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Health and Environmental Effects of Landfilling and Incineration of Waste - A Literature Review

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Health and Environmental Effects of Landfilling and Incineration of Waste

– A Literature Review

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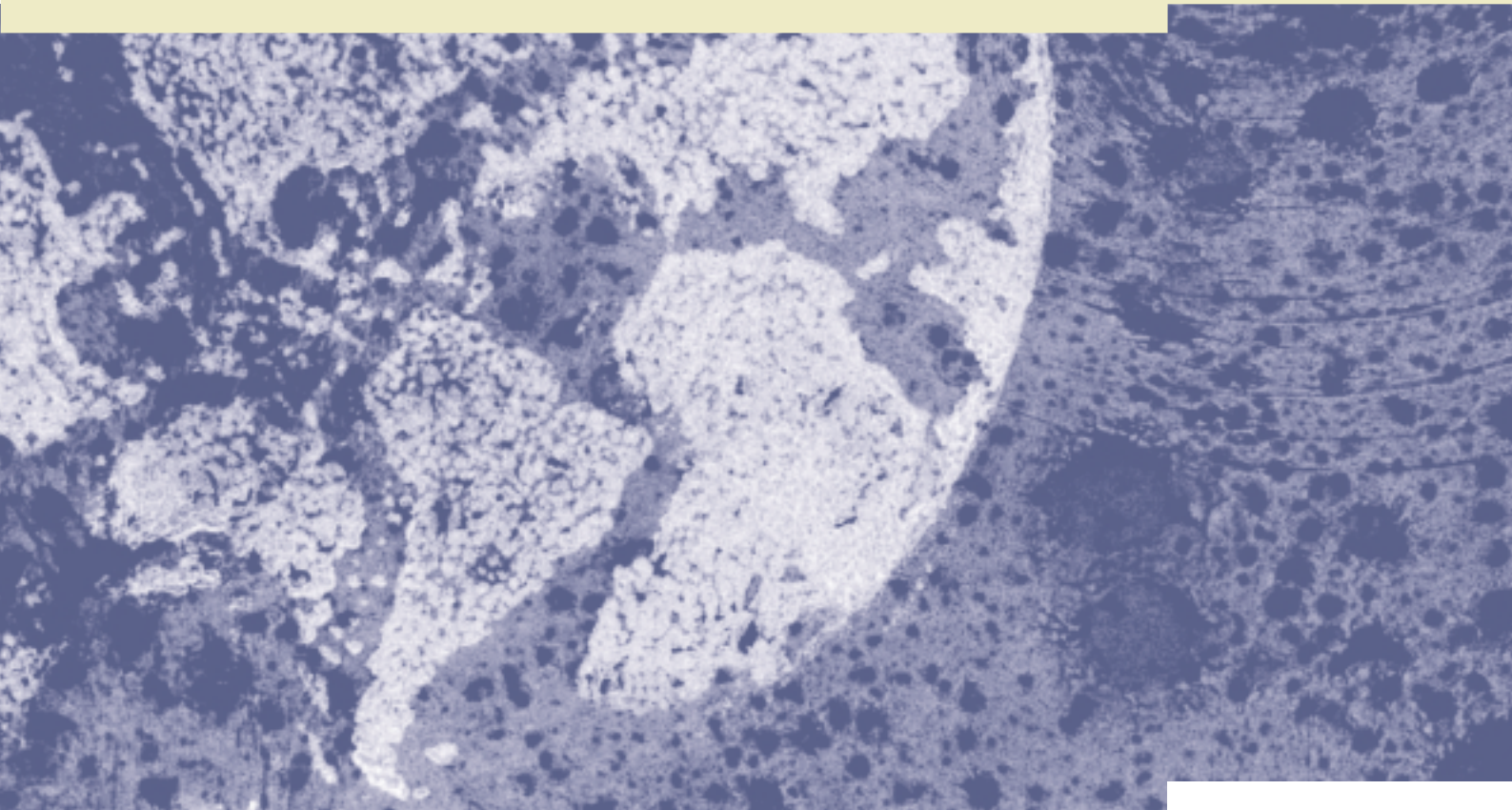
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Executive Summary



Executive Summary

This report was commissioned by the Health Research Board, at the request of the Department of the Environment and Local Government. It aims to inform policy makers of (a) the technical aspects of both landfill and incineration practices in Ireland and (b) the adverse effects that these practices may have on the environment and human health. Specifically, this report reviews the national and international literature on risk assessment and the effects of landfill and incineration of waste on humans and the environment, and reviews current practice and recent developments in landfill and incineration technologies.

It is not within the scope of this report to make recommendations on waste management policy. Rather, this report is intended to serve as a resource for people with such interests.

Although waste management strategies are not addressed in this report, the authors acknowledge that an integrated systems approach is required if effective waste management is to be accomplished at both local and national levels. This approach should reflect the waste management hierarchy of prevention, substitution, reuse and recycling, and energy recovery, with environmentally secure disposal of any residual waste (Forfás 2001).

Irish waste – the scale of the problem

Waste arisings in Ireland for 1998 were estimated at approximately 80 million tonnes. Of these, approximately 64.6 million tonnes (80.7%) originated from agricultural sources, mainly animal manure. The municipal and industrial sectors were estimated to have produced over 15 million tonnes (19.3%) of waste in 1998. Municipal waste alone accounted for 2 million tonnes. Compared with the 1.8 million tonnes of municipal waste arisings in 1995, there was a small increase in this category of waste between 1995 and 1998. Approximately 91% of all household and commercial waste collected in 1998 in Ireland was landfilled.

Landfilling of waste

A landfill is a repository for waste that is deposited in a series of compacted layers in specially constructed cells either on the land surface or in excavations into the land surface. The main potential impacts on health arise from inhaled landfill gas and exposure to groundwater contaminated by landfill leachate. Both gaseous and aqueous emissions from landfills are highly complex mixtures whose characteristics vary considerably from site to site and with waste composition and age of the landfill.

Although landfill gas consists mainly of methane and carbon dioxide, it can contain a large number of other gases at low concentrations, some of which are toxic. Combustion of landfill gas consumes a large amount of these but some dangerous gases are still emitted. Current practice in landfill design must consider the construction, operation, closure, restoration and aftercare of the facility. In terms of leachate containment, this requires that a double liner system be put in place to protect groundwater from pollution. Any leaks through the upper protective layer are collected by an intermediate drainage layer that also provides a warning of the leakage. Comprehensive design guidelines have been provided by the Irish Environmental Protection Agency in a series of Landfill Manuals. These design requirements are in line with international best practice.

Incineration of waste

Incineration is the thermal oxidation of waste at temperatures in excess of 850 °C. Industrial hazardous waste incineration is used by a number of pharmaceutical or fine chemical manufacturing plants in Ireland, as there is no central national facility for the incineration of such wastes. In 1998, it was estimated that 65,631 tonnes of Irish hazardous waste were incinerated, of which 47,751 tonnes were incinerated abroad. Most of this was solvents.

Monitoring of the emissions from industrial hazardous waste incinerators is currently carried out as an Integrated Pollution Control (IPC) licence condition. None of the facilities licensed for hazardous waste incineration have been found to be in breach of their IPC licence conditions. Dioxin emissions to the atmosphere from incinerators were estimated to be less than 1% of the total estimated national atmospheric dioxin emissions from all sources. Accidental fires were found to be the primary source of atmospheric dioxin emissions.

Municipal waste is not incinerated in Ireland; however, this is under consideration as part of integrated waste management plans. In the past, municipal waste incinerators world-wide were major sources of dioxins and other environmental pollutants. However, since the early 1990s, the application of stringent emission limit values to a broad range of environmental pollutants has significantly reduced the environmental impacts of municipal waste incineration. A combination of improved combustion practices and staged air pollution control techniques allows modern municipal incinerators, if operated according to the design standards, to meet the environmental requirements embodied in the recent EC *Directive on the Incineration of Waste*.

Liquid effluents from waste incineration are also tightly regulated. Solid residues, such as fly ash, will probably be classified as hazardous waste and will require the provision of suitable landfill sites. Gasification and pyrolysis are novel emerging technologies which have the potential for recovering energy from a range of waste types, and which may see greater application to municipal waste disposal in future years. The environmental impacts of these processes in comparison with modern incinerator plants have not been fully evaluated.

The effects of landfilling and incineration on the environment

As with any human activity, all methods of waste management have an environmental impact. In this report, the emphasis is on the direct site-related effects of landfills and incineration facilities. There are also substantial environmental effects associated with waste transport and collection. However, these are likely to be broadly similar for any facility, whether a landfill or an incinerator or even a recycling plant handling a given volume of waste. The choices made about the size and location of these facilities will greatly influence these impacts.

Landfill

Landfills are a potential threat to the quality of the environment, although the full extent of this threat has not always been scientifically validated. Landfills can produce gas and contaminated water, as well as wind-blown litter and dust, and attract vermin. Transport of waste to landfill sites can also have a significant impact on the environment in terms of noise, vehicular emissions, accidental spillages, etc.

Landfill gas is generated from the decomposition of the organic component of waste, initially under aerobic conditions to produce carbon dioxide, but ultimately under anaerobic conditions to produce larger quantities of methane. Landfill sites contribute 20% of the total global anthropogenic methane emissions.

Leachate management is also a major concern. The volume of leachate directly correlates with the amount of rainfall, and under Irish conditions this may be larger than in similar landfills in other countries. However, the potential impact of leachate on the environment also depends upon the nature of the material from which it derives. For older unlined landfill sites (which typically have no safeguards to prevent or minimise leachate), leachate can migrate to groundwater or even into surface waters. Contamination of groundwater by leachate has already occurred in Ireland, rendering the groundwater and the associated aquifer unreliable for domestic water supply and other beneficial uses. This is far more serious than river pollution because aquifers require extensive time periods for rehabilitation. The risks are considerably reduced for modern double-lined landfills.

Incineration

Municipal solid waste (MSW) incineration produces a range of volatile and gaseous emissions, which, if released to the atmosphere, can compromise environmental quality. Fly ash and dust can carry contaminants from the facility where they can affect sensitive ecosystems. The actual range of emissions depends upon the specific characteristics of the waste stream and engineering considerations such as combustion temperature and ancillary emission abatement techniques.

The Environmental Impact Assessment (EIA) procedures have had a positive effect on the siting and design of waste management facilities, and there is evidence from Irish research that this has led to improved knowledge and attitudes about incinerator operation and waste management among the service providers. The adoption within these organisations of environmental management plans supported by Environmental Management Systems (EMS) has also been helpful in minimising potential environmental impacts.

The effects of landfilling and incineration on public health

The standard process of estimating the likely effects of waste disposal on human health is known as 'risk assessment'. There are four phases in a typical risk assessment, namely hazard identification, dose-response assessment, exposure assessment and risk characterisation. Each phase is difficult, expensive and time consuming, and involves the exercise of professional judgement. Furthermore, the results of each stage have some degree of uncertainty, and these uncertainties are often unavoidable.

Interpretation of the evidence from epidemiological studies is especially difficult. Both for methodological reasons and for fundamental biological reasons, single epidemiological studies seldom provide sufficient evidence for scientific certainty. There is a tension between the requirement for certainty, and the need to protect public health. This tension is traditionally resolved in the 'precautionary principle'. This has been stated in many forms, but the 1992 Rio conference statement is succinct: 'Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation' (UNCED 1992). This principle does not resolve the scientific uncertainty, but it forms a valuable basis for policy makers on which to make decisions. Scientists can decline to make decisions

pending the availability of new evidence, but legislative and administrative decisions are often made to fixed timetables.

Responding to uncertain results is very difficult. It poses immense challenges for politicians, regulatory officials and the public. Evidence from research shows that people make wide-ranging value judgements, incorporating many different aspects of an issue, before reaching their decisions on disputed environmental questions. Traditional risk assessment is often a relatively minor component of this process.

One of the responsibilities of public officials and elected representatives is to communicate clearly with the general public. There is evidence that members of the public can readily understand complex technical reports, but they do not view risk in the same way as many professionals. A prerequisite for communicating clearly with the general public on waste management issues is a real understanding of how people evaluate information, and what is important for people affected by waste disposal planning decisions. Recent studies have shown the complex processes used by members of the general public to process information on environmental hazards, and these findings need to be taken seriously by those charged with risk communication.

Emissions from waste management sites

Emissions from landfill or incinerator sites are not directly related to human exposure. Exposure requires contact. This contact can be by breathing, through skin contact, or by eating food or drinking liquids contaminated by emissions. Much of the existing evidence on emissions relates to sites operated using older technologies, and may not be directly applicable to more recently constructed facilities.

The effect of exposure depends on the level and duration of exposure, but also, crucially, on characteristics of the people exposed. Children may be more susceptible to toxic effects of many chemicals, and may also behave in ways that increase their exposure. As an example, consider how much time small children and adults, respectively, spend in contact with soil.

Epidemiological studies of the health effects of landfilling and incineration

As there is a paucity of literature relating to modern landfill and incineration sites, nearly all of the studies identified in this report relate to older technologies. It can be assumed that as emission controls improve, risks of adverse effects diminish.

Health effects of landfilling

Landfill sites contain many toxic substances. There have been many studies of different potentially adverse effects. These studies show an increased risk of some adverse health effects linked to residence near certain specific sites. However, although a great number of studies have been carried out, evidence of a causal relationship between specific health outcomes and landfill exposures is still inconclusive. For many reasons, it is almost impossible to give definitive answers to questions about these health effects. There is modest evidence for an association between birth defects and residence near some landfill sites. In the future, examination of specific types of defects, possibly related to exposure to specific environmental agents, may serve to clarify this link. This is further complicated by the fact that little is known about the causes of birth defects in general.

At present there is insufficient evidence to demonstrate a clear link between cancer and exposure to a landfill. When residence in proximity to a landfill has been examined as a health risk, excesses of

bladder, lung, leukaemia and stomach cancer have been reported in some studies and not in others. Reports of increased risk of respiratory, skin and gastrointestinal illnesses are based mainly on self-reported symptoms. These studies are hard to interpret when trying to establish causal relationships.

Health effects of incineration

There is some evidence that incinerator emissions may be associated with respiratory morbidity. Acute and chronic respiratory symptoms are associated with incinerator emissions.

A number of well-designed studies have reported associations between developing certain cancers and living close to incinerator sites. Specific cancers identified include primary liver cancer, laryngeal cancer, soft-tissue sarcoma and lung cancer. It is hard to separate the influences of other sources of pollutants, and other causes of cancer and, as a result, the evidence for a link between cancer and proximity to an incinerator is not conclusive.

Further research, using reliable estimates of exposure, over long periods of time, is required to determine whether living near landfill sites or incinerators increases the risk of developing cancer. Studies of specific environmental agents and specific cancers may prove more definitive in the future.

Biomonitoring studies

Biomonitoring studies are valuable tools for risk assessment and can demonstrate exposure of individuals to specific substances. Most studies have examined exposure to trace metals, volatile organic compounds or dioxins. Other markers of adverse health effects have been described, including markers of kidney and liver function and markers of molecular or chromosomal damage. These studies are far more sensitive than studies of disease incidence. However, as pollutants often originate from more than one source, it can be difficult to attribute specific biomarkers to landfill and incineration emissions.

Knowledge and perceptions of waste management options

A series of qualitative studies was conducted, including focus groups and semi-structured interviews, with representatives of service providers, industry, environmental health officers and the general public. Submissions were also invited through an advertisement in the national press. The purpose of this was to document and analyse the knowledge and perceptions of those promoting waste management systems, and members of the general public affected by their operations.

Waste policy

All informants were agreed that waste management in Ireland is currently facing a crisis. The precise nature of this crisis varied depending on the perceptions of the informant. There was virtual unanimity that landfilling of waste no longer offered a medium- to long-term solution; but there was disagreement as to the acceptability of incineration as a replacement means of waste management.

Members of the public participating in our studies favoured greater use of recycling and the introduction of measures to reduce the amounts of waste generated, but it was the 'professional view' that such measures would only have a marginal impact in the medium term, requiring maintenance of substantial

waste disposal capacity for the time being. 'Professionals' tended to favour incineration as the option for this, and saw the major challenge to be increasing its acceptability to the general public.

At the root of this divergence lies a significant difference of opinion (i.e., perception) in relation to the environmental and health hazards of the various options for waste management, the capability of existing structures and institutions to 'police' compliance with the regulation of waste disposal and the likelihood of achieving significant change in public attitudes towards waste generation and waste disposal.

Health and environmental impacts

It was difficult to draw out any distinction between 'health' and 'environmental' impacts in the responses of participants. In the case of landfilling, venting and potential leakage of gases, pests and water contamination were identified as health hazards. In the case of incineration, emissions of dioxins and disposal of waste ash were similarly mentioned.

In general, informants showed little detailed knowledge of epidemiological relationships. Specific health impacts were seldom listed. Informants frequently commented critically on the absence of local studies. There was a tendency from the representatives of the waste management industry to equate this absence of local studies with an absence of impact.

The perception of the general public was that incineration was 'unpalatable'. In contrast, informants from the industrial and commercial sector tended to demonstrate a strong belief in the current state of incineration technology as a safeguard against health impact. This view was generally dependent on a rider concerning the quality of management; this view was even more strongly held about landfill. Service providers believed that the poor public perception of landfill and the consequent suspicion of incineration had their origins in the previous poor management of waste disposal sites.

Representatives of the service providers and of industry were generally optimistic that greater compliance with regulation could be achieved in the future. While it was frequently noted that Ireland exhibited a 'non-compliant' culture, it was felt that, in relation to waste management, this had to change because of pressure from the European Union.

There was little satisfaction with existing agencies and structures. There was a general ambiguity as to whether the primary responsibility for ensuring compliance should rest with central government or locally.

Local authorities were felt to be 'compromised' or to behave erratically, because of the ambiguities arising from their responsibilities for waste management and public representation. Regional plans were perceived as duplicating, or being inconsistent with, local plans.

Health boards were seen as having a potentially greater role to play, with reference being made to the new Health Strategy, and its call for the wider use of health impact assessment and for health proofing of the plans of other sectors, and to the *National Environmental Health Action Plan*. Some ambiguity was also perceived in the role of health boards, given their parallel responsibility as managers of the large quantities of hazardous hospital waste.

Information issues

From their respective positions and perspectives, informants agreed that the key to the resolution of existing disagreements on the future of waste management lay in the production of trustworthy and

trusted information. Not unnaturally, the various parties were generally convinced that this would persuade other parties over to their own particular view. Apart from reservations about some press reports, most informants were confident that the information actually presented to the public was credible. For example, service providers were often complimentary of bodies like Greenpeace as a source of reliable information. Likewise, a number of informants rated the Internet as a valuable information source, yet professionals would argue that there is generally no 'quality control' to assure that information available on the Internet is accurate and unbiased.

The diffusion of better information was never perceived as being sufficient in itself to resolve local fears concerning the location of waste disposal facilities. It was felt that it would assist in giving the general public more ownership of the debate and in facilitating their participation.

Summary of research and development needs identified in this report

(a) Risk assessment

Ireland presently has insufficient resources to carry out adequate risk assessments for proposed waste management facilities. Although the necessary skills are available, neither the personnel nor the dedicated resources have been made available. In addition, there are serious data gaps (addressed under point (c) below). These problems should be rectified urgently.

(b) Detection and monitoring of human health impacts

Irish health information systems cannot support routine monitoring of the health of people living near waste sites. There is an urgent need to develop the skills and resources required to undertake health and environmental risk assessments in Ireland. This should be considered as an important development to build capacity in Ireland to protect public health in relation to potential environmental hazards. The recommendations in the *Proposal for a National Environmental Health Action Plan* (Government of Ireland 1999) could form a basis for this.

(c) Detection and monitoring of environmental impacts

The capacity (in terms of facilities, financial and human resources, data banks, etc.) must be developed for measuring environmental damage, and changes over time in the condition of the environment around proposed waste sites and elsewhere. There is a serious deficiency of baseline environmental information in Ireland, a situation that should be remedied. The lack of baseline data makes it very hard to interpret the results of local studies, for example around a waste management site. Existing research results should be collated and interpreted as a step toward building a baseline data bank. A strategically designed monitoring programme needs to be initiated that can correct deficiencies in current ambient environmental monitoring. In addition, capacity needs to be built in environmental analysis. In particular, Irish facilities for measuring dioxins are required, and should be developed as a priority. However, the high public profile of dioxins should not distract attention from the need for improved monitoring of other potential pollutants.

(d) Risk communication and perception

Qualitative studies about waste management perceptions revealed a diversity of opinion about waste management issues generally, and about the links between waste management and both human health and environmental quality. To facilitate public debate on the issues of waste management policy and effects, a systematic programme of risk communication will be necessary. This should concentrate on providing unbiased and trusted information to all participants (or stakeholders) in waste management issues. Public trust, whether it is placed in the regulators, in compliance with the regulations or in the information provided, will be fundamental in achieving even a modicum of consensus for any future developments in waste policy in Ireland.

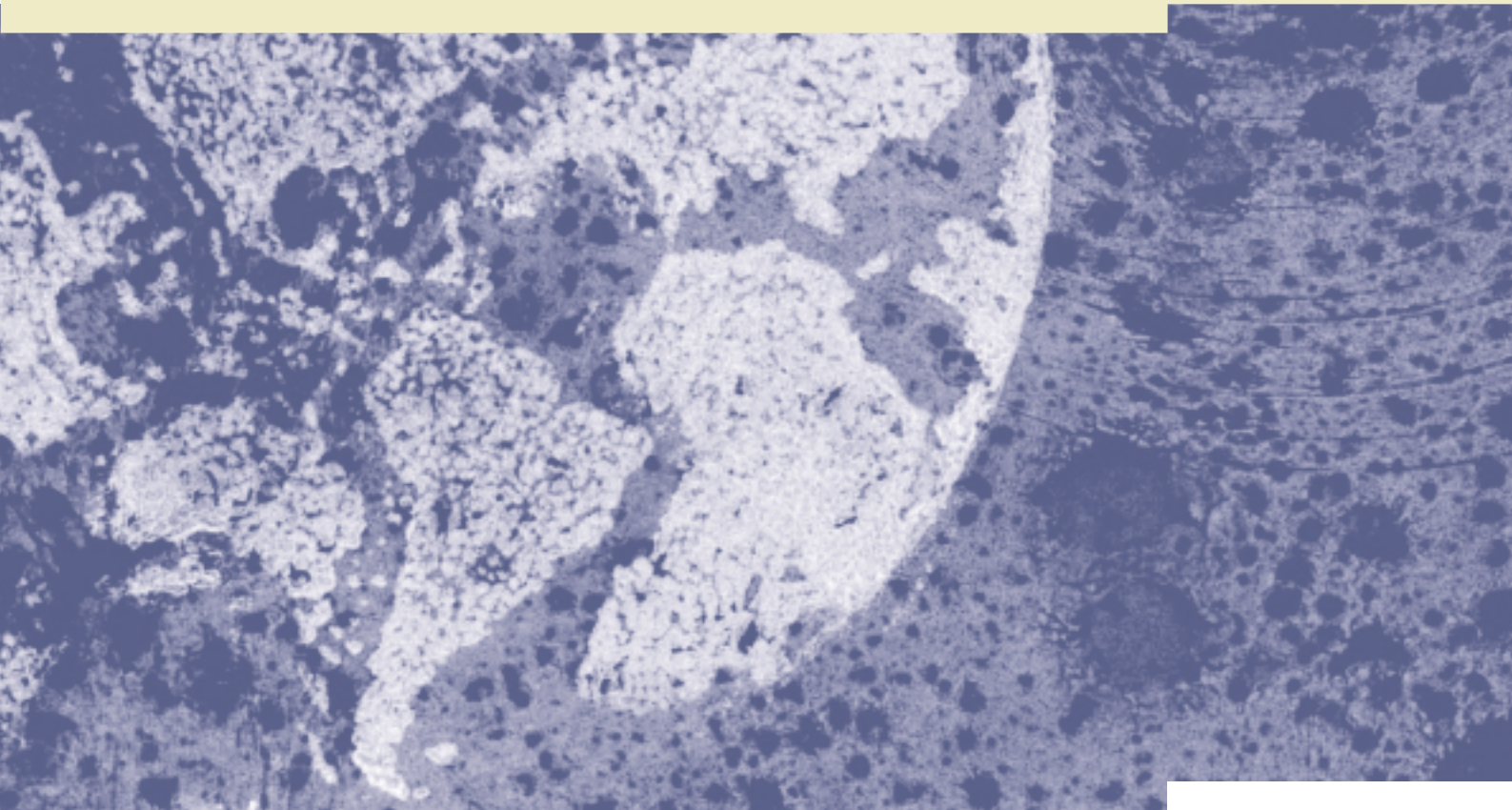
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Chapter One: Introduction



Chapter One: Introduction

In Ireland, there is perhaps no more locally emotive issue among the general public than that of solid waste management. As evidenced by the attendance and comments at recent regional waste management strategy public meetings, sensitivity to the waste management issue is particularly high among those living in close proximity to existing and proposed waste management facilities. Primary sources of concern are the use of landfilling and incineration as techniques to manage the large quantities of waste produced. Advances in technology and stringent regulatory control have resulted in improvements in the design and management systems for both landfill and incineration. As a result, modern facilities are likely to produce lower emissions than older systems.

Concerns among the public still exist, however, about the potential negative effects that these facilities have on the environment and public health. These concerns are not limited to waste management issues. As described by a number of social scientists (Stirling & Mayer 1999, p.5), industrialised societies have, by the end of the twentieth century, evolved into 'risk societies' in which 'the concept of risk has become a dominant ordering principle, helping to structure and condition social and institutional relations and, to some extent, replacing monetary wealth and cultural privilege as the focus of distributional tensions and political conflict'. The average person on the street now openly questions (and perhaps distrusts) so-called 'expert institutions' such as central governments and scientific bodies-organisations that were held in high regard just a generation ago. Given the inability of such institutions to either foresee or circumvent recent technological risks such as BSE, hepatitis-C, and a range of other issues that touch people individually, it is perhaps little wonder that the public now examines ever more critically any claim from established institutions about the relative safety of 'technology'. As regards waste management specifically, the images of the poorly-managed landfills of the past are difficult to dispel.

A recent Forfás report (2001) on the key issues in waste management has highlighted the need to build capacity in Ireland to conduct scientific research in risk assessment and to provide advice for policy and planning for waste management. As Stirling and Mayer (1999, p. 6) highlight, traditional methods of risk assessment also must be incorporated into an improved decision methodology that caters for the variety of perspectives about technological developments involving risk. Important among these viewpoints are those held by the general public.

In response to a request by the Department of the Environment and Local Government (DoELG), the Health Research Board invited tenders for a review of the environmental and public health effects of landfill and incineration. An outline of the successful proposal is included in Appendix A.

