiratory | 686938 |
| 11 | Pyrolysis | 4835 |
| 12 | Gasification | 648 |
| 13 | plasma gasification | 6 |
| 14 | 1 and 4 | 55 |
| 15 | 1 and 6 | 338 |
| 16 | bottom ash | 507 |
| 17 | 1 and 4 and 16 | 2 |
| 18 | 1 and 6 and 16 | 25 |
| 19 | 1 and 8 | 5 |
| 20 | 1 and 9 | 72 |
| 21 | 1 and 5 | 0 |
| 22 | Morbidity | 492188 |
| 23 | 1 and 22 | 20 |
| 24 | 1 and 22 | 20 |
| 25 | 1 and 7 and 10 | 21 |
| 26 | 2 and 4 | 15 |
| 27 | 2 and 5 | 0 |
| 28 | 2 and 6 | 94 |
| 29 | 2 and 7 | 43 |
| 30 | 2 and 8 | 1 |
| 31 | 2 and 9 | 116 |
| 32 | 2 and 4 and 16 | 0 |
| 33 | 2 and 9 and 16 | 0 |
| 34 | 2 and 16 and 22 | 0 |
| 35 | 1 and 22 | 20 |
| 36 | 2 and 22 | 78 |
| 37 | 3 and 4 | 1 |
| 38 | 3 and 6 | 32 |
| 39 | 3 and 7 | 32 |
| 40 | 3 and 8 | 0 |
| 41 | 3 and 9 | 26 |
| 42 | 3 and 10 | 16 |
| 43 | 3 and 16 | 4 |
| 44 | 4 and 28 | 4 |
| 45 | 5 and 28 | 0 |

## APPENDIX 5 DIOXIN TOXIC EQUIVALENCY FACTORS

Dioxin and Furan are the common names associated with polychlorinated dibenzo-p-dioxins (PCDD) and polychlorinated dibenzofurans (PCDF). These compounds can be created as unintended by products of combustion. Toxic Equivalency Factors (TEF) are a measure of how toxic a substance is where a value of 1 is the most toxic.

| Compound | WHO 1998 TEF | WHO 2005 TEF* |
|---|---|---|
| **chlorinated dibenzo-p-dioxins** | | |
| 2,3,7,8-TCDD | 1 | 1 |
| 1,2,3,7,8-PeCDD | 1 | 1 |
| 1,2,3,4,7,8-HxCDD | 0.1 | 0.1 |
| 1,2,3,6,7,8-HxCDD | 0.1 | 0.1 |
| 1,2,3,7,8,9-HxCDD | 0.1 | 0.1 |
| 1,2,3,4,6,7,8-HpCDD | 0.01 | 0.01 |
| OCDD | 0.0001 | **0.0003** |
| **chlorinated dibenzofurans** | | |
| 2,3,7,8-TCDF | 0.1 | 0.1 |
| 1,2,3,7,8-PeCDF | 0.05 | **0.03** |
| 2,3,4,7,8-PeCDF | 0.5 | **0.3** |
| 1,2,3,4,7,8-HxCDF | 0.1 | 0.1 |
| 1,2,3,6,7,8-HxCDF | 0.1 | 0.1 |
| 1,2,3,7,8,9-HxCDF | 0.1 | 0.1 |
| 2,3,4,6,7,8-HxCDF | 0.1 | 0.1 |
| 1,2,3,4,6,7,8-HpCDF | 0.01 | 0.01 |
| 1,2,3,4,7,8,9-HpCDF | 0.01 | 0.01 |
| OCDF | 0.0001 | **0.0003** |
| | | |

Numbers in bold indicate a change in TEF value.

([Online], Available: http://www.who.int/ipcs/assessment/tef_update/en/index.html [accessed October 2009])

# APPENDIX 6 CRITERIA FOR ASSESSING THE STRENGTH OF EVIDENCE FOR ASSOCIATION

In their review of evidence relating to the human health impact of waste management practices, Saffron *et al* (2003) made judgements on the strength of evidence base relating to different waste management methods by considering a number of criteria as outlined below.

1. Have studies been done on human populations?
2. Have hazards been identified?
   Does the appearance of the hazard precede the health outcome?
   Is the association biologically plausible?
   Are there data on exposure?
3. Are there any hypothesis-testing studies?
4. Have any of the hypothesis-testing studies controlled for possible confounding factors?
5. Are there more than 20 hypothesis-testing studies consistently showing strong or moderate relative risks?

In their assessment of the strength of reported relative risks, the following criteria were applied by Saffron:

***"Strong"***

A strong association is when the RR > 2 or RR < 0.5 and is statistically significant.

***"Moderately Strong"***

A moderately strong association is when the RR > 2 or RR < 0.5 and is not statistically significant OR

RR is of 1.5 – 2.0 or between 0.5 – 0.75 and is statistically significant.

***"Weak"***

A weak association is when the RR is between 1.5 - 2.0 or between 0.5 – 0.75 and is not statistically significant

***"No Association"***

No association is considered when the RR is between 0.75 and 1.5, whether or not statistically significant.

These criteria were applied by the Saffron *et al*, to the body of literature as a whole, to decide if the evidence was sufficient or insufficient to establish a causal relationship between incineration and adverse health outcomes. For this report, some modification of the evidence assessment questions was needed to enable their use in individual appraisal of the 8 newer studies.

**Modified Saffron Appraisal Criteria**

The following modified Saffron assessment questions were used for this report:

1. Has the study been carried out on a human population?

2. Have hazards been identified?

   Does the appearance of the hazard precede the health outcome?

   Is the association biologically plausible?

   Are there data on exposure?

3. Does the study test a specific hypothesis?

4. Has the study controlled for possible confounding factors?

5. Does the study report strong or moderate relative risks?

## APPENDIX 7 CRITERIA FOR GRADING STRENGTH OF EVIDENCE

The Scottish Intercollegiate Guidelines Network (SIGN) have produced a number of recommendations for grading the quality of evidence, which have been applied to a number of peer-reviewed publications in Section 4 of this report (SIGN, 2008).

The following summarises the grading system recommended by SIGN, and reflects the gradings used within Section 4 (and summarised in Table 4A) of this report.

| Evidence Rating | SIGN Definition (SIGN, 2008) |
|---|---|
| **1 + +** | High quality meta-analyses, systematic reviews of RCTs*, or RCTs with a very low risk of bias. |
| **1 +** | Well conducted meta-analyses, systematic reviews, or RCTs with a low risk of bias. |
| **1 -** | Meta-analyses, systematic reviews, or RCTs with a high risk of bias. |
| **2 + +** | High quality systematic reviews of case control or cohort studies.<br>High quality case control or cohort studies with a very low risk of confounding or bias and a high probability that the relationship is causal. |
| **2 +** | Well conducted case control or cohort studies with a low risk of confounding or bias and a moderate probability that the relationship is causal. |
| **2 -** | Case control or cohort studies with a high risk of confounding or bias and a significant risk that the relationship is not casual. |
| **3** | Non-analytic studies, e.g. case reports, case series. |
| **4** | Expert opinion. |

*Randomised Controlled Trials (RCTs)

Health Protection Scotland

SEPA Scottish Environment Protection Agency

NHS National Services Scotland

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2009