The specific research objectives were as follows:

- To review national and international literature relating to the effects of landfill and thermal treatment of waste on (a) human health and (b) the environment.
- To describe the knowledge and attitudes of service providers, special interest groups and the general public to waste management options and to undertake an analysis of the source and basis of knowledge and attitudes.
- To describe (a) the current policy and practice of waste management in Ireland in terms of the hierarchy of principles in waste management, including methods of monitoring of waste and

surveillance of emissions, and (b) practices in waste management in other countries, in order to identify best practice in terms of efficiency and safety. This will include technical descriptions of different waste management options and new technologies.

- To review national and international literature on environmental risk assessment and to identify and describe formal risk assessments that have been carried out on landfill and thermal treatment facilities to date. This will also describe those emissions that have been identified as hazardous to human health and the environment.
- To compare the risks posed to public health and the environment by emissions from landfill and from modern thermal treatment plants with those posed by similar emissions from other sectors.

Due to limitations of time, and the absence of Irish data on the environment and health, it was not possible to carry out this last objective to any adequate standard. However, this task is very important, and should be undertaken as soon as possible.

Other aspects of waste management, such as waste prevention measures, reuse, recycling, and composting, are beyond the scope of the terms of reference and are not reviewed in this report. Likewise, this study did not address the management of organic waste (mostly animal manure) from the agricultural sector. However, the authors acknowledge that an integrated systems approach is required for effective waste management at both local and national level. Such an approach includes prevention of waste generation, prevention of impact on the environment, recovery of material or energy and safe and efficient final disposal of residual waste materials that cannot be re-utilised.

It is not the purpose of this report to make recommendations on waste management policy in Ireland. We refer interested readers to the Forfás report (2001) already cited. Our goal is to produce a contribution to the ongoing political and scientific debate on waste management policy by providing a resource for interested parties. This report aims to inform policy makers of (a) the technical aspects of both landfill and incineration practices in Ireland and (b) the potential adverse effects that these practices have on the environment and public health. Work commenced on this project in December 2001 and the literature search was completed at the end of February 2002.

Chapter Two provides some background information on waste arisings in Ireland. These data have been generated by the relevant statutory bodies (e.g., the Environmental Protection Agency (EPA), DoELG) and document the magnitude of the waste management challenge in Ireland.

Chapters Three and Four describe the technical aspects of landfilling and incineration respectively. Relevant international literature in relation to specific waste systems, emissions and control measures are also discussed.

Environmental systems and the ways in which landfilling and incineration can adversely affect ecosystems are described in Chapter Five.

Methods for assessing and managing risks to human health are presented in Chapter Six. This chapter is followed by a literature review of the health effects of landfilling and incineration in Chapter Seven.

Qualitative research on the knowledge and perceptions of service providers, environmental health officers and the general public was carried out as part of this study, and the results are presented in Chapter Eight. This research provides new information to inform both the planning and implementation of waste management policy, education and risk communication programmes.

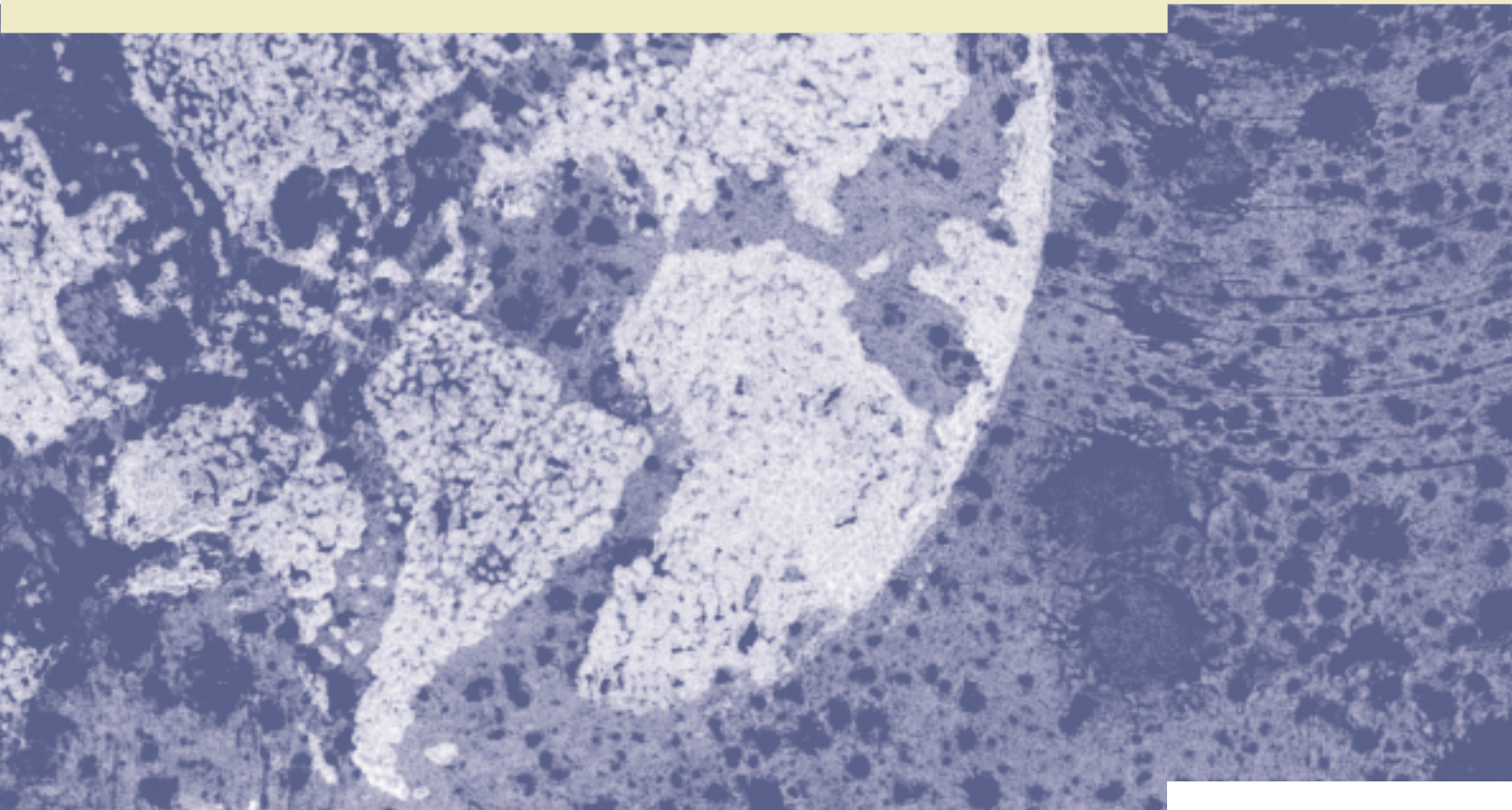
Appendix A contains the initial proposal to the Health Research Board. Appendix B contains a glossary of technical terms used in the report. Other appendices contain supplementary technical information on landfilling and incineration and additional information on the original research carried out in this study.

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Chapter Two: Solid Wastes in Ireland



Chapter Two: Solid Wastes in Ireland

Definition and categories of waste

The Waste Management Acts of 1996 and 2000 define waste as ‘any substance or object belonging to a category of waste specified in the First Schedule or for the time being included in the European Waste Catalogue which the holder discards or intends or is required to discard, and anything which is discarded or otherwise dealt with as waste shall be presumed to be waste until the contrary is proved’.

The first level of waste classification used in the *European Union Waste Catalogue* (2001) lists 20 categories as shown in Table 2.1. Municipal waste is the last classification on this list and is the primary subject of this report. Interestingly, as well as its non-hazardous components (Table 2.2), municipal waste includes some components classed as hazardous (Table 2.3).

Table 2.1 Categories of waste

Code	Origin/nature of waste
01	Exploration, mining quarrying, physical and chemical treatment of minerals
02	Agriculture, horticulture, aquaculture, forestry, hunting fishing, food preparation and processing
03	Wood processing, panels, furniture, pulp, paper, cardboard
04	Leather, fur, textiles
05	Petroleum refining, natural gas purification, pyrolytic treatment of coal
06	Inorganic chemical processes
07	Organic chemical processes
08	Manufacture, formulation, supply and use of coatings, sealants and printing inks
09	Photographic industry
10	Thermal processes
11	Chemical surface treatment and coating of metals and other materials; non-ferrous hydro-metallurgy
12	Shaping and physical and mechanical surface treatment of metals and plastics
13	Oil wastes and wastes of liquid fuels
14	Organic solvents, refrigerants and propellants
15	Waste packaging, absorbents, wiping cloths, filter materials, protective clothing
16	Wastes not otherwise specified in this list
17	Construction and demolition
18	Human and animal health care and/or related research
19	Waste management facilities, water and waste water treatment plants
20	Municipal wastes (household waste and similar commercial, industrial and institutional wastes)

(Source: *EU Waste Catalogue 2001*)

Table 2.2 Non-hazardous components of municipal waste

Code	Category of waste
20 01 01	Paper and cardboard
20 01 02	Glass
20 01 08	Biodegradable kitchen and canteen waste
20 01 10	Clothes
20 01 11	Textiles
20 01 25	Edible oils and fat
20 01 28	Paint, inks adhesives and resins other than those included in 20 01 27*
20 01 30	Detergents other than those mentioned in 20 01 29*
20 01 32	Medicines other than those mentioned in 20 01 31*
20 01 34	Batteries and accumulators other than those mentioned in 20 01 33*
20 01 36	Discarded electrical and electronic equipment other than those mentioned in 20 01 21, 23 or 35*
20 01 38	Wood other than that mentioned in 20 01 37*
20 01 39	Plastics
20 01 40	Metals
20 01 41	Wastes from chimney sweeping
20 01 99	Other fractions not mentioned Garden and park (incl. cemetery) wastes
20 02 01	Biodegradable waste
20 02 02	Soil and stones
20 02 03	Other non-biodegradable wastes Other municipal wastes
20 03 01	Mixed municipal waste
20 03 02	Waste from markets
20 03 03	Street cleaning residues
20 03 04	Septic tank sludges
20 03 06	Waste from sewage cleaning
20 03 07	Bulky waste
20 03 99	Municipal wastes not otherwise specified

*See Table 2.3 Hazardous components of municipal waste

(Source: EU Waste Catalogue 2001)

Table 2.3 Hazardous components of municipal waste

Code	Category of waste
20 01 13	Solvents
20 01 14	Acids
20 01 15	Alkalis
20 01 17	Photochemicals
20 01 19	Pesticides
20 01 21	Fluorescent tubes and other mercury-containing waste
20 01 23	Discarded equipment containing chlorofluorocarbons
20 01 26	Oil and fat other than edible oil and fat
20 01 27	Paint, inks, adhesives and resins containing dangerous substances
20 01 29	Detergents containing dangerous substances
20 01 31	Cytotoxic and cytostatic medicines
20 01 33	Batteries and accumulators
20 01 35	Discarded electrical and electronic equipment other than those covered by 20 01 21 and 20 01 23 containing hazardous components
20 01 37	Wood containing dangerous substances

(Source: EU Waste Catalogue 2001)

Waste flows in Ireland

Waste arisings in Ireland for 1998 were estimated as approximately 80 million tonnes (Crowe et al. 2000). Of this, approximately 64.6 million tonnes (80.7%) originated from agricultural sources, mainly animal manure. The municipal and industrial sectors are estimated to have produced over 15 million tonnes (19.3%) of waste in 1998. Municipal waste alone accounted for 2 million tonnes. This is a small increase in this category of waste since 1995, which had 1.8 million tonnes of municipal waste arisings (Carey et al. 1996) (Table 2.4).

The composition of household and commercial waste in Ireland, by weight, in 1998 is shown in Table 2.5. Note that paper (34.7%) and organics (24.9%) are the largest fractions. This is in sharp contrast to the situation fifty years earlier when ash (mostly from heating systems) formed by far the largest fraction in the US (Table 2.6) and in the UK (Table 2.7). This change in composition has greatly increased the difficulties and risks involved in dealing with MSW.

Variability of municipal solid waste (MSW) flow and composition with time and space

Temporal and spatial variation in waste composition is an important factor in the efficient operation of incineration facilities. There is no information on waste arisings in Ireland at high-resolution spatial and temporal scales. Some indication of possible variability can be gauged from a study conducted by Porcel et al. (1997) on the physical and chemical characteristics of MSW in the city of Cordoba in Spain and its variability with space and time. This study revealed that MSW physical and chemical

characteristics vary with time (days of the week or seasons of the year) and with location depending on socio-economic factors.

Average results for the within-week daily variations of MSW flow for two years are given in Table 2.8 and show considerable variation.

Table 2.4 Comparison of amounts and types of waste arisings in Ireland in 1995 and 1998

Waste Category	1998		1995	
	(Tonnes/annum)	(%)	(Tonnes/annum)	(%)
Agricultural	64,578,724	80.7	31,000,000	73.4
Manufacturing	4,876,406	6.1	3,540,226	8.4
Energy, Gas, & Water Supply	448,674	0.6	351,849	0.8
Mining & Quarrying	3,510,778	4.4	2,200,002	5.2
Hazardous Waste	370,328	0.5	243,754	0.6
Municipal Waste	2,056,652	2.6	1,848,232	4.4
End-of-Life Vehicles/Scrap Metal	187,484	0.2	52,154	0.1
Construction & Demolition Waste	2,704,958	3.4	1,318,908	3.1
Urban Wastewater Sludges	505,686	0.6	851,380	2.0
Drinking Water Sludges	38,988	0.0	58,095	0.1
Dredge Spoils	734,000	0.9	784,600	1.9
Total	80,012,678	100.0	42,249,200	100.0

(Source: Carey et al. 1996, Crowe et al. 2000)

Table 2.5 Composition of household and commercial waste in Ireland in 1998

Material	Amount	Percentage of total
	(Tonnes/annum)	(%)
Paper	642,151	34.7
Glass	116,757	6.3
Plastic	200,403	10.8
Ferrous	32,559	1.8
Aluminium	15,455	0.8
Other Metals	6,236	0.3
Textiles	39,388	2.1
Organic	460,869	24.9
Others	338,630	18.3
Total	1,852,448	100.0

(Source: Crowe et al. 2000)

Table 2.6 Composition of refuse in the US (1950s)

Material	% Composition by weight	% Composition by volume
Garbage (kitchen waste, organics)	13	18
Ashes	80	57
Other	7	25

(Source: *Encyclopaedia Britannica 1953*)

Table 2.7 Composition of refuse in the UK (1950s)

Material	% Composition by weight
Fine dust/large cinders (ash)	81.61
Bricks, pots / shards	6.5
Tins	1.3
Rags	0.54
Glass	0.83
Bones	0.09
Vegetable matter	4.05
Scrap iron	0.42
Paper	2.26
Miscellaneous	2.4

(Source: *Encyclopaedia Britannica 1953*)

**Table 2.8 Daily variation in mass of waste arisings in Cordoba, Spain.
Average results from July 1993 to May 1994**

Year	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
1993	26.6	15.81	15.62	15.63	15.77	10.63	—
1994	17.65	14.47	14.79	14.34	15.17	13.94	9.64

(Source: *Porcel et al. 1997*)

Average results for the monthly variations among the different sectors are shown in Table 2.9.

Table 2.9 Monthly variation of waste arisings in Spain

Sector	July	September	November	February	March	May
Popular	66.97	68.41	68.68	71.97	71.24	70.87
Residential	7.59	6.02	6.48	6.29	6.3	6.84
Commercial	25.44	25.56	24.85	21.73	22.46	22.29

(Source: *Porcel et al. 1997*)

Composition of municipal solid waste

Some idea of the expected composition of MSW can be inferred from the municipal waste sub-categories in Tables 2.2 and 2.3. However, there is considerable variation from country to country and from waste stream to waste stream. For example, in Cordoba, MSW composition varied with season (Table 2.9) and with location within the city (Table 2.10). Temporal variation in quantity and in composition of waste may have implications for the optimal operation of waste incinerators.

Table 2.10 Variability of MSW composition among different sectors

Sector	Organic matter (%)	Plastic (%)	Paper (%)	Others (%)	Glass (%)	Metal (%)	Textiles (%)
Popular	56.79	14.43	16.83	1.27	5.23	3.7	2.74
Residential	53.34	11.75	18.33	2.65	6.85	4.96	2.11
Commercial	49.06	10.5	24.38	1.46	8.19	3.46	2.95

(Source: Porcel et al. 1997)

A study of the composition of the landfill fraction of sorted demolition wastes, which can sometimes be deposited in landfills, in two sites in Switzerland revealed elevated levels of Pb and Zn and of organic matter when compared with typical composition of the Earth's crust (Table 2.11). The acid-neutralising capacity of the contents (especially calcite) is sufficiently large to control the solubility of the Pb and Zn over long periods. However, the organic carbon composition is sufficient to contribute to leachate in the short term (Johnson et al. 1999).

A study of over 60 landfills in Finland showed a large variation in metal content of waste (Assmuth 1992) (Table 2.12).

Methods of solid waste treatment in Ireland

The composition and amount of MSW (mainly household and commercial wastes) treated (landfilled) or recovered in Ireland annually is shown in Table 2.13.

In 1998, there were 117 active known landfill sites (Crowe et al. 2000). The immediate future position may be estimated from the status of solid waste treatment EPA licence applications, summarised in Table 2.14. This was the position at the time of the last comprehensive survey in 1999. A considerable number of licences have been issued since then. The current position (as of 12/02/2002) is that 104 landfill licences and 16 draft licences have been issued. Eleven applications have been withdrawn or rejected and one application failed compliance. Fifty-five applications were under consideration (EPA, personal communication.).

Table 2.11 Composition of the landfill fraction of sorted demolition wastes from Nesselbach and Frick in Switzerland, compared with natural levels in the Earth's crust

Element	Nesselbach Day 1	Nesselbach Day 2	Frick Day 1	Frick Day 2	Earth's Crust
Si	173	173	188	169	270
Ca	167	163	149	139	50
AL	19.6	20.8	24.6	19	80
Fe	28.6	14.4	12.3	15.7	60
Na	3.6	3.2	3.2	1.1	25
K	7.8	7.8	8.4	10.4	20
Mg	6.6	9.7	8.3	15.1	30
Ctot	114	68.6	76.3	74.1	0.2
Corg	72.8	28.2	42.7	38.4	0
CO3	41.3	40.5	33.7	35.7	0.2
N	1.74	0.91	0.98	0.71	0.02
S	20.2	14.1	14	7.2	0.3
P	0.35	0.8	0.36	0.29	1
Cd	0.73	0.44	0.26	0.12	0.2
Cr	0.08	0.03	0.03	0.03	0.1
Cu	0.19	0.05	0.02	0.02	0.06
Pb	0.49	1.36	0.03	0.12	0.01
Zn	0.51	0.51	0.23	0.18	0.08

(Units g.kg⁻¹ for all elements except Cd, for which the units are mg.kg⁻¹)

(Source: Johnson et al. 1999)

Table 2.12 Waste contaminant concentrations in municipal co-disposal landfills in Finland

Item	Median	Mean	Maximum	Number of sites
pH	7.7 - 7.9		12	61
Moisture content (%)	23 - 40		86	66
As (mg/kg)	5 - 8	5.9 - 17	55	61
Cd (mg/kg)	0.18 - 0.6	0.3 - 4.3	45	61
Cr (mg/kg)	27 - 220	36 - 810	13000	61
Cu (mg/kg)	24 - 360	41 - 950	5400	61
Ni (mg/kg)	9 - 36	12 - 67	480	61
Pb (mg/kg)	27 - 290	80 - 450	2400	61
Zn (mg/kg)	89 - 910	180 - 1200	3600	61

(Source: Assmuth 1992)

Table 2.13 Disposal and recovery rates in the household and commercial waste streams in Ireland in 1998

Material	Landfilled	Recovered	Total	Landfill rate	Recovery rate
	<i>(Tonnes/annum)</i>	<i>(Tonnes/annum)</i>	<i>(Tonnes/annum)</i>	<i>(%)</i>	<i>(%)</i>
Paper	547,849	94,302	642,151	85.3	14.7
Glass	80,757	36,000	116,757	69.2	30.8
Plastic	192,927	7,476	200,403	96.3	3.7
Ferrous	28,491	4,069	32,559	87.5	12.5
Aluminium	14,724	731	15,455	95.3	4.7
Other Metals	6,209	28	6,236	99.6	0.4
Textiles	36,142	3,247	39,388	91.8	8.2
Organic	455,204	5,665	460,869	98.8	1.2
Other	323,463	15,167	338,630	95.5	4.5
Total	1,685,766	166,684	1,852,450	91.0	9.0

(Source: Crowe et al. 2000)

Table 2.14 Summary of waste licensing in Ireland up to 31 December 1999

Facility type	No. of applications	Proposed decisions	Licences issued	Abandoned applications
Landfill	71	8	13	
Transfer Station	29	1	6	
Composting	7			
Hazardous Waste Treatment & Transfer	7		1	
Healthcare Risk Waste Treatment	6		3	2
Soil Remediation	4		1	
Hazardous Waste Transfer Station	3		2	
Integrated Waste Management Facilities	3		1	
Dredging	2		1	
Hazardous Waste Treatment	2		1	
Healthcare Risk Waste Treatment & Hazardous Waste Transfer Station	1		1	
Recovery	1			
Total	136	9	30	2

(Source: Crowe et al. 2000)

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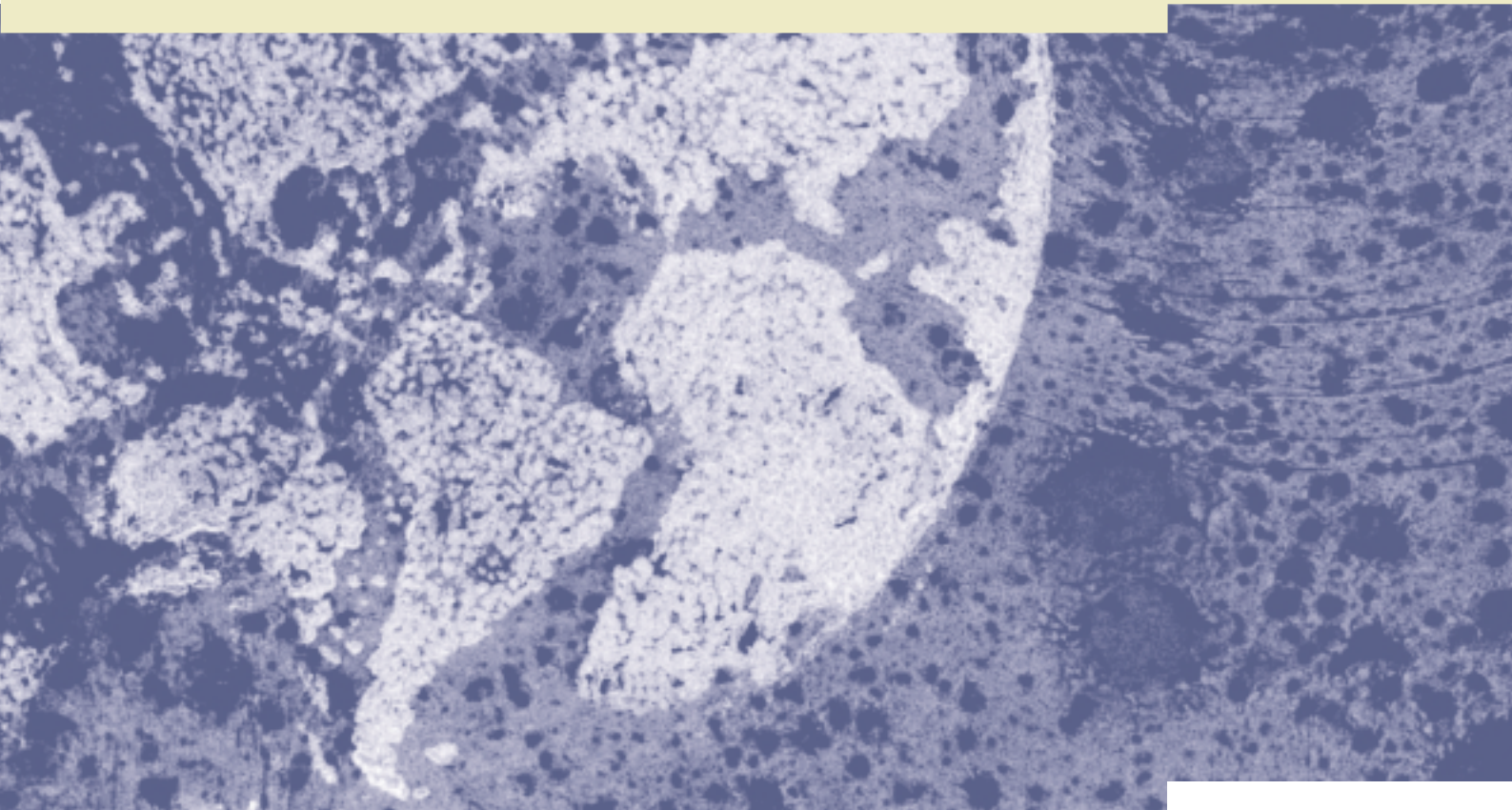
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Chapter Three: Landfill Emissions



Chapter Three: Landfill Emissions

Introduction

As can be seen from the previous chapter, the most commonly used method of management of solid waste in Ireland is landfilling. About 91% of all household and commercial waste collected in 1998 in Ireland was landfilled (Crowe et al. 2000). A landfill is where waste is deposited in a series of compacted layers in specially constructed cells either on the land surface or in holes created on the land surface by excavation. The design of a landfill must take account of the ground conditions, the geology and hydrogeology of the site, the potential environmental impacts and the location of the landfill. The investigations for a landfill should provide sufficient information to enable the formulation of a site-specific design.

Design considerations

Past design characteristics

In the not too distant past, landfills were called 'dumps' and were located in areas of cheap, poor-quality land. They included disused quarries and low-lying marshy ground. Landfill gas was allowed enter the atmosphere to be dispersed and the policy of 'dilute and disperse' applied to the contaminated liquid, called leachate, which seeped from the waste. This practice presumed that contaminants in leachate would be attenuated by passage through the soil and diluted by the receiving water, that is, groundwater, surface water or marine water, to the extent that its impact would be minimal. The environmental hazards posed to groundwater by 'dumps' have been recognised and efforts to close (and sometimes remediate) these facilities have been undertaken in the EU and elsewhere. Currently, natural attenuation is rarely considered as the sole method of leachate management. Some 'monitored natural attenuation' protocols are mentioned by Rifai et al. (2000) in relation to hazardous waste sites.

Current design characteristics

Current practice in landfill design must consider the construction, operation, closure, restoration and aftercare of the facility. The landfill designer should consider all of its potential environmental impacts and the factors influencing them, including those itemised below.

- Nature and quantity of waste deposited
- Water control on site
- Protection of soil and water
- Leachate management
- Gas control
- Environmental nuisances

- Slope stability of both waste and containment cells
- Visual appearance and landscaping
- Operational and restoration requirements
- Monitoring requirements
- Estimated cost of the facility
- Construction
- After use and aftercare

The Irish Environmental Protection Agency (EPA) has produced a set of Manuals for use in landfill design, operation, monitoring, restoration and aftercare (EPA 1995a, 1995b, 1997, 1999, 2000). The UK Department of the Environment has also produced guidelines, (DoE 1995). The Department of the Environment and Local Government (DoELG), the Environmental Protection Agency (EPA) and the Geological Survey of Ireland (GSI) have produced guidelines for groundwater protection, which have an important input into the selection of suitable sites for landfills (DoELG, EPA & GSI 1999). These guidelines were supplemented by a document on groundwater protection responses for landfills (GSI 1999). The reader is referred to these publications for detailed technical information and only those details needed specifically for the purpose of this review are examined here.

Possible emissions from landfills

The main possible emissions from landfills are:

- Leachate: a contaminated liquid that flows from the waste material. It consists of infiltrating rain or groundwater picking up contaminants as it passes through the waste. It can also be derived from water produced by the mineralisation of the biodegradable organic compounds of the waste. It can also contain non-aqueous liquids.
- Landfill gas: a gas generated in the waste decomposition process.
- Wind-blown litter: loose surface material blown by the wind.
- Vermin and insects: pests attracted to the landfill by the ready availability of food, which breed, multiply and move from the landfill.

All of these may well constitute some threat to health. However, scientific information sufficient to formulate general principles regarding the threat to health of wind-blown material, vermin and insects is not readily available in the literature. Aerosol transport of bacteria and viruses from sludge disposal has been studied by Dowd et al. (2000) but their results are not easily translated into generalised guidelines for landfill management. So, of necessity, the following discussion is limited to the threats from landfill gas and leachate only.

Processes of degradation

The waste is degraded by a complex range of reactions, which include the following general categories:

- Hydrolysis, in which large organic molecules such as lipids and proteins are broken down into their monomeric components, which can then be ingested by micro-organisms.
- Acidogenesis, by which micro-organisms break down the products of hydrolysis into smaller molecules such as small organic acids (known as volatile fatty acids), accompanied by the liberation of carbon dioxide and dihydrogen.
- Fermentation, by which different micro-organisms convert the small organic acids into methane and carbon dioxide. This is also called the methanogenic phase.

Landfill gas (LFG)

Landfill gas (LFG) results from the biodegradation of waste. Gas production within the landfill takes place at elevated temperature and the gas is usually saturated with water. Undiluted landfill gas can be expected to have a calorific value of 15 - 21 MJ/m³ (EPA 2000), which is approximately half that of natural gas.

The major components of landfill gas are methane (CH₄) and carbon dioxide (CO₂) (typically in a 3:2 ratio), with a large number of other constituents at low concentrations (Tables 3.1, 3.2 and 3.3). Methane is flammable and can be asphyxiant. Carbon dioxide is asphyxiant. The occupational exposure limits for carbon dioxide are short-term (15 min.) 1.5% (percentage by volume, v/v) and long-term (8 hours) 0.5% in air (EPA 2000). However, from a human health perspective, some of the constituents found in low concentrations may be as important as the major components.

Farquhar and Rovers (1973) describe four phases in the production of landfill gas:

- Aerobic decomposition: of short duration (few weeks) depletion of O₂ and production of CO₂ and H₂O.
- Anaerobic, non-methanogenic: CO₂ production peaks and volatile fatty acids and H₂ production begins. Methane (CH₄) is not produced.
- Anaerobic methanogenic phase: Methane (CH₄) production starts and increases to a relatively substantial constant rate; H₂ is rapidly used up and CO₂ production falls to a relatively constant rate; N₂ is produced.
- In the final phase, gas production rates vary only slowly until the nutrient is depleted or sufficient amounts of inhibitory substances build up.

Gas production shows considerable variation with depth in the landfill, with a dramatic increase in the vicinity of a water (or leachate) table (if one exists in the waste) as explained by Rees and Granger (1982).

Fires and explosions can occur when a flammable gas or vapour from a flammable liquid mix with air and ignite when within certain concentration limits. The concentration limits are known as the Lower Explosive Limit (LEL) and the Upper Explosive Limit (UEL). The LEL and UEL of methane are approximately 5% and 15% (v/v).

Table 3.1 Typical landfill gas composition (% volume)

Component	UK – typical value (EPA 2000)	UK – observed maximum (EPA 2000)	US typical (Ham 1979)*	Palos Verdes, CA, USA (Brosseau & Heitz 1994)
Methane	63.8	88	47.4	53.28
Carbon dioxide	33.6	89.3	47	45.59
Oxygen	0.16	20.9	0.8	0.07
Nitrogen	2.4	87	3.7	0.27
Hydrogen	0.05	21.1	0.1	0.06
Carbon monoxide	0.001	0.09		
Ethane	0.005	0.0139		
Ethene	0.018	–		
Acetaldehyde	0.005	–		
Propane	0.002	0.0171		
Butanes	0.003	0.023		
Helium	0.00005	–		
Higher alkanes	< 0.05	0.07		
Unsaturated hydrocarbons	0.009	0.048		
Halogenated compounds	0.00002	0.032		
Hydrogen sulphide	0.00002	35	0.01	0.002
Organosulphur compounds	0.00001	0.028		
Alcohol	0.00001	0.127		
Others	0.00005	0.023		
Paraffin hydrocarbons		0.1		
Aromatic hydrocarbons		0.2		
Trace		0.5		

(Source: UK DoE, quoted in EPA (2000), * Ham (1979) quoted by Lisk (1991), Brosseau & Heitz (1994))

Some of the non-methane organic compounds found include benzene, heptane, nonane, acetaldehyde, acetone, and ethylmercaptan (Gandola et al. 1982). Toluene, xylenes, propylbenzenes, vinyl chloride, tetrachloroethylene, methanethiol and methanol have been reported from landfills that received both municipal and industrial wastes (O'Leary & Tansel 1986). The US EPA (1991) listed 94 non-methane organic compounds found in air emissions from municipal solid waste landfills, which included benzene, toluene, chloroform, vinyl chloride, carbon tetrachloride, and 1,1,1 trichloroethane. Forty-one are halogenated compounds. One of the limitations of gas composition surveys is the practical one of selecting in advance those compounds to seek by analysis. Of all the surveys found in this review, the survey of landfill gas from the Fresh Kills landfill investigated the most compounds, namely 202. To indicate the range of compounds found, Appendix C shows a sample analysis result for one day (US EPA 1995).

Taking data from a number of sources, El-Fadel et al. (1997) give concentration ranges for a number of categories of trace compounds in landfill gas, as shown in Table 3.2.

Table 3.2 Concentration ranges for certain categories of trace constituents of landfill gas

Category of compound	Concentration range (mg/m ³)
Alcohols	2 - 25000
Organosulphur compounds	3- 240
Halogenated hydrocarbons	1-2900
Aromatic hydrocarbons	30 -1900
Aldehydes	0 - 200
Ketones	0 - 50
Alkanes	20 - 4500
Alkenes	6 - 1100
Cycloalkanes	1 - 1000
Esters	0 - 1300
Ethers	0 - 250

(Source: El-Fadel et al. 1997)

Volatile Organic Compounds (VOCs) can migrate from a landfill or from an associated contaminated groundwater plume through the soil in the form of vapour or can be carried with other gases, such as methane, over considerable distances (Foster & Beck 1996). Once landfill gas enters a house it tends to accumulate in basements. The greatest threat to humans is by inhalation.

There has been the suggestion that the VOCs in landfill gas, together with nitrogen oxides from other sources, could lead to the formation of ozone, a lung irritant (Brosseau & Heitz 1994). Foster and Beck (1996) have estimated human health risk from inhalation of a number of components of landfill gas and differentiate between cancer and non-cancer risks and between the risks to children and to adults.

Table 3.3 Average concentrations of gaseous volatile organic compounds in 66 California landfills

Compound	Average concentration (ppm by volume)
Benzene	2.1
Tetrachloroethylene	5.2
1,1-Dichloroethane	2.8
Dichloromethane	25.7
1,1-Dichloroethylene	0.13
Ethylbenzene	7.3
1,1,1-Trichloroethane	0.62
Trichloroethylene	2.1
Toluene	34.9
Vinyl Chloride	3.5
Methyl ethyl Ketone	3.1
Xylene	2.7

(Source: Lang et al. 1989a, 1989b, quoted by Foster & Beck 1996)

Quantity of landfill gas generated

The rate of gas generation at a landfill site varies throughout the life of the landfill and is dependent on factors such as waste type, organic matter content, depth, moisture content, degree of compaction, landfill pH, temperature, soil type, bacterial content and length of time since the waste was deposited.

Gas quantity can be estimated by using empirical guidelines or mathematical models. Such guidelines suggest that every 1 tonne of degradable waste will produce approximately 6 m³ of landfill gas per year for ten years from the time of emplacement, although this gives a lower total production than the theoretical maximum under optimal conditions (EPA 2000). Foster and Beck (1996) estimate that from 3 to 6 cubic feet are generated per pound of waste (0.2 to 0.4 m³ per kg). Another method of quantifying landfill gas quantity produced is by pumping and measuring. Landfill gas emission has been mathematically modelled by Pelt et al. (1991) and by Eichler et al. (1986).

Landfill gas control

Landfill gas should be controlled and managed in order to avoid any potential risk or damage to human health and the environment. Normally, landfill gas management systems are installed with the following objectives:

- Minimise the risk of migration of LFG beyond the perimeter of the site.
- Minimise the risk of migration of LFG into services building on site.
- Avoid unnecessary ingress of air into the landfill and thereby minimise the risk of landfill fires.
- Minimise the damage to soils and vegetation within the restored landfill area.

- Permit effective control of gas emission.
- Where practicable, permit energy recovery.
- Minimise the impact on air quality and the effect of greenhouse gases on the global climate.

Table 3.4 Trace gas amounts in landfill gas

Compound	Average concentrations (ppb by volume)		
	Zimmerman & Goodkind (1981)	Lang (1989b)	Desourdy-Biothermica Inc. (1989)
Acetone	32500	6838	
Alpha terpinene	11100		
Benzene	5500	2057	960
Butyl alcohol	5200		
Chlorobenzene		82	
Chloroform		245	440
Dichlorobenzene	4110		
1,1-dichloroethane		2801	
1,2-dichloroethane		36	20
1,1-dichloroethylene		130	
Dichloromethane		25694	21950
Diethylene chloride		2835	
Ethylbenzene	21400	7334	
Ethylene dichloride		59	
2-ethyl-1-hexanol	6200		
Ethyl mercaptan	21100		
Styrenes		1517	
Terpene	12400		
Tetrachloroethane		246	550
Tetrachloroethylene	5244		
Toluene	20400	34907	76700
1,1,1-trichloroethane		615	150
Trichloroethylene		2079	710
Trichloromethane			440
Vinyl acetate		5663	
Vinyl chloride		3508	7470
Xylene	14900	2651	10900

(Source: as quoted in Brosseau & Heitz 1994)

Landfill gas may migrate from the landfill by diffusion, convection or transportation by water or leachate. These modes of transport of gases are independent of each other but may occur simultaneously so that some migration control measures may mitigate one without removing the risk presented by others.

The common LFG migration control systems are:

- **Barriers:** properly designed modern landfills have liner systems on the sides and bottom to prevent escape of leachate and landfill gas. While the landfill is being filled, gas may escape to the atmosphere by migrating upwards. However, when a section (cell) of the landfill is full of waste, it is covered with a clay cap, which may include a synthetic barrier layer to control infiltration of rainwater and egress of landfill gas.
- **Venting:** a system of pipes underneath the cap collects landfill gas. This can then be released for atmospheric dispersion.
- **Active control / flaring / energy recovery** (see below for options): suction pumps are used to extract landfill gas, which may be used as a fuel in a turbine or internal combustion engine to generate electricity.

The available management options include:

- Allow LFG to escape to the atmosphere.
- Flare LFG.
- Combust to heat boilers (to produce usable heat).
- Use to fuel an internal combustion engine (to convert to mechanical energy, usually to generate electricity).
- Use to fuel a gas turbine, usually to generate electricity.
- Feed a fuel cell.
- Convert the methane to methanol.
- Deliver purified LFG to a national or regional gas supply.

Hodgson et al. (1988a, 1988b) and Wood and Porter (1986) warn of the possibility of landfill gas migrating through the ground to nearby buildings and of the possible accumulation of some toxic gases (vinyl chloride) before odours are detected. Molton and colleagues (cited by Brosseau & Heitz 1994) warn of the danger of increased migration due to the capping of the landfill. Presumably this applies where active gas extraction and combustion, for instance, does not take place.

Landfill gas combustion products

Air pollutants from combustion of landfill gas depend on the type of equipment used. Emissions from a gas turbine are less significant than those from an internal combustion engine because of the greater amounts of air used and the higher combustion temperature of the turbine. Brosseau and Heitz (1994) quote earlier unpublished research, which suggests that trace gas destruction efficiencies

are of the order of 95% to 99%. Nevertheless, Keller (1988) recommends that trace gases be removed before combustion to reduce human health hazards in the emissions. Dent et al. (1986) report that (i) sulphur and chlorine can react with oxygen in the combustion process to produce corrosive acids which can damage a combustion system and (ii) concentrations of chlorine greater than 100 mg per m³ may be found in the gas during early stages of a landfill.

Landfill leachate

Leachate is defined as any liquid (for instance, precipitation or ingress groundwater) percolating through the deposited waste and emitted from or contained within a landfill. As it percolates through the waste it picks up suspended and soluble materials that originate from, or are products of, the degradation of the waste. The principal organic contents of leachate are formed during the breakdown process described above and its organic 'strength' is normally measured in terms of biochemical oxygen demand (BOD), chemical oxygen demand (COD), or total organic carbon (TOC). The composition of leachate generated from a municipal landfill changes with time as the degradation of the waste continues inside the landfill. Tables 3.5 and 3.6 show typical constituents of leachate formed at different stages of the waste degradation. Först et al. (1989) show how headspace analysis can be used to quantify trace volatile organic compounds in leachate.

Some of the inorganic trace elements may be used as indicators of leachate contamination of groundwater (Looser et al. 1999).

Due to the potential threat of leachate to both the environment, particularly groundwater, and human health, indirect discharges (leachate) from waste disposal are expressly mentioned in Article 10 of the *Groundwater Directive* (CEC 1980). It is therefore important to control and manage it.

Properly designed leachate management systems will accomplish the following objectives:

- To reduce the potential for seepage out of the landfill through the sides or the base either by exploiting weaknesses in the liner or by flow through its matrix.
- To prevent liquid levels rising to such an extent that they can spill over and cause uncontrolled pollution to ditches, drains, watercourses, etc.
- To influence the reaction rates of the processes leading to the formation of landfill gas and leachate. This will also change the time required for chemical and biological stabilisation of the landfill.
- To minimise the interaction between the leachate and the liner.
- In the case of above-ground landfill, to ensure the stability of the waste.

Leachate volumes

Knowledge of the likely leachate generation of a landfill is a prerequisite of a leachate management strategy. Water balances are used to assess likely leachate generation volumes. The commonly used equation (EPA 2000) is

$$L_o = [ER(A) + LW + IRCA + ER(I)] - [aW]$$

Where:

- Lo = leachate volume produced within a landfill (m³/yr);
- ER = effective rainfall (use actual rainfall (R) for active cells of landfill) (m/yr);
- A = area of landfill cell (m²);
- LW = liquid waste (also includes excess water from sludges) (m³/yr);
- IRCA = infiltration through restored and capped areas (m/yr);
- I = surface area of lagoons (m²);
- a = absorptive capacity of waste (m³/tonne);
- W = weight of waste deposited (tonne/yr).

The calculated leachate quantity is used in designing leachate collection and treatment systems and in the design of different landfill cells.

Leachate collection and removal system

An effective leachate collection and removal system is a prerequisite for all non-hazardous and hazardous landfill sites. It is a component of the landfill liner system and its purpose is to allow the removal of leachate from the landfill and to control the depth of the leachate above the liner. The leachate collection system must function over the landfill's design lifetime irrespective of the liquids management strategy being used.

Therefore, any leachate management system should include the following components:

- A drainage layer (blanket) constructed of natural granular material (sand, gravel) or synthetic drainage material (e.g. geonet or geocomposite);
- Perforated leachate collection pipes within the drainage blanket to collect leachate and carry it to a sump or collection header pipe;
- A protective filter layer over the drainage blanket, if necessary, to prevent physical clogging of the material by fine-grained material;
- Leachate monitoring points;
- Leachate collection sumps or a header pipe system by which leachate can be removed.

A landfill liner is used as a barrier to prevent leachate leaving the bottom and sides of a landfill and can also prevent groundwater entering. Note, however, if groundwater levels are such that it would enter the landfill naturally, then groundwater should be managed in some other way to reduce uplift pressures on the liner.

Minimum liner specifications for non-hazardous biodegradable waste landfills are prescribed by the EPA (2000) as

- A minimum of a 0.5 m thick leachate collection layer with a minimum hydraulic conductivity of 1×10^{-3} m/s. (Flow through the layer is calculated by multiplying the hydraulic conductivity by the hydraulic gradient.)
- Above this should be a flexible membrane liner, minimum of 2 mm high-density polyethylene (HDPE) or equivalent.
- Below the leachate collection layer should be a layer (minimum thickness 1 m) of compacted soil with a hydraulic conductivity of not more than 1×10^{-9} m/s compacted in 250 mm (or less) layers. Alternatively, a layer of 0.5 m or thicker of enhanced soil or similar material giving the same level of protection can be used.

Some studies suggest additional design limitations, for instance a leachate depth < 30.5 cm and a leakage rate < 1000 l/ha/day. Most liner designs are based on advective transport only and do not consider diffusive flux of contaminants (Lo et al. 1999).

Landfill liners

Leachate attack of liners

Certain plastics used in liners, such as crystalline polyethylene, polypropylene and polybutylene, were not found to be affected after one year of contact with leachate, but some thermoplastics, such as chlorinated polyethylene, chlorosulfonated polyethylene and polyvinyl chloride, showed some swelling (Rees 1980a).

Liner leakage

Liners may leak because of tears or faults during manufacture, transport, laying, infilling with waste, interaction with leachate or by diffusion. Leakage rates are related to the depth of leachate accumulating on the liner. There is a broad range of quoted synthetic liner leakage rates in the USA. A typical value of 200 litre/ha/day is claimed to be equivalent to a 2 mm diameter hole with a hydrostatic head of 30 mm. Diffusion through the linear material may also be a significant source of groundwater contamination. In the double liner design specified by the Irish Environmental Protection Agency (EPA 2000), leakage through the liner would be retarded by the lower second barrier and collected by the intermediate drainage layer. This not only gives a second level of protection for groundwater but also provides a warning of leakage through the top liner. Some studies have been made of the attenuating effects on leachate constituents of specific clays (see, for instance, Mimides and Perraki 2000), but it is difficult to generalise the results.

Table 3.5 Summary of composition of acetogenic (early phase) leachates sampled from large landfills with a relatively dry high waste-input rate

Determinant	Overall range		Overall values	
	Minimum	Maximum	Median	Mean
pH-value	5.12	7.8	6	6.73
Conductivity ((S/cm)	5800	52000	13195	16921
Alkalinity (as CaCO ₃)	2720	15870	5155	7251
COD	2740	152000	23600	36817
BOD ₂₀	2000	125000	14900	25108
BOD ₅	2000	68000	14600	18632
TOC	1010	29000	7800	12217
Fatty acids (as C)	963	22414	5144	8197
Ammoniacal-N	194	3610	582	922
Nitrate-N	<0.2	18	0.7	1.8
Nitrite-N	0.01	1.4	0.1	0.2
Sulphate (as SO ₄)	<5	1560	608	676
Phosphate (as P)	0.6	22.6	3.3	5
Chloride	659	4670	1490	1805
Sodium	474	2400	1270	1371
Magnesium	25	820	400	384
Potassium	350	3100	900	1143
Calcium	270	6240	1600	2241
Chromium	0.03	0.3	0.12	0.13
Manganese	1.4	164	22.95	32.94
Iron	48.3	2300	475	653.8
Nickel	<0.03	1.87	0.23	0.42
Copper	0.02	1.1	0.075	0.13
Zinc	0.09	140	6.85	17.37
Arsenic	<0.001	0.148	0.01	0.024
Cadmium	<0.01	0.1	0.01	0.02
Mercury	<0.0001	0.0015	0.0003	0.0004
Lead	<0.04	0.65	0.3	0.28

Note: All values in mg/l except pH and conductivity (S/cm).

(Source: UK DoE, quoted in EPA 2000)

Leachate toxicity

Leachate can be highly toxic (Clément et al. 1996). Methods have been developed for rapid toxicity tests of leachate prior to release into sewage treatment plants (Ward et al. 2000). A cancer risk analysis conducted in the US which focused mainly on leachate indicated that 60% of Municipal Solid Waste landfills posed a cancer risk of less than one in 10 billion, another 6% posed a risk of less than one in a billion and 17% presented a risk of less than one in a million (Chilton & Chilton 1992). Assmuth (1996) furnishes a detailed consideration of the difficulties in developing risk indices.

Lead and zinc are the metals most easily leached from old landfills (Assmuth 1992), with concentration distributions skewed towards small values and irregular spatial distributions but with some maximum concentrations exceeding drinking water standards.

Important factors in exposure modelling

If a leak does occur from a landfill, or when considering older, unlined landfills, the most important groundwater flow variables influencing exposure through water abstraction in wells have been determined by Mills et al. (1999) as follows:

- Net recharge to groundwater,
- Source width,
- Hydraulic gradient,
- Hydraulic conductivity of waste materials,
- Longitudinal dispersivity coefficient,
- Distance to groundwater receptor,
- Source length.

A substantial body of literature exists on the transport of contaminants by groundwater. A widely used computer model is MT3DMS (Zheng & Wang 1999, Zheng et al. 2001), which can support the modelling of biological and geochemical processes as well as advective transport, diffusion and dispersion. However, the modelling of leachate transport is complicated by the large number of components with different transport mechanisms, some floating on the groundwater, some dissolved in it and some more dense components tending to sink downwards through the aquifer. Each may also have its own biological and geochemical reaction mechanisms and rates. In Ireland, modelling difficulties are also compounded by the high degree of spatial variability and inhomogeneity in groundwater systems, which require special care in characterising the flow system and in calibrating and verifying the model. Difficulties arise with preferential flow paths, fracture and karstic flow systems, which, if not adequately modelled, can result in overly optimistic predictions of contaminant travel times, concentrations and exposure risks.

Leachate treatment

The main constituents of leachate requiring treatment are the ammoniacal content and the organic constituents of the leachates. Treatment methods may be divided into four categories.

- Physical/chemical pre-treatment (e.g. air stripping of methane or ammonia and precipitation or flocculation).
- Biological treatment (e.g. activated sludge, sequencing batch reactors, rotating biological contactors, combined leachate and urban wastewater treatment, anaerobic treatment, and biological nitrogen removal).
- Combination of physical-chemical and biological treatment (e.g. membrane bioreactor, powdered activated carbon, or filtration).
- Advanced treatment (activated carbon adsorption, reverse osmosis, chemical oxidation, evaporation, and reed bed treatment).

Protection of groundwater and surface water

Good landfill design includes provisions for the management and protection of both groundwater and surface water.

A groundwater management system is required to minimise or prevent:

- Interference with the groundwater regime during the landfill construction period;
- Damage to the liner (by uplift);
- Transport of contaminants from the landfill;
- Leachate generation by preventing groundwater infiltration.

Hydrology and groundwater protection issues are first dealt with at the site selection phase. These have been addressed in a set of guidelines for groundwater protection, issued jointly by the Geological Survey of Ireland and the Environmental Protection Agency (DoELG, EPA & GSI 1999).

Modern design requires monitoring systems to detect the movement through the ground of either leachate or landfill gas (EPA 2000). Because of the relatively slow speed of movement of water through the ground, there may be a significant time lag between the occurrence of a leak and the detection of contamination at a monitoring point. However, the slow movement also means it is likely the contaminant plume will not have a wide extent when detected.

A surface water management system is required to minimise:

- Leachate generation, by providing for surface water runoff, preventing surface ponding and the infiltration of water into the fill;
- Transport of contaminants from the landfill;
- Degradation of the liner or cover material.

Modern landfill design, with its double liner and capping systems, aims to minimise emissions of leachate and landfill gas from a landfill. This is in contrast with the 'dilute and disperse' policies applied previously. As a consequence, care is needed when inferring effects from observations of emissions at older landfills.

Table 3.6 Summary of composition of methanogenic (mature phase) leachates sampled from large landfills with relatively high waste-input rate

Determinant	Overall range		Overall values	
	Minimum	Maximum	Median	Mean
pH-value	6.8	8.2	7.35	7.52
Conductivity ((S/cm)	5990	19300	10000	11502
Alkalinity (as CaCO ₃)	3000	9130	5000	5376
COD	622	8000	1770	2307
BOD ₂₀	110	1900	391	544
BOD ₅	97	1770	253	374
TOC	184	2270	555	733
Fatty acids (as C)	<5	146	5	18
Ammoniacal-N	283	2040	902	889
Nitrate-N	0.2	2.1	0.7	0.86
Nitrite-N	<0.01	1.3	0.09	0.17
Sulphate (as SO ₄)	<5	322	35	67
Phosphate (as P)	0.3	18.4	2.7	4.3
Chloride	570	4710	1950	2074
Sodium	474	3650	1400	1480
Magnesium	40	1580	166	250
Potassium	100	1580	791	854
Calcium	23	501	117	151
Chromium	<0.03	0.56	0.07	0.09
Manganese	0.04	3.59	0.3	0.46
Iron	1.6	160	15.3	27.4
Nickel	<0.03	0.6	0.14	0.17
Copper	<0.02	0.62	0.07	0.13
Zinc	0.03	6.7	0.78	1.14
Arsenic	<0.001	0.485	0.009	0.034
Cadmium	<0.01	0.08	<0.01	0.015
Mercury	<0.0001	0.0008	<0.0001	0.0002
Lead	<0.04	1.9	0.13	0.2

Note: All values are in mg/l except pH value and conductivity (S/cm).

(Source UK DoE, quoted in EPA 2000)

Table 3.7 Contaminant concentrations in landfill leachate runoff from municipal co-disposal landfills in Finland

Variable	Median	Mean	Maximum	Number of samples	Ranges of results from other countries
pH	7		8.6	208	6.2 - 8.2
Cl (mg/l)	130	220	1800	141	359-4130
NH ₄ -N (mg/l)	14	46	340	153	59-1380
COD	200	400	2200	52	273-21260
As	< 6	9.5	760	177	56 - 243
Cd	< 6	0.8	70	248	2.7 - 18
Cu	20	22	190	248	22-336
Ni	12	260	3200	72	48 - 701
Pb	3	0.7	63	136	29 - 249
Zn	90	1200	110000	255	150 - 13000
Dichloromethane	19	520	5700	53	64 - 20000
CHCl ₃	< 0.1	0.82	100	53	15 - 21800
1,2-dichloroethane	2.6	55	680	53	5.5 - 20000
Tetrachloroethane	0.34	3.3	110	30	26 - 23600
Toluene	0.61	53	1500	66	7.5 - 660000
Xylenes	0.5	100	2400	66	12 - 48000
Ethylbenzene	< 0.1	48	980	66	n.a.
1,2-dichlorobenzene	< 0.1	0.31	2.8	54	10 - 32
Hexachlorobenzene	< 0.01	0.51	10	54	n.a.
2,4,6-Trichlorophenol	0.098	0.82	6	29	n.a.
Pentachlorophenol	0.083	0.15	3	29	n.a.
Cresols	4.2	78	870	47	n.a.
Lindane	< 0.05	0.43	15	46	n.a.
Dieldrin	< 0.05	0.058	1.1	49	n.a.
DDT isomers	< 0.05	0.023	0.23	49	n.a.
PCBs	< 0.05	0.49	3.8	36	n.a.
AOCls	37	160	3200	111	5000-360000

Note: All values, other than pH, as mg/l.

(Source: Assmuth 1992)

Future directions for landfills

Landfill as a reactor

At present the active life of a MSW landfill, during which the waste is being decomposed, is estimated as over fifty years. There is considerable interest in techniques for shortening this time because it has the potential of reducing overall costs and risks. To do this, the landfill is considered as a bio-reactor in which the degradation processes must be accelerated. A substantial quantity of water must be added to a landfill cell if methane production is to be optimised. The temperature should be maintained at approximately 40°C. Rates of water addition of 1 to 2 m (i.e. 1 to 2 cubic meters per square meter of landfill area) per year have been suggested as a suitable compromise between the required moisture and the negative effect of lowering the temperature (Rees 1980b). However, the raising of the moisture content will increase leachate leakage if the liner has been damaged.

Sustainable landfill

Westlake (1997) distinguishes between environmental pollution and contamination. He points out that prevention of pollution from landfill cannot be guaranteed and, from the viewpoint of sustainable landfill, urges (i) a risk-based approach to site selection, design and operation and (ii) further research into proposed management options, such as the bio-reactor mentioned above.

Summary

In summary, this chapter considers emissions from landfills. A landfill is where waste is deposited in a series of compacted layers in specially constructed cells either on the land surface or in holes created on the land surface by excavation. The main potential impacts on health are due to inhaled landfill gas and leachate contaminated groundwater. Both are highly complex mixtures and vary considerably from site to site and with waste composition and age of the landfill. Although landfill gas consists mainly of methane and carbon dioxide, it can contain hundreds of other gases at low concentrations, some of which are toxic. Combustion of landfill gas consumes a large amount of these but some dangerous gases are still emitted. Leachate is a liquid generated by ingressing water moving through the waste and picking up some of the products of the waste decomposition. Current design practice requires a double liner system to protect groundwater from pollution. Any leaks through the upper protective layer are collected by an intermediate drainage layer, which also provides a warning of the leakage. Comprehensive design guidelines have been provided by the Irish Environmental Protection Agency in a series of landfill manuals. These (EPA 1995a, 1995, 1997, 1999, 2000) are now in effect mandatory requirements.

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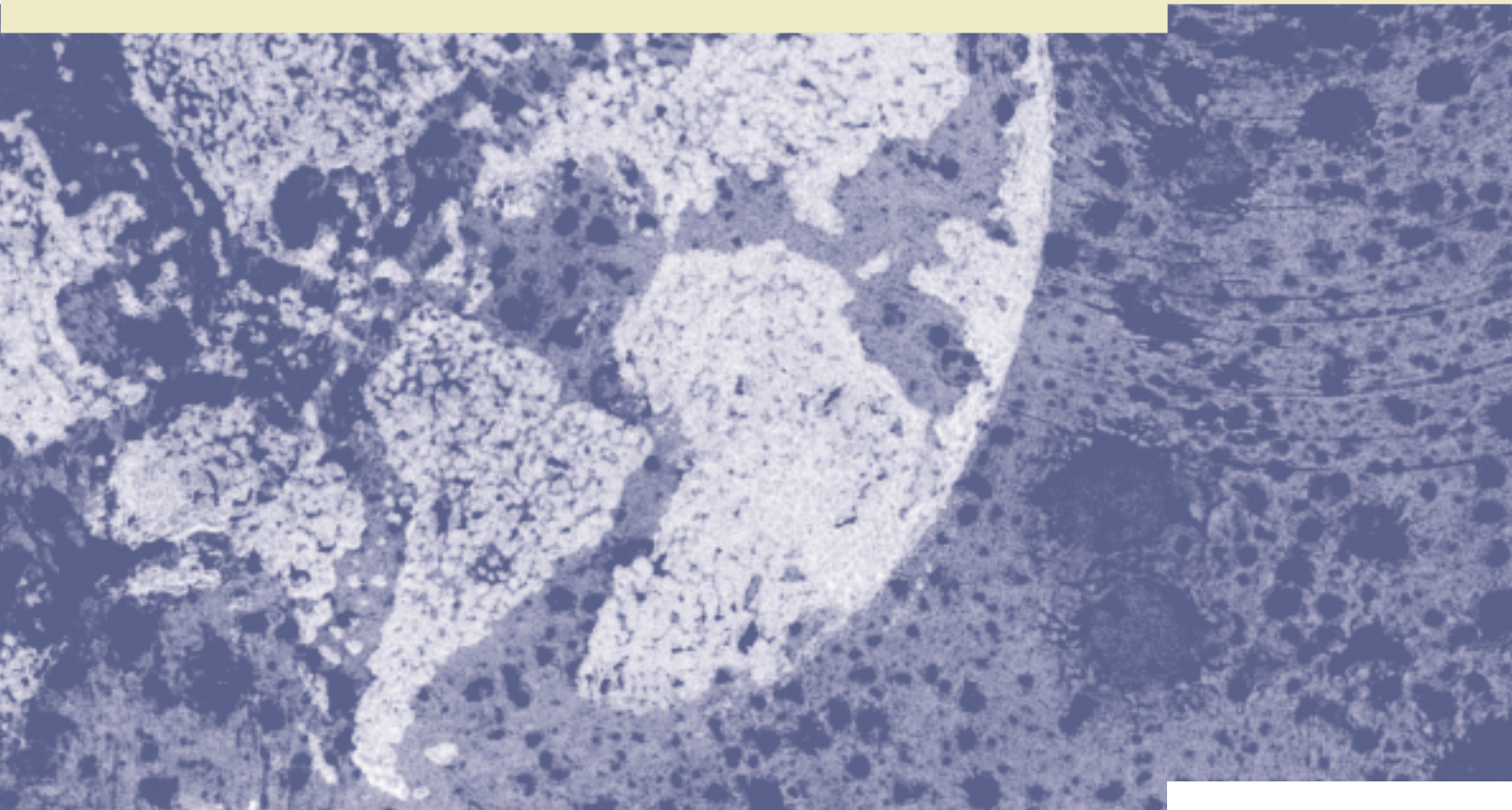
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Chapter Four: Incineration of Waste



Chapter Four: Incineration of Waste

Introduction

The controlled burning of wastes at temperatures in excess of 850°C in the presence of air is referred to as incineration. The wastes can arise from industrial, municipal and domestic activities and can be in the solid, liquid or gaseous state. The principal types of materials which are incinerated include industrial hazardous and non-hazardous waste, commercial waste, municipal domestic refuse, hospital waste and some agricultural wastes. In industry, gas streams that are contaminated with low levels of volatile organic or odour-causing compounds may be fed through existing liquid/solid incinerators or, in many instances, may be treated by a combustion process commonly referred to as thermal oxidation or fume incineration. Where human remains are burned under similar conditions the term cremation is used to describe the incineration process. The mass destruction of farm animals during the recent foot and mouth epidemic in the UK by burning in open pits would not normally be classified as incineration due to the lack of any control on the combustion process. Environmental impacts were directly attributable to this burning operation, with significant emissions of sulphur dioxide, nitrogen oxides, particulate matter, volatile organic compounds and dioxins (Department of Health (UK) 2001).

The demand for incineration has arisen for a number of reasons. In Ireland municipal waste, consisting of both domestic and commercial waste, amounted to some 1,933,450 tonnes in 1998 (Crowe et al. 2000), of which 91.4%, or 1,766,765 tonnes, were landfilled, with the remaining 8.6% being recovered. It was reported that the total amount of municipal waste is growing at the rate of some 3.8% annually. Over the three-year period from 1995 to 1998, domestic refuse collected for management increased by 13.3%, while commercial waste arisings grew by some 44.5%. This increased growth, along with the low level of recovery and recycling, has brought about a 7.2% increase in the amount of municipal waste going for landfill. There has been a significant number of regional waste management plans, many of which include the thermal treatment of waste, otherwise referred to as incineration, as an integral part of the waste management strategy (Rudden 1999, 2001). Furthermore, a number of studies into the feasibility of thermal treatment/recovery options have been conducted (Crowe et al. 2000).

Incineration will bring about a ten-fold reduction in the volume (equivalent to a 70% loss of weight) of solid refuse treated and hence will extend the life of existing and proposed landfill sites. The high temperatures existing in incinerator furnaces also ensure the destruction of pathogens, such as fungi, bacteria and viruses, that may be present in the wastes. New landfills are being sited further from the source of the waste so that not only must the environmental impacts of the landfill operation be considered, but the effects of the collection and transport of the waste must also be assessed. Incineration may lead to a significant reduction in these environmental effects and may paradoxically be seen as a net contributor to the reduction of greenhouse gas emissions. The heat that is released in the high-temperature furnaces can be used to generate electricity and can also be employed in the provision of steam for both district heating and process plant applications. Incineration is also, however, associated with the emission of solid, liquid and gaseous pollutants, including, SO_x, NO_x, CO_x, PM, HCl, HF, PCBs, PAHs, dioxins and furans, ash, fly ash and trace metals (see Glossary in Appendix B). In recent years a number of applications have been made by private companies for

planning permission to construct incineration plants. However, to date planning permission has been granted only to Indaver Ireland to construct a 150,000 tonne/annum municipal waste facility near Carranstown, Co Meath. This permission is at present subject to appeal.

The need for industrial waste incineration has arisen from concerns over the disposal of an ever-increasing number of materials which are considered to be hazardous. The *Toxic And Dangerous Waste Directive (78/319/EEC)* defined 'toxic and dangerous waste' as any waste containing or contaminated by the substances listed in the Annex to this Directive. The Annex listed some 29 categories of substances and materials which required priority consideration. Using this list, McMahon (1980) reported that some 20,000 tonnes of such wastes arose in Ireland. The Hazardous Waste Directive (91/689/EEC), on the other hand, has significantly increased the range of wastes defined as hazardous. In the *National Waste Database Report* Crowe et al. (2000) reported that some 370,328 tonnes of hazardous wastes were generated annually in Ireland. This quantity of waste is substantially greater than that of 1980. However, the numbers reflect not only a general increase in waste arisings due to increased industrial activity and development, but also (i) the wider definition of waste used in collecting the statistical data, (ii) more comprehensive data collection, and (iii) better record keeping as a result of the introduction of the Integrated Pollution Control licensing by the EPA (S.I. 1994).

The disposal of hazardous wastes to landfill requires the availability of chemically secure hazardous waste landfills. No general-purpose chemically secure landfill site exists in Ireland, although some landfills will accept some hazardous wastes which are considered to pose an acceptable risk. Some hazardous wastes are also considered unsuitable for long-term storage. Incineration is seen as a reliable disposal process, which will destroy some hazardous wastes and reduce risks associated with their disposal. While many of the EU Member States have established central hazardous waste treatment facilities, which include incineration as an integral part of the overall hazardous waste management, no such facility exists in Ireland. The *National Hazardous Waste Management Plan* (EPA 2001) has identified as one of the priorities for 2001-2006 'the development of hazardous waste landfill capacity and thermal treatment for hazardous wastes requiring disposal to achieve self sufficiency and reduce our reliance on export'. The provision of a hazardous waste landfill cell at an existing landfill site was the favoured option as the establishment of a dedicated landfill site was considered to be unnecessarily expensive. This lack of waste management infrastructure has led to the necessity of installing hazardous waste incineration facilities in existing pharmaceutical and fine chemical production plants. All of these facilities have received IPC licences from the EPA. In 1998, it was estimated that some 65,364 tonnes of largely solvent waste were incinerated, of which some 47,752 tonnes were incinerated abroad. Table 4.1 summarises the destinations of all waste exported for incineration in 1998.

Incineration in Ireland has had its share of controversy and legal challenges. In 1985, the Hanrahan family sought 'injunctions restraining the operation of the factory (Merck Sharp and Dohme of Ballydine, Co Tipperary) in a manner resulting in the damaging emissions complained of and claiming damages for the personal injuries and material damage alleged'. Merck Sharp and Dohme is an American pharmaceutical company that had been established on a green-field site in the early 1970s. The High Court case failed: however, on appeal to the Supreme Court, substantial damages were awarded against the company. Three possible sources of harmful emissions were implicated, the main boiler-house stack, other point sources from the main process building and the incinerator stack. The low operating temperature of the incinerator was cited as one of the possible reasons for the generation of harmful emissions. Other cases have related to appeals against the granting of planning

permissions or integrated pollution control licences by the EPA. The most recent case involved the application by Roche Ireland to construct an incinerator at the factory site in Clarecastle, Co Clare. This state-of-the-art incinerator has been constructed and has been operational since 1999.

Table 4.1 Hazardous waste incineration

Country	Total quantity exported (tonnes)	Thermal treatment (tonnes)
UK	34,188	9,773
Holland	30,162	6,367
Germany	13,192	11,154
Belgium	10,554	10,381
Denmark	8,820	8,714
Finland	1,362	1,362
USA	88	0
France	27	0
Totals	98,393	47,752

(Source: Crowe et al. 2000)

Waste incineration

Incineration of waste in purpose-built plants was first used in the UK in the 1870s. However, it was not until the 1960s that significant numbers of incineration plants, with and without energy recovery, were constructed. The growth in large urban areas and the reduction in available landfill sites close to the source of waste facilitated this development. Economic rather than environmental or health factors were the main driving force of this expansion of large-scale waste incineration. For example, between the late 1960s and early 1970s some 40 new municipal waste incinerators were constructed in the UK. In the early 1990s more stringent European legislation and the growing environmental demands saw the introduction of ever more stringent environmental controls. By December 1992, 28 incinerators were still in operation in the UK and this number was further reduced to five operational incinerators by the close of 1996, burning some 1.8 million tonnes of waste. The costs of complying with the EU Directives have caused the closure of many of the smaller, older incinerators. The *Directive on the Incineration of Waste* (2000/76/EC) has introduced even more restrictive emission limits, which are bound to impact on incineration. The new standards will apply to new plants by the end of 2002 and to existing plants by the end of 2005.

At present, there are 304 large-scale municipal incinerators in Europe in 18 countries (ASSURE 2001) (Table 4.2). Most of these incinerators (96%) recover energy and it has been estimated that the total amount of recovered energy is equivalent to the annual electricity demand of a country the size of Switzerland. It was also reported that the trend currently in Europe is towards the construction of fewer and larger plants with improved energy efficiency, more sophisticated environmental controls and lower unit costs.

Table 4.2 Incineration facilities in other countries

Country	Incineration facilities	Incineration facilities (2001)	Waste incinerated (2001) %	Plants with energy recovery (2001) %
Belgium	28	29	51	90
Denmark	38 (1992)	42	70	100
France	280 (1985)	307	42	25
Germany	47 (1986)	47	35	100
Luxembourg	1	1	69	100
Netherlands	11	12	40	60
Spain	8 (1987)	22	6	50
Sweden		23	55	86
UK	48	30	7	33
USA	78	152	16	83
Japan		1,900	75	-

(Source: South East Regional Authority, available at: www.sera.ie/wm/framef.html)

Waste composition

Municipal waste is composed of a large number of diverse constituents. One form of waste analysis, referred to as a compositional analysis, is listed in Table 4.3. Commercial waste consists mainly of paper, while domestic waste has a significant organic fraction. The energy content of a material is reported as its calorific value and municipal waste is roughly equivalent to a medium-grade coal in terms of its energy content.

Table 4.3 Composition analysis of domestic and commercial waste in Ireland

Category	Domestic waste (%)	Commercial waste (%)
Organics	32.9	15.1
Textiles	2.9	0.6
Metals	3.5	1.7
Plastic	11.9	10.6
Glass	5.5	3.4
Paper	19.5	58.6
Other	23.8	9.9

(Source: Crowe et al. 2000)

An ultimate analysis of waste that lists the percentage of the principal elements contained in the refuse is given in Table 4.4. When municipal waste is combusted, the main elements listed below are volatilised and converted into gaseous products. Hence, when 1000 kg of municipal waste is burned, approximately 700 kg are volatilised as gaseous products and the remaining material is converted to

ash. The primary products of combustion consist of carbon dioxide (CO₂), water vapour (H₂O), nitrogen oxides (NO_x) and sulphur dioxide (SO₂). Other lesser constituents, such as chlorine and fluorine, will be converted predominantly to the acid gases, hydrogen chloride and hydrogen fluoride.

Table 4.4 Ultimate analysis of municipal waste components

Component	Percentage by weight					
	Carbon	Hydrogen	Oxygen	Nitrogen	Sulphur	Ash
Food Wastes	48	6	38	2.5	0.5	5
Paper/Cardboard	43.5	6	44	0.3	0.2	6
Plastics	60	7	23			10
Glass	0.5	0.1	0.4	<0.1		90
Metals	5	0.6	4.3	0.1		90
Clothing/Textiles	55	7	30	5	0.2	3
Ashes/Dust	26	3	2	0.5	0.2	68
Combustible MSW	23.6	9	66.4	0.7	0.3	0

(Source: Kiely 1997)

Table 4.4, however, does not include the trace metals, which also comprise an important group of constituents present in municipal waste. Nine of the 35 metals commonly reported in municipal waste, together with their concentrations in the waste, are listed in Table 4.5. Buekens et al. (1995) suggested a number of mechanisms whereby metals can move from the burning refuse to different media:

- (i) they remain in the burning solid fraction and form part of the ash, slag or clinker,
- (ii) they become mechanically entrained with the combustion gases, e.g. droplets of molten aluminium,
- (iii) they are vaporised as the metal, e.g. mercury, cadmium, zinc, etc.,
- (iv) they react and convert to another chemical form such as the oxide, sulphate (in the presence of sulphur dioxide) or chloride (in the presence of hydrogen chloride) and then take routes (i), (ii) or (iii).

The metals entrained in the flue gas can condense as a fine aerosol, adsorb onto the surface of fly ash particulates, be captured in air pollution control equipment or escape with the flue gases from the stack gas. The metals are sometimes classified as volatile, e.g., mercury (Hg), thallium (Tl), cadmium (Cd), zinc (Zn), or as non-volatile metals, nickel (Ni), iron (Fe), chromium (Cr). Mercury has been reported as being one of the more difficult metals to remove from the flue gas emissions. It has been suggested (Reimann 1995) that mercury is an excellent indicator for the presence of other metals in the flue gas emissions. If the concentration of mercury in the flue gas is lowered to less than 0.05 ng/m³, all other metal limits will usually be met. Rechberger (2000) has suggested that incineration ash generation might be considered a means of conserving valuable resources such as cadmium, mercury, lead, zinc, etc., since they are effectively concentrated in this medium.

Table 4.5 Concentrations of metals in municipal refuse

Metal	Concentration g/tonne*	Concentration g/tonne**
Cadmium	10-40	1-33
Chromium	100-450	30-2760
Copper	450-2,500	60-2080
Iron	25,000-75,000	Not available
Lead	750-2,500	390-1830
Mercury	2-7	0.5-11.4
Nickel	50-200	
Tin		60-520
Zinc	900-3,500	470-6530

(Source: Farmer & Hjerp 2001*, Reimann 1995**)

Municipal waste is a mixture of many different materials but it is treated as a homogenous substance. Industrial hazardous waste arises as individually well-defined wastes with a broad range in composition. Hence, no general compositional data are relevant to industrial hazardous wastes except in so far as they will contain combustibles, metals and non combustibles, which will generate similar emissions to those of municipal wastes.

Municipal waste combustion

Incineration conditions in municipal incinerators should provide for an adequate supply of oxygen, a gas phase residence time of at least two seconds in the combustion zone, a temperature of at least 85 °C and good mixing conditions to ensure complete combustion of the municipal waste. These conditions should ensure the complete combustion not only of the main refuse constituents but also of the trace quantities of refractory compounds such as furans, dioxins, polycyclic aromatic hydrocarbons and other toxic organic compounds. Dioxin levels in municipal waste have been reported to be present in the range of 10-256 I-TEQ ng/kg (Riemann 1995). However, these compounds have also been associated with emissions from municipal incinerators.

During incineration the following processes can occur:

The heat radiating from the furnace walls and ceiling, the flow of preheated air fed through the grate, and the ignition of other MSW constituents present on the grate dries out the waste. Volatile constituents such as water, mercury and its salts, solvents, etc., are vaporised at this stage.

The waste undergoes a series of well-defined thermal decomposition reactions, e.g., cellulose at 370 °C, PVC 280-465 °C, polythene (PE) 480 °C. Volatiles are emitted leading to local oxygen deficiencies, HCL is released from PVC and reactions may take place with metals to form the metal chlorides.

The residue remaining undergoes a period of further combustion to complete the oxidation reactions.

The volatiles, which have been driven off, will be combusted in the over-fire primary combustion chamber (PCC) or will be further oxidised in a secondary combustion chamber (SCC) in the presence of additional fuel and combustion air. Typically, in modern well-run incinerators the temperature of the SCC is maintained at 1000 °C and the gas phase residence time is of the order of two seconds. These conditions will ensure the destruction of the partially oxidised materials from the PCC.

The formation of dioxins and furans in incinerators is associated with reactions which occur after the combustion zone in the heat recovery section and air pollution control equipment. The *de novo* synthesis hypothesis postulates that carbon, hydrogen, oxygen and chlorine in the presence of a solid catalyst can form aromatic hydrocarbon structures, including dioxins and furans. Fly ash is thought to provide the catalytic sites necessary for the reactions to take place. Furthermore, the reactions take place at lower temperatures than those of the typical combustion zone. Much work needs to be done to establish fully the mechanisms for the formation and destruction of dioxins by this pathway. A second theory, referred to as the precursor hypothesis, suggests that chlorinated aromatic hydrocarbons, such as chloro-phenols (PCPhs) and chloro-benzenes (PCBzs) can act as precursors to the formation of dioxins and furans. Polycyclic aromatic formation may occur when incomplete combustion conditions arise in the combustion zone. In a recent report (Everaert & Baeyens 2001) it was strongly argued that, while the precursor theory may be applicable to pilot and laboratory studies, the *de novo* hypothesis is more relevant to full-scale municipal waste incinerators because of the following observations:

Precursor formation is strongly overestimated in laboratory scale apparatus.

The PCDD/PCDF fingerprint according to the precursor hypothesis predicts a PCDF/PCDD ratio much less than unity. The *de novo* synthesis favours a furan/dioxin ratio that is greater than unity, typical of municipal incinerators.

The *de novo* synthesis model also correctly predicts the distribution of organochloro-compounds.

The product distribution of PCBz/PCPh/PCDF/PCDD remains constant along the flue gas pathway. This behaviour is not consistent with the precursor hypothesis.

While some studies have indicated that PVC in municipal waste is the primary source of chlorine that is incorporated into dioxins and furans, work reported by Wikstrom et al. (1995) indicates that both organic and inorganic forms of chlorine are equally effective in providing the chlorine needed for dioxin and furan synthesis.

Upon exiting the SCC, the hot gases, typically at temperatures in excess of 900 °C, and with more demanding emission limits at temperatures in the order of 1000 °C, will pass into the heat recovery section. The energy that is released by the combustion of the waste can be used for electricity generation or in combined heat and power plants (CHP) for the generation of both electricity and steam for district heating applications or manufacturing processes.

It is generally reported that dioxin formation will not begin to take place in the flue gases until the temperature has fallen below 450 °C (UNEP 1999), and that the maximum rates of formation occur in the vicinity of 300 °C and will continue to be important until the temperature falls to 250-200 °C. The presence of fly ash is critical to this process. Much research work has concentrated on understanding the mechanisms of dioxin formation in order that formation rates may be controlled. One of the main barriers to effective control of dioxins would appear to be the non-availability of rapid/continuous instrumental methods of dioxin analysis. The lack of on-line dioxin analysis has led researchers to attempt to correlate operational parameters as indicators of dioxin formation rates. One such report (Everaert & Baeyens 2001) suggests that the temperature of the flue gas exiting the electrostatic precipitator correlates well with dioxin emissions. There is no doubt that a fuller understanding of dioxin interactions in the post-combustion zone will lead to better control strategies

to reduce or even eliminate dioxin emissions from both the flue gases and the ash and fly ash residues. Clearly, significant improvements in combustion control strategies have resulted in significant reductions in dioxin emissions. For example, Table 4.6 summarises data for PCDD/PCDF levels in municipal fly ash and bottom ash for German incinerators in the late 1980s in comparison with present-day technology.

Table 4.6 PCDF/PCDD in municipal incinerator ash

Waste type	Concentration ng I-TEQ/kg	Sample comments
Municipal Incineration Fly Ash	10,000	Mean, Germany, late 80s
	<1,000	New technology, Germany
Bottom Ash	50	Mean, Germany, late 80s
	5-20	New technology, Germany
Home Heating Systems Soot	4-42,048	Wood, Coal, Germany

(Source: UNEP 1999)

Recent dioxin inventories from a number of countries (UNEP 1999) have also shown significant reductions in dioxin emissions to air due to municipal and hazardous waste incineration. Some of the reductions in the inventory estimates are due to the closure of older plants, which could not be upgraded to meet the more stringent EU emission limits of the early 1990s; however, the improvements in both operating practice and air pollution control also have contributed significantly to the improved estimates. Table 4.7 shows a selection of reported atmospheric dioxin emissions for Sweden, Denmark and the Netherlands for either 1990 or 1995 in comparison with those estimated for 2000.

Table 4.7 Dioxin emissions to atmosphere

Country	Incineration source	1990/5	2000
Sweden	Municipal Waste	96.2	9.9
	Hazardous Waste	7.3	4.9
Netherlands	Municipal Waste	382	2-4
	Hazardous Waste	16	1.7
Denmark	Municipal Waste	20	21.1
	Hazardous Waste	0.27	0.135

(Source: UNEP 1999, Hansen et al. 2000)

Types of municipal incinerators

Municipal waste, unlike much of the industrial hazardous waste, is solid by nature. Furthermore, as the waste stream is heterogeneous, special furnaces are required to deal with the wide range of materials that are present in municipal waste. There are three main approaches which have been adapted for the incineration of municipal waste, (i) mass burning, (ii) fluidised bed and (iii) refuse or waste derived fuel (RDF, WDF) (WHO 1996, Indaver Ireland 1999). Some newer technologies, such as pyrolysis and gasification, which are beginning to penetrate the incineration market, will be described later in this chapter.

Mass burning refers to the combustion of municipal waste with only rudimentary preparation and separation of the waste. A variety of moving grates have been used to facilitate the movement of the waste through the combustion zone. Plants are large-scale and have tended to dominate the municipal waste incineration market in the past. Different furnace designs use a variety of moving grate elements, e.g., roller system, reciprocating system, reverse reciprocating, rocker system, continuous L-stoker system, W-grate system, rotary kiln, etc. The grate ensures the passage of the burning refuse through the combustion zone and also allows the provision of adequate supplies of air to guarantee complete combustion of the waste, and ash removal.

In fluidised bed systems, smaller combustion units are used and there is some pre-processing of the waste to facilitate the operation of the fluidised bed. A bed of inert solid particles is fluidised by the flow of combustion air from beneath the bed. Pre-treatment of the waste to provide a uniform feed material, by crushing and shredding processes, is required prior to combustion. Fluidised bed processes are beginning to make progress in the traditional mass-burn market, particularly for smaller-scale projects.

In WDF or RDF systems, municipal waste is pre-processed using several sorting and shredding stages to produce either, a stable dry 'fluff', which can be burned on site, or a densified pellet product, which may be burned with coal in a conventional power generation or district heating plant. Because of the atmospheric pollutant potential, the trend seems to be for on-site combustion in plant which has been properly equipped with appropriate air pollution controls.

Of the 23 Swedish municipal waste incinerators, for example, sixteen are grate-type mass-burn facilities and the remaining seven are fluidised beds (Rylander 2000). The Eastbourne Local Collection Authority, UK, collected some 31,000 tonnes of refuse in 2000-01, 50% of which was converted to RDF for use in conventional industrial solid fuel boiler systems. On the Isle of Wight, some 50,000 tonnes per annum of refuse are processed to produce a densified RDF; the densification plant is operated by the local authority, some 1,250 of ferrous metal are recovered and 15,000 tonnes of d-RDF are generated. The residual waste is sent for landfill and the d-RDF is burned in a dedicated power generating plant. The vast majority of municipal waste-to-energy plants are, however, of the mass-burn design.

Waste is normally delivered to a waste reception bunker where a certain amount of inspection, segregation and homogenisation may take place. The waste is fed to the combustion zone. Combustion takes place on the grate or fluidised bed in the primary combustion chamber. Once burned, the residue or ash is collected from the furnace and any fly ash passes along to subsequent stages with the combustion gases. The heat content of the flue gas can be recovered in the boiler system by the generation of steam. This steam can be used to produce electricity or used in district heating schemes for residential apartments, hotel space, prisons, industrial applications, etc. The heat recovery section will effect a cooling of the flue, which can then be treated to remove a selection of the flue gas contaminants to meet the stringent emission standards now in force throughout the EU.

Hazardous waste incineration

Much of what has been said about the combustion of municipal refuse also applies to the incineration of industrial hazardous wastes. Usually the combustion of liquid wastes presents fewer operational difficulties, lower emissions to atmosphere and minimal ash and fly ash generation. When mixtures of both solid and liquid wastes are incinerated, there is little difference between industrial hazardous waste and municipal waste incinerators and the air pollution controls that are needed.

Hazardous waste incinerators

While there are a number of different types of industrial hazardous waste incinerators, the most common types used in the Irish context are the liquid injection incinerator and the rotary kiln. The former, as the name suggests, is used for the destruction of liquid wastes that can be pumped or injected into a combustion chamber. The incinerator consists typically of a primary combustion chamber into which liquid is sprayed and mixed intimately with the combustion air. The combustion zone provides sufficient time, ample turbulence, oxygen (as excess air) and the high temperatures to ensure complete destruction of the waste materials. Residence times of some two seconds at temperatures in excess of 850 °C are maintained in the combustion zone. When halogenated liquids (>1 % chlorine) are burned, temperatures in excess of 1100 °C are required. In some applications, the combustion zone may also be used to remove low concentrations of volatile organics, such as fumes and odours, from other streams arising at a site.

The rotary kiln incinerator is a general-purpose device, which is used to destroy a broad range of liquid, semi-liquid and solid materials. This incinerator can deal with wastes such as contaminated cardboard drums, plastic gloves, protective overalls, off-specification products, etc. This type of kiln is similar to the rotary kiln that is used in the cement industry and for municipal waste incineration. In some countries, cement kilns are being used to burn hazardous waste streams, such as solvents, and thus utilise the energy content of the waste to produce the cement clinker in what are designated as co-incineration plants. The rotary kiln is followed by a secondary combustion chamber (SCC) in which auxiliary fuel or a high calorific waste is used to ensure complete combustion of the products released in the kiln. The residence time of the gases in the SCC are typically two seconds at temperatures in excess of 850 °C for non-halogenated wastes and 1100 °C for those wastes containing more than 1% chlorine.

The combustion of solids leads to the generation of fly ash in a similar manner to municipal waste incineration. For low capacity incinerators, the recovery of heat is not considered because of the extra cost of the boiler system. For large-capacity incinerators, heat recovery takes place in a steam boiler following the SCC. As with municipal waste incineration, flue gas cleaning follows the boiler and consists of a variety of air pollution control measures.

Emission factors of selected pollutants per tonne of waste incinerated are included in Table 4.8. Emissions for municipal waste incineration refer to a 'modern' incinerator with acid gas and particulate abatement emission controls. The factors used for dioxin emissions are obtained for plants with both scrubber and carbon injection.

Table 4.8 Typical emission factors of selected constituents from incinerators

Component	MSW incinerator (kg /tonne)	Industrial waste incinerator (kg/tonne)
Sulphur Dioxide (SO ₂)	0.4	0.07
Oxides of Nitrogen (NO _x)	1.8	2.5
Carbon monoxide (CO)	0.5	0.125
Hydrochloric acid (HCl)	0.5 - 0.03	0.105
Lead (Pb)	0.0008	0.0035
Cadmium (Cd)	0.0001	0.003
Mercury (Hg)	0.0011	0.003
∑PCBs	5.8 x 10 ⁻⁶	not reported
∑PAHs	160 x 10 ⁻⁶	0.00002
PCDD/F (Dioxins, Furans)	0.5 µg I-TEQ/tonne ^d	0.5 µg I-TEQ/tonne

(Source: European Environment Agency 1999)

Air pollution control

Air pollution control is necessary for both municipal and hazardous waste incinerators and the general principles are applicable to both processes. Ultimately, the control of the flue gas emissions will involve tailoring the feed and also the optimisation of the combustion and post-combustion operational parameters. Significant improvements in the control of both NO_x and dioxin emissions may be achieved using techniques such as the staged addition of air to the combustion process and the recirculation of the flue gases through the combustion zone. However, at present the emission control is implemented using downstream processing techniques by the staged removal of the major polluting elements generated in the combustion process. The three principal constituents are nitrogen, carbon dioxide and water vapour. While not a pollutant per se, carbon dioxide is a designated greenhouse gas (so too are nitrous oxide (N₂O), methane (CH₄), the perfluorocarbons (PFCs), the halofluorocarbons (HFCs) and sulphur hexafluoride (SF₆)). However, it has been argued that the combustion of waste with energy recovery will (i) reduce the consumption of valuable fossil fuels and (ii) prevent the disposal of waste to landfill and hence reduce the generation of both methane and carbon dioxide.

Upon leaving the energy recovery section, the flue gases will have been cooled to 250-200 °C. At these temperatures, some flue gas constituents will begin to condense from the gas stream. For example, some 85% of cadmium, 75% of arsenic, 30% of lead, 25% of zinc and 15% of chlorine will have condensed (Reimann 1995). The fly ash will act as condensation nuclei for these substances so that it will also act as a concentrator for certain constituents of the flue gas. Unburned carbon deposits on the fly ash will also act as an adsorbent to further concentrate the flue gas constituents. The air pollution control processes target specific constituents of the flue gas and may consist of some or all of the following techniques:

- Electrostatic precipitation (EP) to remove particulates:
- Wet scrubbing (WS) to remove acid gases and particulates:

- Spray dryer absorption (SDA) to neutralise acid gases:
- Fabric or bag filtration (BF) to collect particulate matter:
- Reduction of nitrogen oxides (Denoxification) using selective catalytic reaction (SCR) or selective non-catalytic reaction (SNCR) with ammonia or urea injection for both NO_x and dioxin reactions. Selective catalytic reduction (SCR) uses titanium, vanadium or tungsten oxides in the temperature range 300-400 °C. Both SCR and SNCR reduce the NO to N₂:
- Active carbon adsorption for both mercury and PCDD/PCDF removal.

Other controlling techniques include dioxin filters consisting of charcoal or coal dust, used in Denmark (Buekens & Huang 1998), and novel technologies such as plastic filters (Kriesz et al. 1997) for dioxin adsorption have been reported. Most modern municipal waste incinerators today use either adsorption (activated carbon, cokes or lignite) or catalytic reduction to reduce emissions of dioxins and furans (Everaert & Baeyens 2001).

In a recent report, *Substance Flow Analysis for dioxins in Denmark*, (Hansen et al. 2000) measured dioxin emissions from a number of municipal waste incinerators with a selection of installed flue gas cleaning controls. A total of 2.7 million tonnes of municipal waste was incinerated in 1999 and the total emissions to atmosphere of the dioxins was estimated to be in the vicinity of 21 g I-TEQ/annum. Table 4.9 summarises the effectiveness of the different control strategies; the inclusion of dioxin filters has led to significant reductions in dioxin emissions.

Table 4.9 Dioxin emissions to air from municipal waste incineration in Denmark

Flue gas cleaning process		Dioxin concentration ng I-TEQ/Nm ³				Waste incinerated 1000 tonnes	Dioxin emission g I-TEQ/year	
		Mean	Min	Max	Samples		Best estimate	Assumed interval of uncertainty
No	Wet	1.49	0.1	5.6	7	1,240	17.3	9 - 35
Dioxin Filter	Semi-dry	1.40	1.3	1.5	2	348	2.9	1.5 - 6
	Dry	0.26	0.04	0.75	5	252	0.3	0.15 - 0.6
Dioxin Filter		0.068	0.005	0.254	5	839	0.5	0.25 - 1
Sum						2,679	21.1	11 - 42

(Source: Hansen et al. 2000)

In a recent study of nine Japanese municipal incinerators (Sam-Cwan et al. 2001), removal efficiencies of PCDDs/PCDFs by a selection of air pollution control processes were reported. Best removal efficiencies of 99% were obtained with SNCR-SDA/BF followed by rapid cooling of the flue gases.

Following the air pollution control stage, the flue gas is emitted through a stack, the height of which is related to the requirement of achieving adequate dispersion of the flue gas to minimise ground-level concentrations of selected pollutants. To avoid the formation of a visible plume it is usually

necessary either to dilute the flue gases with air prior to stack discharge, or to reheat the flue gases prior to discharge. In a recent WHO technical document (WHO 1996) it was confidently concluded that, with the advent of the newer air pollution controls and with the application of even stricter atmospheric emission standards, waste management facilities may be permitted within 300-500 m of residential areas by local authorities.

Siting of incinerators

Site selection for waste management facilities is a complex and difficult task, yet it is perhaps one of the most important aspects of waste management. In the absence of top-quality waste management facilities there will be a growth in un-controlled waste disposal and inadequate levels of recovery, re-use and recycling. There are many aspects to the siting of waste management facilities; however, in this section only those aspects relating to site selection will be summarised. Hazardous waste management facility criteria are listed to illustrate conservative location considerations for incineration facilities. Screening criteria are often used as a general tool to differentiate between generally suitable and un-suitable sites. Table 4.10 summarises some of the main factors which the US EPA (1997) suggest may be used to eliminate certain general areas as suitable locations for hazardous waste management facilities.

Table 4.10 Locations that should not be considered for the siting of hazardous waste management facilities

Location	Environmental consequences
Floodplains	Waste ponds may wash out. Tanks may be moved from foundations.
Wetlands	Fish and wild-life are threatened. Spills are spread to groundwater and surface water faster. Cleanup is difficult, costly, and sometimes more damaging.
Land Use	Sensitive populations such as elderly, children, and the sick are more affected by toxic exposures.
High-Value Groundwater	Contaminants are transported quickly. Cleanup is costly and difficult.
Earthquake Zones	Ground fractures and shaking damage structures, leading to spills.
Karst Terrain	Sinkholes can form, causing the collapse of buildings and accidental spills.
Unstable Terrains	Mass movement of soil can cause structures to shift and crack causing contaminant release.
Unfavourable Weather Conditions	Air contaminants are not easily dispersed. Pollutants may be concentrated.

(Source: US EPA 1997)

The World Health Organisation (Sloan 1993) recommends that the following list of exclusionary criteria should be used in all cases for the siting of new hazardous waste management facilities:

- Unstable or weak soils, such as organic soil, soft clay or clay-sand mixtures, clays that lose strength with compaction, clays with a shrink-swell character, sands subject to subsidence and hydraulic influence, and soils that lose strength with wetting or shock
- Subsidence owing to solution-prone subsurfaces, subsurface mines (for coal, salt and sulphur) and water, oil or gas withdrawal
- Saturated soils, as found in coastal or riverine wetlands
- Groundwater recharge, as in areas with outcrops of aquifers of significant or potential use, considering water availability and regional geology (where an impermeable or retarding layer shields the aquifer from the land surface, a specific site analysis should be conducted)
- Flooding, as in flood plains or hydraulic encroachment, coastal or riverine areas with a history of flooding every 100 years or less, and areas susceptible to stream-channel or storm encroachment (even if not historically subject to flooding)
- Surface water, which precludes sites above an existing reservoir or a location designated as a future reservoir, or above an intake for water used for human or animal consumption or agriculture and within a distance that does not permit response to a spill based on high-flow (most rapid) time of travel
- Atmospheric conditions, such as inversions or other conditions that would prevent the safe dispersal of an accidental release
- Major natural hazards, such as volcanic action, seismic disturbance (of at least VII on the modified Mercalli scale) and landslides (see USGS National Earthquake Information Centre, Denver, Colorado, for a full explanation of this earthquake intensity scale (<http://www.neic.cr.usgs.gov/neis/general/handouts/mercalli.html>)).
- Natural resources, such as the habitats of endangered species, existing or designated parks, forests and natural or wilderness areas
- Agricultural or forest land of economic or cultural importance
- Historic locations or structures, locations of archaeological significance and locations or land revered in various traditions (The intention is to prevent not only damage or contamination but also visual, aural or functional encroachment.)
- Sensitive installations, such as those storing flammable or explosive materials, and airports
- Stationary populations, such as those of hospitals and correctional institutions
- Inequity resulting from an imbalance of unwanted facilities of un-related function or from damage to a distinctive and irreplaceable culture or to people's unique ties to a place

While the above criteria are strictly applicable to hazardous waste management facilities, they may also be applied in general to waste management facility planning. The employment of exclusionary

criteria does not replace a detailed site investigation and environmental impact assessment. The use of very general considerations may lead to the rejection of possible sites within certain areas. The screening stage should also highlight those regions with which the waste management facility might be more compatible, for example,

- Areas that have already been zoned for industrial use,
- Existing waste management facilities, such as an existing landfill site,
- Abandoned properties,
- Areas with good rail, road and port access,
- Lands close to the source of the waste.

Many regions have legislation giving minimum distances between waste facilities and other land use areas. The World Bank (1999) recommends a minimum of 300-500 m from residential zones for the siting of incineration facilities. It is also recommended that incinerators should be located near controlled/well-operated landfills in areas zoned for medium or heavy industry within an hour of the waste source. Before siting a facility, health and environmental risk assessments should be carried out on the site and its surroundings. Waste management facilities, such as incinerators, can have effects on surface water, surrounding land, groundwater and air quality and can contribute to traffic, noise and other environmental impacts. Dispersion modelling is often used to predict the concentrations of emissions at selected distances from the stack based on the emission characteristics, the local topology and meteorological data. Air emissions modelling for major developments may extend to a distance of some 30 km downwind of the site (Sloan 1993); however, it is unlikely that waste management facilities in Ireland, because of the scales involved, would warrant this scale of environmental impact assessment.

Regulation of incineration

In Ireland, seven pharmaceutical and fine chemical manufacturing facilities include hazardous waste incineration on their sites. Under the Environmental Protection Agency (Licensing) Regulations, 1994 (S.I. No. 85 of 1994), both the manufacture of chemicals, and hazardous waste incineration are activities which require Integrated Pollution Control (IPC) licences. Before the EPA can grant an IPC licence, it must be satisfied that 'BATNEEC (best available technology not entailing excessive costs) will be used to prevent or eliminate and where that is not practicable, to limit, abate or reduce an emission from the activity' (EPA 1996). The EPA has identified the types of technologies that may be used for a licensable activity and these technologies form the basis for setting emission limit values (ELVs) of selected pollutants. In the identification of BATNEEC, emphasis is placed on pollution prevention techniques, including cleaner technologies and waste minimisation, rather than end-of-pipe treatment. In the case of incineration, Table 4.11 lists those technologies that may be used for air pollution control of hazardous waste incineration operations.

Table 4.11 Technologies to treat air emissions

Emission	Technology								
	Scrubber	Filter	Biofilter	Cyclone	Wet ESP	Thermal	Combined filter, lime and activated carbon injection	Odour control	Afterburners
Particulates		X		X	X		X		X
Sulphur and compounds	X		X				X		
Nitrogen and compounds			X						
Halogens and compounds	X						X		
Metals, metalloids, etc.		X		X	X		X		
Organic compounds	X		X				X		X
Phosphorus and compounds	X						X		
Odours	X		X					X	X
Water Vapour						X			

(Source: EPA, BATNEEC Guidance Notes 1996)

The approach to activity licensing has changed somewhat with the Council Directive 96/61/EC, *Integrated Pollution Prevention and Control* (IPPC). This will extend the range of activities that require licences. There will be a greater emphasis on energy efficiency, residuals management and the reduction of natural resource consumption than was present heretofore. All existing IPC licences will have to be compliant with IPPC by 2007. BATNEEC will be replaced by the principle of Best Available Techniques (BAT), which in turn will be based on BAT Reference (BREF) documents currently being developed for each sector by the EU.

A total of 28 classes of significant waste disposal and recovery activities require licensing by the Environmental Protection Agency (The Waste Management (Licensing) (Amendment) Regulations, S.I. No. 162 of 1998) under the Waste Management Act 1996. The waste licence is similar to the IPC licence, the intent being to ensure that waste recovery and disposal activities operate with minimal environmental impacts.

The emission limit values which are applicable to the incineration of waste are specified in the annexes of the *Directive on the Incineration of Waste* (2000/76/EC). This Directive applies to all incineration and co-incineration processes which include the following;

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

- Any stationary or mobile plant whose main purpose is the generation of energy or production of material products and which uses wastes as a regular or additional fuel or in which waste is thermally treated for the purpose of disposal.

Table 4.12 shows the daily average air emission limit values applicable to waste incineration for some of the major polluting contaminants.

Table 4.12 Daily average atmospheric emission limit values

Parameter	mg/m³
Total Particulate matter	10
Volatile organic compounds (expressed as total organic carbon)	10
Hydrogen Chloride (HCl)	10
Hydrogen Fluoride (HF)	1
Sulphur Dioxide (SO ₂)	50
Nitrogen monoxide (NO) and nitrogen dioxide (NO ₂) expressed as nitrogen dioxide (>6 tonne/h)	200
Nitrogen monoxide (NO) and nitrogen dioxide (NO ₂), expressed as nitrogen dioxide (<6 tonne/h)	400

(Source: CEC Directive 2000/76/EC)

The atmospheric emission limit values that have been placed on metals are listed in Table 4.13.

Table 4.13 Daily average atmospheric emission limit values for metals

Metals and their compounds	mg/m³
Cadmium and thallium taken together	0.05
Mercury	0.05
Antimony, arsenic, chromium, cobalt, copper, lead, manganese, nickel, tin and vanadium, and their compounds, taken together	0.5

(Source: CEC Directive 2000/76/EC)

Furthermore, the Directive confirms the emission limit values for dioxins as 0.1 ng I-TEQ/m³ to be sampled over a six to eight hour period. These strict emission limit values are expected to effect a significant reduction in atmospheric emissions from existing incinerators, which will have to be compliant with this Directive by the end of 2006. All new incinerators have to be compliant with the above requirements as of 2003.

In the application of the air pollution control techniques, both liquid and solid residues may be generated. Water is required to cool both the bottom ash after it leaves the combustion chamber, and in the wet scrubbers to remove acid gases and particulate matter. The wastewater stream will therefore contain trace metals, particulate matter, dioxins and furans. It will also include hydrochloric acid (HCl), hydrofluoric acid (HF), sulphuric acid (H₂SO₄), nitric acid (HNO₃) and carbonic acid (HCO₃). If a caustic solution is used in the scrubber system, the wastewater will also contain sodium chloride (NaCl) and sodium sulphate (Na₂SO₄). If lime is used, compounds such as calcium sulphate

(CaSO₄), calcium chloride (CaCl₂), calcium carbonate (CaCO₃) will be present. In the case of liquid effluents, the Directive has therefore placed strict ELVs on the discharges for both trace metals and dioxins (Table 4.14).

Table 4.14 Emission limit values for discharges from the cleaning of exhaust gases

Total suspended solids as defined by Directive 91/271/EEC	95% of samples must be less than 30 mg/l 100% of samples must be less than 45 mg/l
Mercury and its compounds, expressed as mercury (Hg)	0.03 mg/l
Cadmium and its compounds, expressed as cadmium (Cd)	0.05 mg/l
Thallium and its compounds, expressed as thallium (Tl)	0.05 mg/l
Arsenic and its compounds, expressed as arsenic (As)	0.15 mg/l
Lead and its compounds, expressed as lead (Pb)	0.2 mg/l
Chromium and its compounds, expressed as chromium (Cr)	0.5 mg/l
Copper and its compounds, expressed as copper (Cu)	0.5 mg/l
Nickel and its compounds, expressed as nickel (Ni)	0.5 mg/l
Zinc and its compounds, expressed as zinc (Zn)	1.5 mg/l
Dioxins and furans, defined as the sum of the individual dioxins and furans evaluated as I-TEQ	0.3 mg/l

(Source: CEC Directive 2000/76/EC)

Solids generated in the flue gas purification processes are also covered by the *Directive on the Incineration of Waste* (2000/76/EC). Such residues have to be minimised in terms of 'quantity generated' and their 'harmfulness', and where appropriate they should be recycled internally within the incineration plant or externally 'in accordance with relevant Community legislation'. When considering the possible disposal or recycling options for residues, appropriate tests to establish their physical and chemical characteristics and their polluting potential have to be performed. Specifically, the Directive refers to the possibility of leaching of soluble constituents, such as trace metals and dioxins, from the recovered fly ash and activated carbon additives. Fly ash and bottom ash may be treated by a variety of processes, including melting, solidification and stabilisation, treatment with chemical agents, extraction, ferrous removal and vitrification. Fly ash is more susceptible to leaching than bottom ash (Ruth 1998). Products have been made from ash, including tiles, insulating material, piping and blocks for erosion control and construction (Pecqueur et al. 2001). Dioxins in fly ash can be destroyed by thermal treatment or by base-catalysed decomposition (BCD). At present, where recycling is not an option, the solid residues are likely to be classified as hazardous wastes and will require landfill in an appropriate landfill site.

The hazardous waste incinerators that have received IPC licences are listed in Table 4.15. Some of the liquid injection incinerators burn both liquid and vapour streams; two of the sites have the capacity for solids combustion. The IPC licence specifies the ELVs for atmospheric and water emissions and the disposal/recovery routes for the residues. The licence also covers such requirements as sampling frequency, record keeping, annual reporting, waste management system/programme, etc.

Table 4.15 Hazardous waste incinerators in Ireland

Name	Location	Type
Lawter International	Grannagh, Co. Kilkenny	Liquid Injection
SmithKline Beecham	Currabinny, Co. Cork	Liquid Injection ((3)
Novartis	Ringaskiddy, Co. Cork	Liquid Injection
Novartis	Ringaskiddy, Co. Cork	Pulsed Hearth (Solid)
Yamanouchi	Mulhuddart, Co. Dublin	Liquid Injection
Eli Lilly	Kinsale, Co. Cork	Liquid Injection
Eli Lilly	Kinsale, Co. Cork	Rotary Kiln (Solid /Liquid)
Swords Labs	Mulhuddart, Co. Dublin	Liquid/Gas
Roche	Clarecastle, Co. Clare	Liquid Injection

(Source: EPA website for Integrated Pollution Control Licences available at www.epa.ie)

Typical monitoring requirements are specified in the *Waste Incineration Directive* as follows:

The following measurements of air pollutants shall be carried out in accordance with Annex III at the incineration and co-incineration plant:

- Continuous measurements of the following substances:
- NO_x, provided that emission limit values are set, CO, total dust, TOC, HCl, HF, SO₂.
- Continuous measurements of the following process operation parameters:
 - temperature near the inner wall or at another representative point of the combustion chamber as authorised by the competent authority, concentration of oxygen, pressure, temperature and water vapour content of the exhaust gas.
- At least two measurements per year of heavy metals, dioxins and furans; one measurement at least every three months shall, however, be carried out for the first 12 months of operation. Member States may fix measurement periods where they have set emission limit values for polycyclic aromatic hydrocarbons or other pollutants (2000/76/EC).

The small number of measurements required annually for dioxins and metals reflect the difficulties and costs involved in such measurements. For example, it is not unusual for a company to employ a specialist firm to supervise the sampling of the flue gas for dioxins. The samples are then sent abroad, to the UK or elsewhere, for analysis. Clearly, such spot checks are not satisfactory and do not serve in any way to influence directly the day-to-day operation of the incineration facility. The EC (OJ C 322/02) has identified the 'measurement methods and standards' for dioxins and dioxin-like PCBs as one of the 'major gaps in our knowledge'. An action plan must be developed which will allow for the implementation of an effective strategy for the monitoring and control of such substances in human health and the environment.

The EPA also conducts un-announced visits to IPC-licensed facilities and takes spot samples as they consider appropriate. In 2000, the EPA carried out a total of 2,033 monitoring and inspection visits. This compliance monitoring activity included full audits at 46 IPC facilities. Of the ten facilities that were found to be compliant, eight were in the chemical sector and this high compliance rate for the

chemical sector is consistent with results from previous audits. Of the remaining facilities, seven had minor non-compliances, 23 were more significant and six plants were to be found in serious breach of their IPC licences. The Food and Drink sector was reported to have the highest level of complaints, non-compliance with IPC licence audits and the highest level of prosecutions. No hazardous waste incineration facility was reported to be non-compliant. To date, despite the shortcomings identified above, there are no indications that dioxins and metal emissions have had negative impacts on the environment in the vicinity of IPC-licensed facilities.

Proposed incinerators

Recently there have been a number of proposals to site municipal waste management facilities (WMF) in Ireland. Table 4.16 summarises the most recent proposed projects at time of submission. The Thermal Waste Management application for planning permission for a WMF at Kilcock has been rejected. No information is available as to the future plans of this company. The two Indaver Ireland WMFs are well advanced and the technical details are available. All of the other projects are only at the early stages of planning and firm details are not yet forthcoming.

Table 4.16 Recent WMF proposals

Name	Location	Area	Type	Waste type	Capacity (tonnes/yr)
Thermal Waste Management (Ireland) Ltd.	Kilcock, Co. Kildare	R	Rotary Kiln	Municipal Industrial Hazardous Waste	50,000 100,000
Indaver Ireland	Carranstown, Co. Meath	R/I	Grate	Municipal waste	150,000
Indaver Ireland Phase I	Ringaskiddy, Co. Cork	I	Fluidised Bed	Hazardous Industrial Commercial	100,000
Indaver Ireland Phase II	Ringaskiddy, Co. Cork	I	Grate	Municipal waste	100,000
Dublin Corporation Public Private Partnership	Poolbeg, Dublin	U		Municipal waste	
Waterford/ Kilkenny (Waste to Energy)				Municipal waste	
Connaught Region (Waste to Energy)				Municipal waste	

(R = rural, I = industrial, U = urban)

(Source: EPA website for Integrated Pollution Control Licences, available at www.epa.ie)

Indaver Ireland applied for planning permission for a municipal waste management facility at Carranstown, Co Meath. This proposal was granted planning permission on 31/07/2001 and it is subject to a Bórd Pleanála appeal. The facility will include provision for a 150,000 tonne/annum incineration facility, which will produce approximately 11 MW of electricity annually. Two identical grate furnaces and boilers will be built which will operate at a minimum of 850 °C. A five-stage air pollution control scheme is proposed which it is claimed will meet the EU emission limit values as specified in the *Directive on the Incineration of Waste (2000/76/EC)*. The location of the facility is close to the Platen cement works and also close to a number of ESB substations, which will facilitate the export of the electricity that will be generated on site. The proposal also includes facilities to recycle local household and industrial waste.

In Cork, Indaver Ireland proposes to construct a waste management facility along similar lines to the Meath facility. However, the waste to energy plant will be constructed in two phases. The first phase waste to energy facility is for a 100,000 tonne/yr fluid bed incinerator, which will deal with hazardous wastes from local industry and also non-hazardous solid wastes from both industry and commercial sources. Progress to a second phase, in which it is envisaged that a 100,000 tonne/yr waste to energy grate incinerator for municipal waste will be constructed, will depend on the local authority regional waste plans. Planning permission for this proposal was sought in November 2001. No decision has yet been made by the Planning Authority.

Miscellaneous combustion processes

Fume incineration/oxidation

The elimination of emissions of volatile organic compounds (VOCs) from solvent storage tanks, nitrogen blanketing, wastewater treatment, etc., is often achieved using thermal or catalytic oxidisers. In some reports, these devices are referred to as fume or VOC incinerators. In some instances, an industrial plant that has installed liquid/solid hazardous waste incineration capacity will burn the VOC gas/fume streams in the incinerator. Thermal oxidation is achieved by burning a fuel such as natural gas using the fume/VOC gas stream to supply the necessary combustion air. The hot combustion gases are typically used to preheat the cold feed streams to reduce energy consumption in the process. In some instances, recuperators are used to recover the energy; however, regenerative thermal oxidisers, although more costly, are generally more efficient. Thermal or catalytic destruction of organic vapours is viewed as an air pollution control process rather than a hazardous waste incineration activity. Operating temperatures are generally in excess of 850 °C. Where chlorinated solvent fumes are incinerated, an operating temperature of 1100 °C is specified and stringent emission limit values are set. No information is currently available on possible dioxin emissions from this source but, as no fly ash is produced, it is likely that dioxin emissions will be low and similar to those arising from oil or natural gas combustion processes.

Medical waste incineration

Hospital waste can be categorised as 'specific hospital waste' and 'other hospital waste'. Specific hospital waste includes human anatomic remains and organ parts, waste contaminated with bacteria, viruses and fungi, and large quantities of blood. The two main types of medical waste incinerators are classified as 'Starved Air' and 'Excess Air'. These incinerators are made up of two chambers with burners in each. In 'Starved Air' units the waste is pyrolysed in the primary combustion chamber and

complete combustion is ensured in the secondary chamber. The 'Excess Air' incinerator operates with 60-200% excess air in the first chamber. Alternative heat treatments for medical wastes include steam treatment (autoclaving) or thermal inactivation of the wastes by bringing the temperature above 900 °C to destroy all cytotoxic compounds and pathogenic organisms. Autoclaving does not reduce the volume of the waste and the waste must still be disposed of in landfill. Only two hospitals in Ireland hold IPC licences for the incineration of hospital waste: Our Lady's Hospital for Sick Children and Adelaide & Meath Hospital. Neither incineration facility is operational at present.

Cremation

Cremation is a combustion process in which human remains are burned, resulting in the formation of ash and atmospheric emissions. In Ireland, there are three crematoria in operation. The Glasnevin Cemeteries Group operates its main unit in Glasnevin and a smaller unit at Newlands Cross. The third crematorium is located at Mount Jerome Cemetery. In 1999, a total of 1604 cremations took place and it is expected that this number, though small in comparison to Japan where 99% of all bodies are cremated, and the UK where the cremation rate is 70% of all deaths, will increase at a modest rate. It has been reported that crematoria can be sources of air emissions including trace metals, particularly mercury, and dioxins. The *European Dioxin Inventory (2000)* suggests that emission rates can be estimated using a typical emission factor of 8 (g I-TEQ/cremation (minimum value 3 (g I-TEQ/cremation; maximum value 40 (g I-TEQ/cremation). The estimated contribution of cremations to the overall annual emission of dioxins is 13 mg I-TEQ.

The scale of cremation in Ireland is very small compared with other European countries. Each crematorium must have planning permission and is also required to conform to the UK *Guidelines for Crematoria* issued by the Secretary of State (DoE UK 1995). This document is issued 'as a guide to local authorities on the techniques appropriate for the control of air pollution in relation to crematoria to ensure that, in carrying on a prescribed process, the best available technologies not entailing excessive cost (BATNEEC) will be used'.

Other miscellaneous combustion sources

It is generally accepted that when combustion reactions take place, depending on conditions and the type of material combusted, the emissions referred to earlier in connection with incineration will be present to a greater or lesser extent. To help put these emissions in perspective, Table 4.17 summarises the best estimates of the annual dioxin emissions to atmosphere from the main sources of these pollutants (Malone & Barrett 2002). The base year for these data is 1999 and since then the Irish Ispat steel plant in Haulbowline, Co Cork, which was estimated to contribute some 6.2% of the total estimates, has closed. The total amount of dioxin emitted was estimated to be between 6 and 20 g I-TEQ/annum, with the major single source being identified as accidental fires. There are large uncertainties in these estimates and more research needs to be done to verify the data presented here. The EPA is awaiting the results of a more extensive study, which will provide a more complete dioxin inventory for Ireland.

Table 4.17 Estimated dioxin atmospheric releases from specific sources in Ireland

Source	Emission estimate (g I-TEQ/a)			% Total
	Typical	Min.	Max.	
Coal combustion (industrial and power generation)	0.600	0.15	2.40	7.36%
Electric furnace steel plant	0.495	0.07	3.50	6.07%
Cement production	0.502	0.16	1.58	6.16%
Traffic	0.147	0.02	0.90	1.80%
Cremations	0.018	0.01	0.06	0.22%
Incineration of hazardous waste	0.026	0.03	0.03	0.32%
Coal combustion (domestic)	1.006	0.28	3.66	12.34%
Fires-natural	0.056	0.01	0.31	0.68%
Fires-accidental	3.626	3.63	3.63	44.49%
Illegal combustion of domestic waste	1.000	1.00	1.00	12.27%
Wood combustion (industrial)	0.693	0.47	1.02	8.51%
TOTAL	8.150	5.86	18.65	100.00%

(Source: Malone & Barrett 2002)

Non-incineration technologies

Gasification

Gasification processes partially convert waste to a gaseous fuel by heating in air, oxygen or steam to form synthesis gas. By varying the gasifying agent, the air, oxygen or steam, different mixtures of carbon monoxide, carbon dioxide, methane, hydrogen and water vapour in the product gas may be formed. Ash residue, which is 20-25% by weight of the original waste, must be landfilled or re-used.

Gas produced from the waste is only about 30% of the volume of the flue gas generated from combustion and thus the gas cleaning requirements are significantly reduced (Morris & Waldheim 1998). Synthesis gas may be used in gas-powered engines and turbines or as a starting point for the production of liquid fuels, also termed synfuels (McKendry 2002). A variety of designs, including vertical fixed bed, horizontal fixed bed, fluidised bed, multiple hearth and rotary kiln, have been used in large-scale gasification plants.

A preliminary proposal to build a gasification plant in Ireland to convert municipal or hazardous wastes to synthesis gas and solid residue has been made by a German company KSK-WT GmbH. The gas may be used to produce electricity or as a starting point for the production of chemicals. The solid residue may be further processed to make, for example, insulation materials for construction applications. A ferrous metal stream from the pre-sorting of waste will be produced. Air pollution controls will generate a 'pollutant concentrate' from the gas cleaning equipment, which will be classified as a hazardous waste.

Pyrolysis

Pyrolysis is the thermal processing of waste in the complete absence of oxygen (Tchobanoglous et al. 1993). An external heat source is used to convert organic wastes into gas, liquid and a char-fraction at temperatures of 500-800 °C. Although energy is required for the pyrolysis process, there is usually a net production of gas after energy requirements have been satisfied. The gas stream consists mainly of hydrogen, methane, carbon monoxide and carbon dioxide. By varying the temperature of the process the composition of the gas produced can be controlled, thus minimising the quantities of pollutants generated (Avenell et al. 1996). The liquid fraction is a tar or oil stream with acetic acid, acetone, methanol and complex oxygenated hydrocarbons. When processed further, this oil can be used as a substitute fuel oil. The solid residue is made up mostly of carbon, but contains any inert material originally present in the solid waste. Increasing the temperature reduces the amount of solids produced. Wastes which can be treated using pyrolysis include sorted municipal waste, plastic waste, car-tyres, de-watered sewage sludge, impregnated wood waste, contaminated soil, crushed car and electronics residues (Rudden 2001). By controlling the reaction conditions, the waste can be converted to a range of solid, liquid and gaseous products (Rudden 1999, Ramdoss & Tarrer 1998).

Pyrolysis and gasification can be combined in a two-stage process to give upgraded synthesis gas, or, it is claimed, they can be combined with combustion or melting processes to give higher thermal efficiencies and lower CO₂, NO_x and toxic organic flue gas emissions than incineration (Whiting 2000). Gasification and pyrolysis facilities are usually smaller in scale (less than 200,000 tonnes per year) than incineration facilities. At present, five commercial gasification or pyrolysis plants have been constructed world-wide (in Germany, Japan, France and Switzerland). These processes have only recently been applied to municipal waste treatment and there is still a reluctance to invest in this novel technology (Whiting 2000). In a recent report by Frost and Sullivan for Indaver Ireland (Indaver 1999) in which the European waste-to-energy plants market was analysed, it was found that research and development work in the area of gasification and pyrolysis was substantial, highlighting strong opportunities for the future, with this technology expected to have 30% of the market by 2006; incineration using grate technology is predicted to have 51% and incineration using fluidised bed processes will make up the remaining 19%.

Summary

Incineration is the thermal oxidation of waste at temperatures in excess of 850 °C. Industrial hazardous waste incineration is used by a number of pharmaceutical or fine chemical manufacturing plants in Ireland and there is no central national facility for the incineration of such wastes. The *National Hazardous Waste Management Plan* (EPA 2001) has identified as one of the priorities for 2001-2006 'the development of hazardous waste landfill capacity and thermal treatment for hazardous wastes requiring disposal to achieve self sufficiency and reduce our reliance on export'. In 1998, it was estimated that some 65,631 tonnes of largely solvent waste were incinerated, of which some 47,751 tonnes were incinerated abroad. Indaver Ireland has applied for planning permission for a waste management facility in Cork, with plans to incinerate a mixture of municipal and industrial hazardous wastes.

The incineration of hazardous waste is licensed under the EPA by way of Integrated Pollution Control, which is being replaced by Integrated Pollution Prevention and Control by means of BAT (Best Available Techniques). Monitoring of the emissions from industrial hazardous waste incinerators is

required as one of the licence conditions. No hazardous waste incineration facility was reported to be non-compliant.

Dioxin emissions to atmosphere from the incineration of hazardous waste were estimated to be less than 1% of the total estimated national atmospheric dioxin emissions from all sources. Accidental fires were estimated to be the single largest source of atmospheric dioxin emissions (Malone & Barrett 2002).

Municipal waste is not incinerated in Ireland, although Indaver Ireland has obtained planning permission for a waste management facility which will include a 150,000 tonne/annum waste-to-energy plant (grate incinerator) in Co Meath. This planning decision is the subject of an appeal to An Bórd Pleanála. Indaver Ireland has also applied for a second waste management facility to be sited in Ringaskiddy, Co Cork. This second facility will also include a waste to energy plant, which will incinerate 100,000 tonnes/annum of mixed municipal and hazardous wastes. Municipal incineration is considered to be an integral operation within integrated waste management plans.

In the past, municipal waste incinerators in other EU countries were considered to be one of the major sources of dioxins and other environmental pollution. However, since the early 1990s, the application of stringent emission limit values to a broad range of environmental pollutants has significantly reduced the environmental impacts associated with municipal waste incineration. A combination of improved combustion practices and staged air pollution control techniques allows modern well-run municipal incinerators to meet the environmental requirements embodied in the recent EC *Directive on the Incineration of Waste* (2000/76/EC). Liquid effluents from waste incineration are also regulated to a high level. Solid residues, such as fly ash will probably be classified as hazardous waste and will require the provision of suitable landfill. At present there is no such MSW facility in Ireland. Gasification and pyrolysis are novel emerging technologies, which have the potential for recovering energy from a range of waste types, and will see greater application to municipal waste disposal in future years. The environmental impacts of these processes in comparison with modern incinerator plants have not been fully evaluated.

Dioxin analyses are required on a regular and increasingly frequent basis. There is, therefore, a growing need for dioxin sampling and analytical facilities in a variety of media, including atmospheric emissions, air, soil, water, food, human and animal tissues. It would be important that the facilities were established nationally and that the service would be seen as independent.

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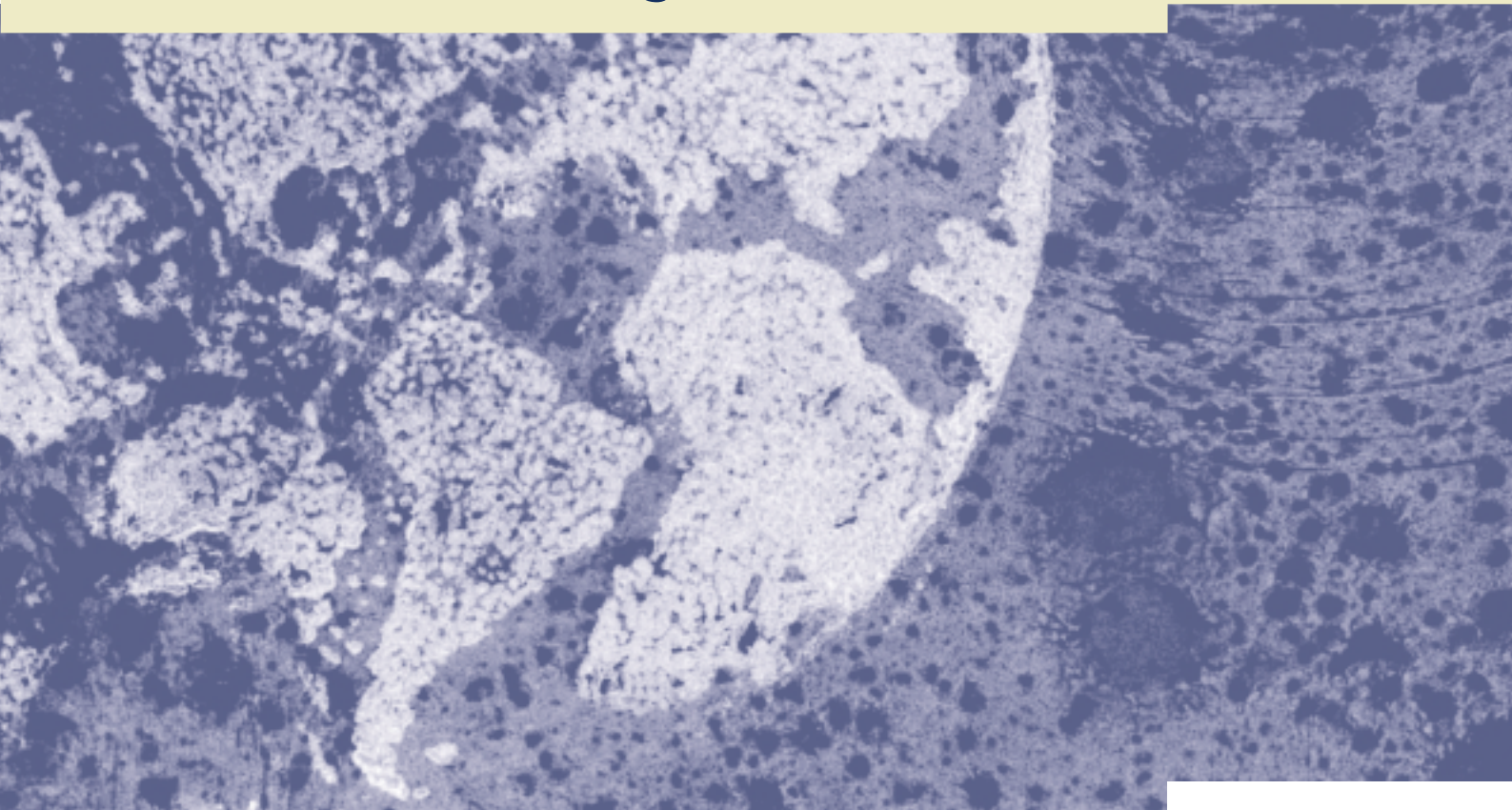
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Chapter Five: The Environmental Effects of Landfilling and Incineration



Chapter Five: The Environmental Effects of Landfilling and Incineration

Introduction

Waste management is a serious problem in most developed countries, including Ireland (DoELG 1998, EPA 2000). It is generally accepted that landfills are a threat to the quality of different components of the environment, although the full extent of these threats has not always been scientifically validated. Potential hazards such as swarms of flies, malodour, smoke, noise, threats to water supplies and increased numbers of vermin are cited as reasons why members of the public do not want to reside close to a landfill.

In response to growing pressures to expand existing facilities or site new landfills, the EU has introduced the *Directive on the landfill of waste* (CEC 1999). This introduces measures to prevent or reduce the negative effects of waste and landfill on the environment. Ireland has set targets whereby the recovery rate for packaging and industrial wastes will have to be greatly improved (Meldon 1998, Clenaghan et al. 1999, Lehane 1999). It is arguable whether these targets adequately meet the levels demanded by the EU, and further measures to curtail and control waste will clearly have to be introduced in the near future. Owing to unsightliness and the threat to terrestrial and aquatic ecosystems, landfilling is giving way to incineration in many communities in Europe. Incineration poses its own potential threats to the environment which need to be objectively assessed and balanced against those of landfilling or any alternative disposal options.

This chapter describes the particular effects of landfilling and incineration on the broader environment (vegetation, whole ecosystems and landscape) together with the specific impacts on soil (compaction, loss, acidification), air (emissions of greenhouse gases) and aquatic ecosystems (pollution of ground and surface water by leachates). The study does not directly address impacts from hazardous waste, which is subject to separate policy and legislation (EPA 1999) and much of which has previously been exported from the country.

This chapter was compiled from a wide range of sources, including materials in the main UCD library and the comprehensive collection in the Department of Environmental Resource Management in the UCD Faculty of Agriculture. Information was also gleaned from recent theses and project work conducted in conjunction with the M.Sc. (Agr.) in Environmental Resource Management and the Diploma in EIA Management. Further materials were obtained or accessed through the Department of Environmental Studies, UCD, the library of the Royal Irish Academy, the EPA offices and the environmental information office (ENFO) in Dublin. A number of recent articles were obtained directly from scientific journals available through the Internet, and websites for several regulatory and scientific agencies were also accessed. These included the EPA (Ireland), EPA (USA), Environmental Agency (UK) and the European Environment Agency. A number of experts actively researching in specific areas were contacted in person or electronically. All of the information collected is available in the Department of Environmental Resource Management, UCD.

Landfill

As described in Chapter Three, all landfill sites where waste decomposition is active produce two main components: landfill gas and leachate (EEA 2000). Once waste is landfilled, complex and variable chemical and biological degradation commences in the presence of moisture and naturally occurring micro-organisms. Five stages are recognised in this degradation, which are designated 'initial adjustment', 'transition', 'acid formation', 'methane fermentation' and 'final maturation' (EPA (US) 1995). Moisture is supplied by precipitation, which also percolates through the landfill, selectively dissolving some materials to create highly acidic leachate. The length of time required to complete the degradation depends to a large extent on the nature of the waste and its degree of compaction. It also varies from cell to cell within a complex modern landfill. Maturation, and its associated pollutant production, can continue for many years after a landfill has been sealed, with the result that impacts have to be monitored well beyond the official closure date (Finnecy & Pearce 1986).

Landfill gas is generated from the decomposition of the organic component of waste, initially under aerobic conditions to produce carbon dioxide (CO₂), but ultimately under anaerobic conditions to produce larger quantities of methane (CH₄) in a dynamic equilibrium of approximately 60% CH₄ / 40% CO₂. Some carbon monoxide (CO) is also produced, but significant CO emissions are mainly associated with burning waste in poorly managed sites (Westlake 1995). Carbon dioxide and methane are greenhouse gases, which were the main focus of the 1997 Kyoto Agreement and of subsequent efforts at world-wide emissions reduction. Landfill sites contribute 20% of the total global anthropogenic methane emissions and possibly 17-58% of emissions in the UK (Eduljee 1995, Hutchinson 1997).

Leachate management is also a major concern. The volume of leachate directly correlates with the precipitation rate, and under Irish conditions this may be larger than in similar landfills in other countries. However, the potential impact of leachate on the environment also depends upon the nature of the material from which it derives. Municipal solid waste (MSW) leachate contains a wide variety of hazardous, toxic or carcinogenic chemical contaminants (EEA 2000), the main constituents being listed in Table 5.1. In uncontrolled instances, mining wastes have also been added to landfill sites. These contain high concentrations of trace metals, a range of acids, and even radioactive material. Sewage sludge and residual solids from air pollution control equipment have also contributed trace metals. Under the acidic conditions hazardous trace metals such as copper, cadmium, zinc and lead dissolve and travel with the leachate. Trace metal contamination of water is globally widespread in industrialised regions, but a major reservoir of these pollutants is contained in landfills and only a fraction of this has yet been released to water bodies (UNEP 1991).

Although it is now a pre-requisite, in the past Irish landfill sites were not lined. This has meant that, for older landfill sites, leachate can migrate to groundwater or even into surface waters. Not surprisingly, contamination of groundwater by leachate has already occurred in Ireland (Donal Daly, GSI, personal communication) rendering it and the associated aquifer unreliable for domestic water supply and other beneficial uses. This is far more serious than river pollution because aquifers require extensive time periods for rehabilitation (UNEP 1991). Some landfills employ the 'biocell' approach in which leachate is recycled through the fill to enhance the rate of waste stabilisation and compress the gas production phase from 30-50 to 5-10 years. This approach has significant environmental benefits, but needs to operate in conjunction with re-utilisation of landfill gas and does not solve the problem of potential leaching of contaminants to groundwater (Jones-Lee & Lee 2000). Ironically, moves to divert cellulosic materials (green waste, wood and paper) away from landfill may reduce methane levels to a point that significantly affects the economics of gas utilisation.

**Table 5.1 Summary list of emissions or effects
of environmental concern from landfill and incinerators**

Landfills		Incinerators	
<i>Gaseous emissions</i> <u>Landfill gas:</u>	-	<u>Flue Gas:</u>	Water vapour (H ₂ O)
	Carbon dioxide (CO ₂)	<i>Acid Gases</i>	Carbon dioxide (CO ₂)
	Carbon monoxide (CO)		Carbon monoxide (CO)
	Hydrogen sulphide (H ₂ S)		Oxides of sulphur (SO _x)
	Ammonia (NH ₃)		Oxides of nitrogen (NO _x)
	-		Hydrochloric acid (HCl)
	-		Hydrofluoric acid (HF)
	Methane (CH ₄)		-
	-	<i>Persistent Organic</i>	PCDD (Dioxins)
	-	<i>Compounds</i>	PCDF (Furans)
	-		
	-	<i>Polynuclear Aromatic</i>	Fluoranthene
	-	<i>Hydrocarbons (PAH)</i>	Benz(a)anthracene
	-		Benzo(bk)fluoranthene
	-		Benzo(a)pyrene
	-		Dibenzo(ah)anthracene
	-	<i>Polychlorinated</i>	IUPAC No. 77
	-	<i>Biphenyls (PCB)</i>	IUPAC No. 126
	-		IUPAC No. 169
	-	<i>Trace metals</i>	(see below)
<i>Leachates and wastewater</i>	Methane (CH ₄)*		-
	Fatty acids		-
	Sulphate (as SO ₄)		Sodium sulphate (Na ₂ SO ₄) (if caustic scrubbing)
	-	<i>Acids</i>	Calcium sulphate (CaSO ₄) (lime scrubbing)
	-		Sulphuric acid (H ₂ SO ₄)
	-		Hydrochloric acid (HCl)
	-		Hydrofluoric acid (HF)
	-		Carbonic acid (HCO ₃)
	Nitrate - N		Nitric acid (HNO ₃)
	Nitrite - N		-
	Phosphates (as P)		-
	Calcium		Calcium chloride (CaCl ₂) (i)
	-		Calcium carbonate (CaCO ₃) (i)
	Sodium		Sodium chloride
	Chloride		

Table 5.1 (continued)

Landfills		Incinerators	
	Magnesium Potassium BOD20/BOD 5 COD TOC		- - - - -
<i>Trace metal(oid)s</i>	Chromium Manganese Iron Nickel Copper Zinc Cadmium Mercury Lead - - - - - - - - - -	<i>Arsenic</i>	Chromium (Cr) Manganese (Mn) Iron (Fe) Nickel (Ni) Copper (Cu) Zinc (Zn) <i>Arsenic (As)*</i> Cadmium (Cd) Mercury (Hg) Lead (Pb) Thallium (Tl) Antimony (Sb) Cobalt (Co) Tin (Sn) Titanium (Ti) Vanadium (V) Selenium (Se) Platinum (Pt) Palladium (Pd) Rhodium (Rd) Barium (Ba)
<i>Solid waste</i>	- - - -		Particulates** Ash residues Activated carbon Dioxins and Furans***
<i>Non-contaminant effects</i>	Fire hazard Noise & vibration Odour Traffic Birds Colonising animals Vermin		Fire hazard Noise & vibration Odour Traffic - - -

* Dissolved methane can be contained in leachate and can later emanate from solution.

** Some filters can remove particles > 10 mm.

*** Dioxins and Furans are present in all municipal solid waste incinerator ash residues.

Incineration

Although thermal treatment (incineration) of municipal solid waste (MSW) is an established practice in many countries, it is only now being evaluated for use in Ireland (MCOS 1999). The technical details of waste incineration are discussed in Chapter Four. Oxidative thermal treatment of waste generates a wide range of potentially problematic emissions (Tables 5.1, 5.5) (EEA 2001). Arguably, many of these can be controlled through the use of appropriate technology, but this is dependent upon rigorous maintenance and management practices to deliver the promise of optimal performance.

MSW incineration produces a range of volatile or gaseous emissions (Table 5.1). Fly ash and dust can carry contaminants from the facility where they can affect sensitive ecosystems of the surrounding area. The actual range of emissions depends upon the specific characteristics of the waste stream and engineering considerations such as combustion temperature. A number of these constituents can dissolve in the spray and quench-water used in the incinerators, generating a contaminated water stream, which could have impacts on the aquatic environment crudely comparable to those produced by leachate, if released untreated. MSW incineration also generates a considerable quantity of residual ash, which requires disposal. If placed in landfill, this can give rise to its own toxic leachate problems. However, these are less significant than those caused by standard landfill leachate, due to the smaller volume and general consistency of the material. Any secondary leachate produced by incinerators is of lesser environmental concern than the potential impact of gaseous emissions.

Waste management facilities, EIA and the environment

Landfills and incinerators/thermal treatment plants are covered by the Environmental Impact Assessment (EIA) procedures derived from Directives 85/337/EEC and 97/11/EC (CEC 1985, CEC 1997). Prior to 1 May 1999, landfills were covered by category 2.11.c of the European Communities (Environmental Impact Assessment) Regulations (S.I. 349 of 1989) and incinerators by categories 1.9 and 2.11.c. Following amendment by S.I. 93 of 1999 transposing Directive 97/11/EC and confirmed by the Planning and Development Act 2000 (S.I. No. 600 of 2001), landfills are covered by categories 1.9, 2.11.b and 2.11.d (sludge deposition) and incineration by categories 1.9, 1.10 and 2.11.b.

A cumulative catalogue of known *Environmental Impact Statements* (EIS) was produced up until the end of 1996 (Brangan 1997) and an unpublished cumulative listing covering the remaining period up to the present is held in the environmental information office (ENFO) in Dublin. Since the introduction of formal EIA in 1989, at least 39 EISs have been produced for landfill, eight for incineration facilities, and two for associated waste transfer stations (Table 5.2).

The EIA procedures have had a positive effect on the siting and design of waste management facilities, and there is evidence from research carried out in the Department of Environmental Resource Management at UCD that this correlates with improved knowledge and attitudes among the service providers. The latter have also been stimulated by the adoption within these organisations of environmental management plans supported by Environmental Management Systems (EMS), whether for their own inherent operational merits or as a component of Integrated Pollution Control (IPC) or Waste Licensing procedures (EPA 1997a, EPA 1997b).

Table 5.2 Irish environmental impact statements (EISs) produced for waste facilities

Waste category Incinerators (1.1.9) & landfills (2.11.c – secondary)			
<i>ENFO no.*</i>	<i>Date</i>	<i>Facility</i>	<i>Authority</i>
180	1991	Retain incinerator	Dublin CB
206	1991	Electricity generating site, Dunsink – Enercol Engineering Systems (landfill methane)	Dublin CC
251	1992	Hannan-Extension of fuels to include clinical waste, Newton, Crecora	Limerick CC
361	1994	Process waste incinerator – Lawter International	Kilkenny CC
386	1994	Healthcare/confidential paper waste – Waste to Energy Ltd	Dublin CB
439	1994	Process waste incinerator – Lawter International	Kilkenny CC
469	1995	Incinerator for pharmaceutical vapour/liquid Syntex (Ireland) Ltd, Clarecastle, Co. Clare	Clare
912	1999	Thermal waste treatment plant & business park	Kildare CC
<i>Waste Category Landfills (2.11.c)</i>			
24	1989	Landfill for poultry waste, Reansgreens, Roscarbery	Cork CC
139	1991	Landfill site, Ballypatrick, Clonmel	Tipperary SR CC/Min Env
158	1991	Landfill site, Muingnaminnane, Co. Kerry	Kerry CC/Min Env
245	1992	Sanitary landfill for baled municipal waste, Arthurstown, Kill, Co. Kildare, for Dublin CC	Kildare CC
323	1993	Extension of existing bauxite residue storage area, Anisland, Askeaton – Aughinish Alumina	Limerick CC
334	1993	Waste baling transfer station, Ballymount	Dublin CC/Min Env
392	1994	Landfill Ballyguyroe North, Mallow	Cork CC/Min Env
400	1994	Sanitary landfill, Newry Rd., Dundalk	Dundalk UDC/Min Env
406	1995	Materials recovery facility (prior to recycling/landfill) – Recycle Ireland Ltd	Donegal CC
419	1994	Landfill project, Kilmartin, Tyrrellstown, Mulhuddart – Nat Roads. PLC	Fingal CC
574	1997	East Wicklow landfill	Wicklow CC/EPA
627	1996	Continuation of landfill operations including rehabilitation, Corobane townland	Galway CC Galway Corp
641	1997	Hard bog municipal waste landfill site	Tipperary SRCC/EPA
668	1997	Waste disposal facility at worked out sand and gravel pit (construction waste)	Wicklow CC
710	1997	Extension to facility, Gortdroma	Limerick CC

Table 5.2 continued

Waste category Incinerators (1.1.9) & landfills (2.11.c – secondary)			
<i>Waste Category</i>		<i>Landfills (2.11.c)</i>	
726	1997	Transfer station and store for flammable and other materials – Minchem Chemicals Ltd	Dublin CB
759	1998	Expansion/continuation of use as landfill site	Cork CC
783	1998	Waste disposal facility – Carnegie JW & Co Ltd	Wicklow CC
825	1998	Hazardous/non-hazardous waste reception facility	Clare CC/EPA
826	1998	Landfill site	Monaghan CC
828	1998	Ash repository facility – Bórd na Móna Peat Energy Division	Offaly CC
829	1998	Landfill site	Kildare CC
830	1998	Inert waste disposal facility – Southern Excavation Ltd	Wicklow CC
831	1998	Landfill	Galway CC
832	1998	Remediation extension of landfill	Cavan CC
834	1998	Waste disposal facility – KTK Sand & Gravel Ltd	Kildare CC
837	1998	Johnstown land restoration – Nephin Trading Ltd	Kildare CC
838	1998	Landfill waste disposal facility	Offaly CC
839	1998	Development upgrading of landfill site	Mayo CC
841	1999	Landfill	Laois CC
842	1998	Continued operation of landfill site	Wicklow CC
844	1999	Landfill site	Carlow CC
846	1998	Construction of landfill facility	Westmeath CC
861	1999	Landfill site	Cork CC
888	1999	Proposed landfill at Garryard West and Gortshaneroe townlands, Silvermines, Co. Tipperary – MC O’Sullivan for Waste Management Ireland	Tipperary NR CC /ABP
915	1999	Landfill, Knockhardy, Kentstown	Meath CC
944	n.d.	Integrated waste management facility	Clare CC
945	1999	Peat ash disposal facility – ESB International for Peat Ash Ltd	Offaly CC
947	n.d.	Landfill facility	Kerry CC
971	1998	Continuation of landfill/rehabilitation measures to landfill – Galway Corporation	Galway CC
1030	2000	Waste transfer recycling facility – Panda Waste Services	Meath CC/ABP
1039	n.d.	Inert landfill site-Joyce PK	S Dublin CC

n.d. = no date available

* ENFO no. refers to the catalogue number of the EIS in the collection at ENFO, Dublin

(Source: Brangan 1997, ENFO, Dublin)

Impact on ecosystems

General comments

Site selection for waste management facilities can be an issue. All infrastructural projects have the capacity to damage the ecology of the site on which they are developed, causing landscape changes, loss of habitat and displacement of fauna. Such impacts are generally site-specific and need to be assessed on a case-by-case basis (EPA 1995a, EPA 1995b, Treweek 1999).

However, the political expediency of developing waste management facilities in remote locations means that they can be expected to have a higher than average risk of impacting on surrounding semi-natural habitats. Similarly, the placing of landfill facilities in peatland can place pressure on these habitats - ecosystems of concern under the provisions of the *Directive on the Conservation of Natural Habitats and of Wild Fauna and Flora 92/44/EEC* (CEC 1992). In some cases, a strategy of reusing previously developed 'brown-field' sites can also have ecological impacts since sites such as abandoned quarries may have developed unique volunteer ecosystems (Mellanby 1992). Once again, this will need case-by-case assessment (DG XI 2001).

Some measures adopted to mitigate the more serious effects of these projects can have their own lesser environmental effects or potential risks. The preferred use of evergreen species for visual, dust or litter screening often introduces exotic coniferous species, which are ecologically less attractive. The possible use of constructed reedbeds for wastewater/leachate treatment may alter local ecological conditions and, world-wide, bio/phytoremediation treatments increasingly involve the use of exotic and/or genetically modified species with their attendant real or perceived risks (Hinchee et al. 1994, Wild et al. 1997).

Industrial sites tend to suffer from high levels of disturbance, and their chemical and physical properties differ from those of the surrounding area due to the general removal of topsoil as well as specific process-related changes. Both these factors adversely affect the original vegetation, but may create opportunities for short-lived species with specific site tolerances, with knock-on consequences for associated animal species. Some derelict soils may support rare and important ecosystems and a number of landfills have been shown to support a rich and varied flora even during their operational phase (Mellanby 1992).

Both landfill and incinerator developments will generate increased local traffic with heavy vehicles causing noise, vibration, dust and some level of windblown litter. Soil compaction will also occur whenever these vehicles move off metalled road surfaces. A combination of site development and increased traffic will disrupt any existing livestock movement patterns (e.g. dairy herds) and expose such animals to a greater risk of injury or contamination. Apart from standard operational risks, both types of facility have attendant fire hazards, which could spill over onto surrounding sites. This can impact on wildlife and domestic animals, and will temporarily affect vegetation, but little permanent effect would normally be anticipated.

Impacts on soils

Soil is an important resource, which supports a variety of ecological, economic and cultural functions. These relate to soil quality, which is highly dependent upon soil structure operating through factors such as porosity, density, water-holding capacity, aggregate strength and friability. These are best developed in the topsoil fraction, subsoils being more poorly developed and having a lower ability to support plant growth.

Industrial activity can affect soil quality through physical pressure within the soil resulting in compaction, which reduces soil stability and drainage. These are generally site-specific problems, which relate to local geology and soil structure. The movement of heavy machinery during general waste management operations can lead to excessive compaction of topsoils and subsoils, and in deeper soils this may only be reversible over relatively long time periods. Serious compaction is most likely to occur (and may be deliberately engineered) during remedial work to increase the impermeability of the basal layer of a landfill site.

Construction of landfill sites can result in significant displacement of topsoil and subsoil components. Topsoil can only be stored on a temporary basis before it loses its quality and goes 'sour', but it has a high market value. The sub-soil component requires separate disposal or possible storage for later re-use. An operational landfill generates a heavy daily demand for inert capping material to seal the waste in order to control odour, litter, vermin and the spread of disease.

Loss of soil structure, the deposition of chemical contaminants including metals, wet deposition of gases, and seepage of gas through soil can all suppress microbial activity, with knock-on effects throughout the soil ecosystem. Soil can become contaminated with a range of substances, including acidifying agents, metals, organic pollutants and pathogenic microorganisms. Contamination can arise through direct migration from adjacent land, through water pollution or by indirect deposition from air.

Soil acidification is caused by several pollutant gases, including sulphur dioxide, oxides of nitrogen and ammonia. These gases are either deposited directly onto the soil (dry deposition) or washed out of the air by rain (wet deposition). Acidification results whenever the acid deposition exceeds the capacity of the ecosystem to neutralise it. Soil processes can slow down and populations of soil microorganisms may change with a shift towards acid-tolerant species. Acidification alters the solubility and mobility of a number of soil minerals. It can release forms of aluminium, that may damage plants, for example by affecting fine plant roots and mycorrhizae (root/fungal relationships).

The supply of nutrients within the soil is governed by cycles that depend on the activities of soil organisms ranging from bacteria and fungi (micro-flora) to small invertebrates (micro-fauna) and earthworms. The actions of all these organisms are affected by physical and chemical disturbance of the soil during management operations.

The trace metal content of a soil depends primarily upon the geochemistry of its parent mineral, but metals can also migrate into a soil from adjacent land or be deposited from air or water pollution. Such contamination is likely to result in prolonged, if inconsistent, uptake by plants and thereby provide a key route for entry of metals into the food chain. Fly ash particulates are a significant carrier since their large surface area gives them a high absorption capacity. Soils derived from ore-bearing rocks generally show an even distribution of trace metals throughout their profile, while sites contaminated by deposition or water pollution generally show higher levels in the upper soil profiles. Therefore, topsoil levels alone are considered to be unsuitable indicators of contamination or bioaccumulation. Models are being developed to simulate the transport of chemicals in soil systems (e.g. Ghadiri & Rose 1992, Selim & Iskander 1999, Lipnick et al. 2001a, Lipnick et al. 2001b), but this approach needs to be extended to take account of a greater range of potential contaminants.

Invertebrates are increasingly being used as indicator species for trace metal contamination. The relative toxicity of trace metals to soil organisms decreases in the sequence: Hg >Cd >Cu >Zn >Pb. Ross and Kaye (1984) give tables of relative toxicity for a range of organisms; metal loading rates of

soils and threshold toxicity concentrations; tissue metal concentrations and concentration factors for soil organisms; and soil contamination classifications. Analysis of earthworms is a well-established technique and was, for example, a monitoring condition imposed on the Arcon Pb/Zn mine at Galmoy, Co Kilkenny. A move to the use of a mixed microfaunal index of indicator species has been strongly advocated and is in the process of being validated (Good 1995, Good 1996, Good & Wistow 1997).

Impacts on vegetation

For the purposes of this report, bacteria and many fungi (including mycorrhizal fungi) have been treated as being part of the soil microflora, while lichens and some other fungi are considered along with mosses, ferns and higher plants as part of the surface vegetation.

All green plant species are adversely affected by dust deposition, which limits photosynthesis by reducing light penetration to leaves and clogging the stomatal pores. This is alleviated by rainfall, but some dusts (e.g. cement products) can form a permanent foliar crust, which is particularly problematic for evergreen foliage, which has a long replacement cycle. Essential root activity can be adversely affected by changes in soil pH, hydrology or by lateral seepage of leachate or gaseous contaminants such as methane or hydrogen sulphide (Finnecey & Pearce 1986).

Trees and hedgerows are regularly retained or planted to provide visual screening, shelter and passive capture for dust and litter. Trees are effective scavengers from dust-laden air and may therefore be better indicators of pollution from proximal sources than herbaceous vegetation (Kukkonen & Raunemaa 1984). Evergreen species provide the best all-year-round service, but these are generally non-native species which make the smallest contribution to local biodiversity.

Dust deposition on pasture or forage crops may cause palatability or toxicity problems (Lepp 1981a), or induce exaggerated tooth wear in herbivores, whether directly or after silage production. Apart from being unsightly, flyblown litter can also directly affect the quality of silage and impede harvest of other crops. Deposition of toxic (e.g. trace metal) dust on foliage can affect crop growth and productivity, but may pose a greater threat to animal health and the food chain by direct ingestion. Direct or indirect rain-washed deposition onto the soil is less problematic in the short term, but can lead to long-term soil contamination, especially in soils with an existing naturally high concentration of the element. Elements of concern, such as lead, zinc, and cadmium, show differential mobility through the vegetation/invertebrate trophic levels and must usually be assessed on a case-by-case basis.

Although a range of industrial pollutants reduce plant growth and productivity and have overall negative effects on the associated ecosystem, there are only a few cases in which total or nearly total vegetational denudation of a site can be ascribed to pollution and these are usually associated with mining and metal processing industries.

Impacts on terrestrial fauna

Studies have shown that landfills are capable of supporting a rich and varied fauna including exotic species (Mellanby 1992). Invertebrate (especially insect) populations may reach enormous numbers. Invertebrates found in this habitat include members of the phyla Nematoda (flat worms), Annelida (segmented worms), and Arthropoda (including isopods, insects and arachnids such as spiders,

harvestmen and mites). Many of these contribute to the decomposition processes. Temperature 'hot spots' from decomposition in the upper layers of the site may support animals generally adapted to hotter climates. Among the insects, these can include crickets and grasshoppers (Mellanby 1992). Flies are a group of specific concern as they act as disease vectors and their population growth is also encouraged by the heat generated through decomposition, although new landfill management practices have significantly reduced the risks of infection.

The main vertebrate species associated with landfill sites in Ireland are given in Table 5.3, many of these being attracted to the sites as scavengers (Tom Hayden, Zoology Department, UCD, personal communication 2002). These species may function as useful indicators of environmental contamination, especially if using non-destructive biomarker techniques (Fossi & Leonzio 1994).

Table 5.3 Birds and mammals associated with landfill sites in Ireland

Herring Gull <i>Larus argentatus</i>	Common Gull <i>Larus canus</i>
Black-headed Gull <i>Larus ridibundus</i>	Greater Black-backed Gull <i>Larus marinus</i>
Rook <i>Corvus frugilegus</i>	Jackdaw <i>Corvus monedula</i>
Hooded Crow <i>Corvus corone</i>	Raven <i>Corvus corax</i>
Magpie <i>Pica pica</i>	Starling <i>Sturnus vulgaris</i>
Pied Wagtail <i>Motacilla alba</i>	Linnet <i>Carduelis cannabina</i>
Sparrow <i>Passer domesticus</i>	Kestrel <i>Falco tinnunculus</i>
Rock Dove <i>Columba livia</i>	
Fox <i>Vulpes vulpes</i>	Wood Mouse <i>Apodemus sylvaticus</i>
Feral Cat <i>Felis catus</i>	Badger <i>Meles meles</i>
American Mink <i>Mustela vison</i>	Rabbit <i>Oryctolagus cuniculus</i>
Stoat <i>Mustela erminea hibernica</i>	Brown Rat <i>Rattus norvegicus</i>

(Tom Hayden, Zoology Department, UCD, personal communication 2002)

Birds include members of the gull and crow families, but starlings are also quite common. The habits of gull species have changed in recent decades and they have moved from a coastal to a more universal range where they exploit anthropogenic ecosystems. Landfill sites attract them since they not only provide easily obtainable food, but adjacent areas of exposed capping soil provide ideal conditions for their 'loafing' activities. Although sometimes found, magpies, wagtails, linnets, sparrows and rock doves are generally scarce. Increased bird activity invariably attracts birds of prey like the kestrel (Coveney 1996). Flocks of birds can congregate in sufficient numbers to increase significantly the risk of bird strikes with passing aircraft. Birds of prey can be used to control this behaviour, although their presence in the site will also adversely affect the populations of non-scavenging bird species in the general area (Coveney 1996).

Eight species of mammal are known to frequent landfill sites as either scavengers or predators (Table 5.3). None, apart from the common rat, appear in great numbers. Populations of small mammals (including rabbits) tend to increase within the fenced perimeter of any large facility where they are protected from predation, although they suffer some risk of entombment in landfills during regular daily sealing operations. These animals may be expected to suffer toxicity from accumulated trace metals or other contaminants in their diet, but studies to date have failed to show any significant concentration of contaminants along the food chain. Nevertheless, monitoring reproduction and the level of foetal abnormalities in "top-of-the-chain" species such as rats would provide a useful objective

comparison with human epidemiological studies. The increasing wildlife populations may attract attention from birds of prey (mainly kestrels) or foxes, and these predators can be used as indicators of small mammal presence. Despite this, myxomatosis is likely to be the most significant agent controlling rabbit populations. Increasing populations of flies and other insects tend to attract bats. Badgers, mink, stoats and feral cats are rare but have been recorded. Bottles, cans, jars and similar inert components of surface or partially buried litter within the site or distributed beyond its perimeter also pose a significant risk of entrapment to small mammals such as shrews, mice and hedgehogs.

Farm and domestic animals show differential behaviour patterns and physiological sensitivities to emissions or contaminants, with species-specific responses but a general increase in sensitivity with improved breeding or training for high performance such as racing (Kevin Dodd, Faculty of Veterinary Medicine, UCD, personal communication 2002). Fly ash particulates have a general capacity to transfer trace metals directly into the respiratory tract. Horses are particularly susceptible to impacts from a range of emissions, including ingested plastic. This is especially true of thoroughbreds or stud animals, but rough-bred ponies kept as pets in northwest Dublin and grazed on the Dunsink landfill have suffered high mortality levels (Fry unpublished). Horses are also particularly susceptible to increased noise, light or vibration, as are deer and some other wildlife. Grazing cattle are sensitive to excesses of selenium and molybdenum.

Livestock drinking from contaminated surface water sources are susceptible to poisoning, although this possibility has been reduced with the increasing emphasis under REPS on the protection of watercourses from direct contact with animals. However, this remains an issue for wildlife.

The principal vermin species associated with landfill are flies, wild birds (especially gulls and members of the crow family) and rodents, but other scavenging mammals such as foxes and badgers can also be problematic. Although muscid flies tend to stay near the food source from which they emerge, they have been known to travel up to 8 km within 24 hours when assisted by prevailing winds. A study of fly species in the vicinity of a landfill site in Wicklow found 14 different types, all from the order Diptera (Murray 1996). The resident insect population is liable to be augmented by incoming refuse material. UK estimates for a facility serving 10,000 houses are that some 20,000 fly maggots would be dumped into refuse each week (Busvine 1980).

Potentially pathogenic bacteria can escape directly from operational landfills or composting centres, but these are primarily a hazard for site operatives (Eduljee 1995). Vermin have the ability to carry disease vectors (bacteria, viruses, fungi) and chemical contaminants out of the site, either directly or through the spread of litter. Distributed litter can cause its own visual and physical hazards (e.g. fire hazard, choking of domestic animals, blockage of drains and watercourses). In all cases, the impacts from vermin can be minimised through chemical control with insecticides/rodenticides (which have their own impact on contaminant levels in the site) and by appropriate containment and regular sealing of the landfilled material. Bird populations can be reduced by visual or audible scaring techniques, or through the use of falconry, but birds become acclimatised to these tactics.

Impacts on the aquatic environment

Background levels of water quality should be ascertained before ascribing responsibility to point source pollution (such as waste facilities) for any deterioration in that quality. It should also be noted that the EU *Directive for Establishing a Framework for Community Action in the Field of Water Policy* 2000/60/EC (CEC 2000) demands that water quality be improved within a specific time frame. This will demand greater emphasis on monitoring and modelling the distribution, and assessing the

environmental impacts of anthropogenic chemicals in the aquatic environment, if effective concepts of sustainability are to be developed (Holt et al. 2000, Clenaghan et al. 1999, Lipnick et al. 2001a).

Since previous Irish landfills have been mainly unlined and poorly managed, it is generally assumed that they must have caused pollution through leachate seepage to water. However, there is little evidence to show whether leachate from landfill sites is gaining access to rivers or streams and contributing to the pollution problems in Ireland. The modern approach to freshwater research is through the use of catchment limnology. Where freshwater ecology is no longer confined to specific sites in rivers or lakes it is possible to elucidate, much more accurately, the main causative effects of aquatic problems in a specific catchment. In the future, therefore, many problems, which have previously gone unnoticed, will be highlighted, including possible effects from leachate and mining effluents.

EU Directive 76/464/EEC (CEC 1976) requires member states to reduce pollution from certain defined dangerous substances being discharged to the aquatic environment. This directive has been partially transposed in Ireland (S.I. No. 12 of 2001). Investigations have been undertaken for eight of the List I substances in the directive, for eleven of the List II Priority Substances in the recent national regulations, and for 59 other substances. Concentrations of metals, pesticides and volatile organic compounds were measured at 74 sites in 33 rivers where contamination was thought to be likely (Stephens 2001). Results demonstrate that these substances were only found in low concentrations in Irish waters. The Avoca River was found to be seriously polluted by copper and zinc from past mining operations, and the River Boyne had a high concentration of lead, although this was not confirmed by subsequent sampling and cannot be ascribed to current mining operations. No evidence of pollution from any of the target pesticides or other organic substances was found, and none of the evidence points to significant contamination from landfills.

FRC (Fisheries Research Centre, Abbotstown) records clearly show that there has been a marked upturn in the numbers of fish kills over the last ten years (Moriarty 1996). Accidental spillages of wastes such as untreated sewage, silage liquors and farmyard manures have been mainly responsible. Fish kills have ranged from approximately 100 per annum in the 1970s to double that figure in the late 1980s/early 1990s, followed by a decrease to 116 and then again a surge to 173 during the 1995-1997 period. However, in all that time not one fish kill was attributed to effluents from landfill sites.

In considering the present status of lakes, rivers and streams in Ireland, there appears to be a correlation between poor water quality (Table 5.4) and high human population densities, since pollution problems are more widespread in the Eastern Region of the country (Flanagan & Larkin 1992). This may imply a further correlation with landfills, a suggestion reinforced by the official use of waste management statistics as an indicator of the interaction between households and inland water quality (Clenaghan et al. 1999) and by evidence that dioxin levels may also be higher in the east (Concannon 1996). There is some evidence to support this association between domestic waste generation and poor water quality, but it is not clear-cut.

Recent figures (EPA 2000) indicate that 27% of river channels surveyed were classed as moderately polluted (Class C) and a further 3% as seriously polluted (Class D). Moderate pollution is prevalent, standing at 22% in areas such as Cavan-Monaghan. Eutrophication is seen as being most widespread in the South-Eastern Region with 29% of channels affected, while Shannon (23%) and the Eastern Region (25%) follow close behind. A majority of the serious pollution problems are ascribed to

agriculture and industry in equal amounts, with 44% attributed to municipal waste discharges (Lehane 1999). The latter are primarily due to sewage, but this category could also include waste management facilities.

Table 5.4 Percentage of fresh water channels classified as 'clean waters' (Class A)

Class A	Region	Percentage
1st	North-Western (Donegal-Sligo)	87
2nd	Southern	86
3rd	Western	79
4th	Mid-Western	62
5th	North-Western 'a' (Cavan-Monaghan)	60
6th	Shannon	59
7th	South-Eastern	53
8th	Eastern	45

(Source: EPA 2000)

Until recently it was assumed that levels of nitrate in Irish surface waters were within the limits set for abstraction schemes and drinking water quality (Lehane 1999). However, more recent evidence seems to contradict this (EPA 2000). The EU guideline of 5.65 mg.l⁻¹ N is rarely exceeded by rivers in the west and northwest of the country. Rivers in the east, southeast and south of the country, however, contain significantly higher levels of nitrate. Again, these differences might correlate with high population densities and waste generation rather than agricultural operations. Pollution from intensive agriculture is likely to lead to elevated levels of both nitrate and phosphate. However, in contrast to the pattern of nitrate pollution, recommended phosphate values were exceeded at over 50% of the 1,600 river sampling sites during the mid-nineties. Most, if not all, of the larger rivers had phosphate problems, with levels exceeding 30 µg.l⁻¹, in some cases by a factor of three (EPA 2000).

Experience elsewhere in the EU has shown that landfill sites should not be placed near lakes, rivers or inshore bays (CEC 1999). In the UK, the Environmental Agency brought a case against Devon County Council, which was convicted of polluting the East Devon Brook with leachate from a 30 to 40-year-old redundant landfill (EA 2001). Despite a widespread literature search and contact with relevant scientists we have failed to identify any evidence through legal proceedings that leachate contributed to pollution problems in Ireland. However, proceedings have reportedly been initiated by Kildare County Council against the operators of an unlicensed waste site, which is considered to have damaged Pollardstown Fen (*Prime Time* RTE 28.2.2002).

Eutrophication is also the most extensive threat to the water quality of lakes in Ireland, with increased nutrient loads affecting the trophic status of lakes (Lehane 1999). Eutrophic conditions invariably cause excessive production of planktonic algae and cyanobacteria (blue-green algae) in the open sectors of lakes. At the margins of the lakes and in the littoral zones, when phosphate levels are high, there is a tendency for the growth of rooted macrophytes (large plants) to be dense. During the latest review of water quality in Ireland (EPA 2002) 260 of 304 lakes examined were assigned to the 'oligotrophic' or 'mesotrophic' categories, indicating satisfactory water quality conditions and suggesting a low probability of pollution. Water quality of the remaining 44 lakes was less than satisfactory, with the likelihood of significant impairment of their beneficial use. In the

majority of these cases, the principal sources of the nutrients causing the enrichment are thought to be non-point discharges of agricultural origin. However, discharges from municipal and industrial waste treatment are partly or wholly responsible for the unsatisfactory water quality condition of the others (EPA 2002). Once again, this category could include some waste management facilities.

There is some indirect evidence of impacts from leachate from the consideration of specific pollutants. A number of chemicals can disrupt reproductive behaviour in a range of species by acting as oestrogen mimics. Dempsey and Costello (1998) reviewed the impact of these hormonally active agents on water quality in Ireland and implicated landfill leachate as a potential source for these substances, none of which are being monitored on a regular basis. Sediment in rivers and lakes may hold endocrine-disrupters and other contaminants including trace metals. If deterioration occurs in water parameters such as pH or dissolved oxygen, these contaminants may be released (OECD 1991, Dempsey & Costello 1998).

A certain number of small Irish lakes occur in areas with base-metal (i.e. trace metal) rich bedrock. Such lakes are prone to having limited buffering capacity, which puts them at risk from natural acidification (which is separate to the acidification caused by acid rain). Any acidification (including that from leachate) would increase the potential for solubilising trace metals from trace metal ores. Bowman (1986, 1991) clearly demonstrated that acidification of surface waters due to atmospheric pollution was not a significant problem in Ireland. However, acidification was detected in some afforested areas by Giller et al. (1993) and was attributed to the tree crowns acting as pollutant filters, albeit at low levels. These lakes would also be particularly vulnerable to impacts from additional trace metals from any waste management facility sited in the region.

From an environmental viewpoint it is essential to determine the presence and concentrations of trace metals in water. In Ireland, the four trace metals that are commonly measured are zinc, lead, copper and cadmium. Their concentrations are investigated in the water column, the aquatic flora, certain species of macro-invertebrates and the bottom silt or mud. In addition, certain organisms are also investigated for bioassessment. The basis for this investigation is that the trace metals tend to accumulate in the organisms or in specific organs. In fish, the degree of contamination is determined by analyses of such tissues as the eye, gill, liver and lateral muscle. Unfortunately, there are no official guidelines on what are 'acceptable limits' either in the flora or fauna. Considering the range of trace metals being mined in Ireland and the known content of landfill leachate, this represents a gap in knowledge. Strict limits are applied to drinking water, and fish and gammarids (freshwater shrimps) are selected for such tests. Shrimp samples are collected, kept alive in the laboratory until the gut content clears, and deep-frozen until analysis. Fish samples are obtained by electro-fishing and a standardised sample (usually those in their second year of growth) is taken for analysis.

Constructed wetlands

Wetland plants such as the common reed (*Phragmites australis*), the common club-rush (*Schoenoplectrus lacustris*), cat's-tail/false bulrush' (*Typha spp.*) and flags (*Iris pseudoacorus*) are adapted to fluctuating water and nutrient levels and are tolerant of high pollution conditions. Oxygen is transported internally to the roots to enable them to survive in an essentially anaerobic external substrate. The submerged stems and leaves are colonised by anaerobic microbial populations that reduce pollution levels in the contaminated water. Artificial wetlands utilising these plant species have been put in place in a number of areas in an attempt to protect surface or groundwaters from contamination by mine tailings or sewage effluent and the principle could

be extended to the secondary treatment of leachate (McEldowney et al. 1993, O'Sullivan et al. 1999).

Groundwater

The groundwater zone receives water from surface water systems, but has comparatively little direct effect on biological organisms except where it resurfaces in springs or as the basal flow of rivers and lakes. Unlike surface water contamination, degradation of groundwater often goes undetected until it reaches a high level. Purification is then very difficult, given its inaccessibility, huge volume and slow recharge rate. Groundwater aquifers provide 20-25% of drinking water in Ireland (Daly 1991). Some Irish landfill sites are known to have caused groundwater pollution and other cases are likely to be confirmed by any extension of current groundwater monitoring (Daly 1991). Ammonia, nitrates, phosphorus and iron-manganese values are higher than desirable in various groundwaters throughout the country. A significant number of sources in at least 12 counties have high total and faecal coliform counts (>10 per 100 ml) and landfill sites are implicated as sources of contamination (EPA 2002).

Estuarine and coastal waters

Any polluted water or sediment carried by rivers will eventually discharge into coastal waters. River loads to estuaries have been identified as pressure indicators for the Irish environment, with immediate concern being shown about nitrate loads (Lehane 1999). The assessment of successive surveys (1995-1999 and 1998-2000) of the trophic status of estuaries and bays indicated that although 13 of the 47 water bodies examined were eutrophic, the quality of estuarine and coastal waters around the country has remained generally high (EPA 2002). However, two contrasting landfills, one an old facility at Cork and the other a facility in Dublin utilising modern technology, are both subjected to occasional influxes of sea water. Since all but one of the 47 water bodies have been designated as sensitive areas under the Urban Waste Water Regulations (S.I. no. 254 of 2001), and a number of estuaries and bays continue to exhibit serious pollution due to excessive local enrichment, any further contamination impacts from landfills should be avoided.

Impact of gaseous emissions

Emissions to air from landfills and incinerators, which are of global or regional significance, can be grouped under the following headings:

- climate-relevant gases such as CO, CO₂ and CH₄
- acidic inorganic gases such as NO_x, SO_x and HCl
- organic micro-pollutants (dioxins, furans)
- volatile organic carbons (VOC)
- polyaromatic hydrocarbons (PAH)
- volatile trace metals
- soot and dust

Emissions of these substances contribute to slow but continuous degradation of environmental conditions through processes such as the greenhouse effect and acidification. Others are relevant at a local scale or for individual species (Krupa 1997). Table 5.5 provides a summary of these impacts.

Table 5.5 Summary of the environmental impacts of pollutants found in landfill and incinerator emissions to air

Pollutants	Main impacts	Description
Methane (CH ₄)	Global warming Vegetation dieback	Converted to CO ₂ in the atmosphere, but has a short-term 'greenhouse factor' 30 times that of CO ₂ ; Prevents oxygen entering soil, thus discouraging revegetation of landfills.
Carbon dioxide (CO ₂) and Carbon monoxide (CO)	Global warming Flammability (CO) Toxicity Asphyxiation hazards	Partly (50%) responsible for atmospheric greenhouse effect causing climate change; Elevated CO ₂ levels may stimulate plant (and weed) growth; Inhalation of CO causes deprivation of oxygen to brain and heart tissues.
Nitrogen oxides (NO _x)	Photochemical ozone formation Nutrient enrichment	Nitrogen dioxide (NO ₂) participating in the photochemical smog can result in secondary production of pollutant O ₃ ; NO ₂ is a plant-growth retardant and can cause decreases in agricultural yields; Eutrophication of oligotrophic aquatic and terrestrial ecosystems (e.g. heathland); Loss of habitat, disappearance of flora and fauna.
Organic compounds Volatile organic compounds (VOC)	Toxic and potentially carcinogenic Forms ozone and peroxyacetyl nitrate through photochemical reactions	

Table 5.5 (continued)

Pollutants	Main impacts	Description
Sulphur oxides (SO _x)	Affects lichens at a concentration 6x lower than that affecting human health	Synergistic in combination with smoke; Lower agricultural crop yields.
NO _x and SO _x	Acidification	Affects poorly buffered soils; Decline in coniferous forestry; Fish mortality; Metal corrosion.
Hydrogen fluoride (HF)	Toxicity in plants Affects dairy cattle	Can cause blight in maize; lowers citrus productivity. Cattle grazing on exposed herbage suffer fluorosis (loss of teeth, bone growth at joints, lameness).
Trace metals	Toxic to plants and affect animal health	Some are potent catalysts and can contribute to the post-incineration formation of dioxins. Herbivore health affected through ingestion of plants bio-accumulating trace metals.
Chlorinated organic compounds (dioxins and furans)	Liposoluble compound, persistent and bioaccumulative in different components of ecosystems	
Ammonia (NH ₃)	Toxicity to fish and disturbed behaviour in horses	Affects oxygen demand in exposed water.
Salt e.g. sodium chloride (NaCl)	Ecological toxicity Alters soil conductivity and ionic exchange	Salts can be residues from air pollution control devices.

Carbon dioxide and methane are the primary constituents of environmental importance in landfill gas. They are emitted from decomposition of the filled material, with increasing amounts of methane being produced as the internal conditions become more anaerobic. Chemical or biochemical transformations can take place within the landfill and create new organic or inorganic substances; e.g. tri- and per-chlorethylene to vinylchloride; amino acids to methyl- and ethyl-mercaptans; or sulphur compounds to hydrogen sulphide (H₂S). For these reasons, inclusion of large amounts of particular types of industrial waste in a landfill can generate high quantities of other gaseous compounds.

For example, a very large proportion of plasterboard (i.e. gypsum, CaSO_4) may cause the emission of H_2S (Finney & Pearce 1986, Westlake 1995). Landfill gas contains trace quantities of over 100 organic compounds, many of which are malodorous, potentially toxic, and can sometimes be present at toxicologically significant concentrations (Finney & Pearce 1986, Eduljee 1995).

In contrast to the largely reduced chemistry of landfills, incinerators are aerobic and the emissions from efficiently run operations are primarily in the oxidised state (see Chapter Four). However, a high level of maintenance and management is necessary to ensure that the process operates within predicted margins, and design measures should address both controlled and uncontrolled emissions including occasional pulses of trace metals. A number of countries have compiled inventories of PCDD/F (polychlorinated dibenzo *p*-dioxins/furans) emissions to atmosphere. Whereas in the past, incineration may well have contributed significantly to the atmospheric burden of PCDD/F, the imposition of increasingly stringent emission limits has resulted in a 100-fold reduction in emissions from this source (Eduljee 1995).

Gaseous pollutants have significant effects on plants, animals and entire ecosystems. On a worldwide basis, most emphasis is placed on the effects of such agents on forest ecosystems (Mathy 1988, Vernet 1992, Wellburn 1994, NRC 2000). Forest soils act as sinks for pollutants, generally removing them in the series $\text{CO}_2 > \text{CO} > \text{SO}_2 > \text{NH}_3 > \text{some hydrocarbons} > \text{Hg vapour}$ (Treshow 1984, Saxe 1996). In Ireland, forests are indicators of secondary importance due to the smaller proportion of land under forest cover. Here, more emphasis is placed on impacts on agriculture, on aquatic ecosystems, and on imbalanced or nutrient-restricted terrestrial ecosystems such as peatlands and sand dunes. The latter are a conservation imperative under the *Directive on the Conservation of Natural Habitats and of Wild Fauna and Flora 92/44/EEC* (CEC 1992).

The role of atmospheric chemistry and modelling in the assessment of plant and ecosystem productivity has been reviewed by Treshow (1984) and Krupa (1996). Some air pollutants do not always disperse effectively and may remain together at quite high concentrations, causing unexpected damage some distance from the source. This causes a problem for monitoring programmes since records of sustained and continuous emissions may not reflect the eventual pattern of contamination. Careful siting of any waste management facility is therefore an effective mitigation measure to minimise the environmental impact of emissions. Installations should avoid areas prone to atmospheric inversions or similar unfavourable dispersion conditions, as well as areas of prime agricultural value or ecosystems sensitive to acidification or eutrophication.

Methane, carbon monoxide and carbon dioxide all act as *greenhouse gases* of global significance, with methane being by far the most active but carbon dioxide being produced in the greatest quantities (Krupa 1996). Both methane and carbon monoxide react with hydroxyl radicals and oxygen in the atmosphere to generate carbon dioxide within a period of days to a few years, thereby losing some of their greenhouse gas potential (Clarke 1986, O'Neill 1993, Wellburn 1994, Yunus et al. 1996). Small amounts of methane are also consumed after absorption by soils (Leggett 1990). However, control of these emissions at source, and especially minimisation of methane production, is necessary from an environmental protection viewpoint and to address some of the national obligations under the Kyoto Agreement.

Methane is also inflammable and explosive, and must be vented to the atmosphere or (preferably) collected from landfill sites and flared to convert it to carbon dioxide. The lateral migration of gas through soil beyond landfill boundaries has been the cause of a number of hazardous explosion-related incidents (Gendebien et al. 1992). The use of HDPE (high density polyethylene) synthetic

liners can considerably decrease the potential for lateral gas migration, thus reducing explosion or pollution hazards while increasing the potential for gas utilisation. Burning with energy recovery represents the best environmental option. All three gases are also either directly toxic or present an asphyxiation or anaerobic hazard due to their migration through, and displacement of oxygen from, soils. This results in a decline in soil faunal populations and burrowing animals, and can cause vegetation dieback.

On an individual basis, most plant species (i.e. those operating the C_3 pathway of photosynthesis) can be expected to benefit from a general increase in atmospheric CO_2 levels due to a stimulation of photosynthesis. This could lead to increases of up to 30% in the productivity of the major crops (including forests) since these are mainly C_3 plants. Unfortunately, existing weed species may also benefit in this way, with the result that individual increases in crop productivity may be offset by stresses due to increased competition. Similar changes are likely to occur in semi-natural habitats, with differential effects on plant competitive advantage having unpredictable long-term effects upon ecosystems. The existing ecosystem assemblages are also under uncertain threat from changes in physical aspects of climate, such as temperature, moisture regime and wind speeds, induced by greenhouse gases (Leggett 1990, Yunus & Iqbal 1996, Agrawal & Agrawal 1999).

The acidic gaseous constituents (HCl, SO_x , NO_x and HF) are all of global significance since they contribute to the phenomenon of *acid rain* and its secondary effects on the acidification of soils and ecosystems. Ammonia is a secondary acidifying agent following its atmospheric oxidation to nitric acid. These acidic constituents are all potentially noxious. They have similar general effects on plants, causing loss of stomatal control, a reduction in photosynthesis, enzyme inhibition, changes in synthetic pathways, and depressed growth and yields. Hydrogen fluoride (HF) deposition on exposed herbage reduces yields in some crops (maize, citrus) and can induce fluorosis (loss of teeth, bone growth at joints, lameness) in grazing animals. Mixtures of these pollutants have interactive effects, which are generally additive or synergistic, but with NO_2 being the least problematic in any combination (Treshow 1984, Wellburn 1994, Krupa 1996, Yunus & Iqbal 1996).

Ammonia is also liberated in leachate. Where exposed to air, the ammonia will volatilise and contribute to potential problems of acid rain, although the major source of such emissions is from agricultural manures. Ammonia generated from leachate within landfills will migrate through the soil horizons where it is progressively nitrified (oxidised) to nitrite and nitrate and causes subsequent eutrophication problems. There are no recognised pathways for the complete removal of ammonia and calculations based on flushing rates alone have shown that at least 500 years would be required to achieve criteria levels (the recommended value for ammonia in landfill leachate is 5 mg.l⁻¹). Recent research has identified effective methods that might remove ammonia from leachate, but these remain to be field-tested (Campbell et al. 1995). Emissions of ammonia or hydrochloric acid at levels low enough to constitute primarily an odour (as opposed to a chemical nuisance) can still induce panic attacks in horses (Kevin Dodd, Faculty of Veterinary Medicine, UCD, personal communication).

NO_2 emissions rarely reach a plant injury threshold and low levels of both NO_x and ammonia can stimulate growth in low nutrient situations through eutrophication. Unfortunately this can bring about significant changes in oligotrophic aquatic and terrestrial (e.g. heathland) ecosystems leading to loss of habitat, and the disappearance of specialist flora and fauna. Nitrous oxide (N_2O) is also a greenhouse gas.

Oxides of sulphur (SO_2 and SO_3) mainly enter plants through the stomatal pores in a manner which is affected by light and temperature levels, and by the humidity, velocity and turbidity of the air. Low

concentrations may increase photosynthetic rates in the short term, but higher exposure decreases photosynthesis and ultimate yield, the impact generally being worst after winter exposure (Yunus & Iqbal 1996). Some lichens (and bryophytes) have been found to be particularly susceptible to exposure to sulphur dioxide. This is a species-specific response to differing concentrations of the gas with the result that the more tolerant species replace more susceptible ones. Monitoring the species composition and growth rates of these organisms on or adjacent to waste management sites could provide an effective bioindicator series.

Hydrogen sulphide (H₂S) is an extremely biotoxic gas, effective at a few parts per billion in mammals. Plants are far less sensitive to direct toxicity effects, but these may have a threshold of 1 µg.g⁻¹ (Finnecy & Pearce 1986, Wellburn 1994). The most likely impact on plants is as an indirect result of anaerobic soil conditions created by high concentrations of this gas. Gas production in naturally anaerobic soils or lateral seepage from landfill sites can inhibit root growth and destroy vegetation cover.

Although there is general concern about the loss of stratospheric ozone (O₃), presence of ozone close to ground level is problematic (Agrawal & Agrawal 1999). It is usually a secondary pollutant formed from the interactions of VOCs and NO_x with atmospheric oxygen, and is therefore of some minor relevance to emissions from waste management facilities. Although high ground-level concentrations inhibit photosynthesis, reduce growth and depress agricultural yields (Yunus & Iqbal 1996; Agrawal & Agrawal 1999), lower concentrations are less problematic and difficult to interpret. For example, low-level exposure to ozone (and SO₂ to a lesser extent) can ameliorate Cd or Ni toxicity in plants.

The organic micro-pollutants (dioxins, furans) have a high profile due to the excessively toxic effects of some of these chemicals on humans (see Chapter Seven). Impacts on the general environment have also been studied and modelled, and bioremediation techniques are being developed (Hutzinger et al. 1982, Heffron 1991, Domingo et al. 2000, Hinchee et al. 1994, Wild et al. 1997). Unfortunately, the likelihood of micro-pollutant formation from chlorinated organics in an incinerator waste stream is increased by the coexistence of potent trace metal catalysts such as copper, platinum and nickel in exhaust gases. Mixtures of PCDD molecules found in environmental samples show a profile characteristic of their source and of their subsequent decomposition reactions (Townsend 1980, Townsend 1983, Eduljee & Townsend 1987). This suggests that their passage through the environment can be traced comparatively easily.

High concentrations of PCDDs and dibenzofurans (PCDF) have been found in soils up to 1 km from an incinerator, with the more highly chlorinated forms accumulating to the greatest degree (Berlincioni & di Domenico 1987). These compounds were not confined to the top 5 cm and may have reached deeper soil layers by leaching or ploughing. Although current knowledge of PCDD decomposition in soil is limited, the half-life of TCDD (tetrachlorodibenzodioxin) is approximately 1 year (Domingo et al. 2000). There appears to be a generally poor correlation between accumulation by soils and uptake by plants, with the result that analysis of either component gives a measure of deposition rather than transfer. Soil concentrations reflect cumulative PCDD/F deposition over rather long periods of time, and levels in vegetation can be a more suitable indicator of short-term atmospheric emissions (Domingo et al. 2000).

Elevated concentrations of PCDD/F and PCB (polychlorinated biphenyls) have been found in cow's milk, eggs and poultry meat sampled in the vicinity of incinerators (Lovett et al. 1998), but the levels identified in cow's milk in Ireland are extremely low (Concannon 1996, Concannon 2001). These contaminants are stored in fatty tissues and undergo relatively slow metabolism or elimination. PCDFs

show a considerably higher retention in the liver than PCDDs (Lisk 1988). Soils and water seem to be the main carriers to animals, but the overall toxic effects of mixtures of chemicals such as PCDD and PCDF in biological systems are difficult to predict. The significant health effects of these compounds are addressed in Chapter Seven.

PAHs (polycyclic aromatic hydrocarbons) originating from refuse combustion have been found in soils, sediments and plants. The biodegradability of these compounds in soil generally decreases as the number of aromatic rings increase (Blumer & Youngblood 1975). Plant contamination is virtually all due to deposition of air-borne PAH on foliar surfaces and negligible quantities are absorbed through root uptake.

Apart from any inherent toxicity due to their specific chemistry, dust particles have the capacity to coat, clog or choke organisms. Among domesticated animals, horses are particularly sensitive to dust emissions.

Impact of trace metals

The terminology applied to potentially toxic 'metal' elements is confusing (Lepp 1981a, Wittig 1993). The current evaluation deals with a large number of elements of environmental significance, which normally exist in biota in *trace* concentrations and can generally be afforded that title (Lepp 1981a, Lepp 1981b, Ormrod 1984, Vernet 1992, Ross 1994). Most of these are clearly identified as *metals* on the basis of their physico-chemical properties and position in the periodic table, but others such as arsenic and selenium occupy a more dubious position and can perhaps be best described as *metalloids* (Lepp 1981a). Several of the metals also fall in the periodic category of *heavy metals*, but since this does not apply to all elements of concern, the term *trace metals* has been employed here to embrace both metals and metalloids.

Several metals (e.g. copper, zinc, molybdenum) are also *trace elements*. These are essential at low concentrations for normal growth and development in either plants or animals, but become toxic at higher cellular concentrations (Oehme 1979a, Oehme 1979b, Shkolnik 1984, Paris & Benton-Jones 1997). Characteristic (and distinct) deficiency or toxicity symptoms can be identified in plants in many cases (Lepp 1981a, Farago 1994). Other trace metals (e.g. lead, mercury) are apparently never required and must be regarded as only having potentially negative effects.

Trace metal uptake by plants is generally limited and usually shows saturation characteristics. However, phytotoxicity thresholds (lowest concentration at which decreased plant growth occurs) are generally higher than tissue toxicity thresholds for those animals consuming them. Risks for plants are therefore of lower order than for animals, thus facilitating bioaccumulation and exacerbating problems of trace metal transfer along the food chain.

A key route for entry of metals into the food chain is via uptake by plants from the soil or as a result of accumulation in fish tissues. Approaches to evaluating the fate and distribution of contaminants in ecosystems are discussed by Markert (1993), Ross and Kaye (1994), and Walker et al. (1996), who also outline biomonitoring procedures. Analytical techniques are also detailed in Stoepler (1992). Tessier and Turner (1995) specifically address the chemistry and bioavailability of trace metals in aquatic systems. In the Irish context, Flanagan and Patrick (1990) list 20 trace metals which are likely to be present in a range of effluent discharges including leachate, and nearly all of which are toxic to fish and humans (Table 5.6).

Table 5.6 Heavy (i.e. trace) metals of concern to fish and humans

Antimony (Sb)	Cobalt (Co)	Nickel (Ni)	Tin (Sn)
Arsenic (As)	Copper (Cu)	Selenium (Se)	Titanium (Ti)
Beryllium (Be)	Lead (Pb)	Silver (Ag)	Uranium (U)
Cadmium (Cd)	Mercury (Hg)	Tellurium (Te)	Vanadium (V)
Chromium (Cr)	Molybdenum (Mo)	Thallium (Tl)	Zinc (Zn)

(Source: Flanagan & Patrick 1990)

Uptake by plants is affected by soil pH and salinity, with cadmium and lead uptake being enhanced by chloride complexation of the metals in materials such as leachate (Alloway 1995). Much of what is taken up is held in the roots, which may minimise implications for the food chain from foliage or seed crops. Many plants demonstrate tolerance to those metals they absorb, and cultivars with extreme tolerance are now available in commercial quantities for use in reclamation or decontamination work. Some species hyper-accumulate trace metals, making them problematic food sources, but giving them potential value as indicator species for monitoring programmes or as bioaccumulators during phytoremediation programmes (Treshow 1984, Markert 1993, Farago 1994, Ross & Kaye 1994, Saxe 1996, Brooks 1998). Material harvested from such species used in remediation work will need either to be incinerated or to go to secure landfill.

There is surprisingly little information about the effects of specific contaminants on plant physiology, although this is understandable given the range of elements, the variability among plant species, and the complex nature of uptake at the soil/water/plant interface. Most of the available evidence relates to effects on crop yields. General toxicity effects are depressed root growth (with consequent drought symptoms) and foliar discoloration (chlorosis) resulting from membrane damage and enzyme inhibition (Farago 1994). However, major interactions occur between different trace metals (Lepp 1981a), with many metals inducing copper deficiency symptoms.

Atmospheric scavenging is affected by the surface area available for deposition (including the presence of surface hairs) and shows seasonality with a peak in late winter/early spring. This results from aerial deposition being highest in winter, lead (Pb) and cadmium (Cd) being more mobile at that time due to the seasonal unavailability of soil phosphorus (P), and spring mobilisation of any metals held in the roots. Autumn-sown crops are the most susceptible, while spring-sown ones may partly escape.

The following sections provide an overview of the pathways of environmental transfer and impacts associated with a number of trace metals identified with emissions from landfills or incinerators.

Antimony (Sb) is naturally associated with arsenic and can occur naturally in water; natural levels in USA streams being approximately $1 \mu\text{g.l}^{-1}$. It is readily taken up by plants and appears to accumulate in roots and older leaf and stem tissues (Alloway 1995). Although it is moderately toxic to all organisms, it does not seem to represent a significant environmental hazard (Lepp 1981a, Alloway 1995). Some mosses, liverworts and fungi seem to bioaccumulate antimony (Lepp 1981a).

Arsenic (As) naturally reaches mean soil levels of 2-3 ppm, but can exceed 250 ppm (Dartmoor granites). A major anthropogenic source in the USA is coal-fired power plants. Arsenite is a more toxic chemical form than arsenate, and soil phosphate availability seems to increase uptake. Uptake (by barley) shows saturation characteristics but it can eventually exceed 10 ppm, with a tendency to accumulate in roots, causing root rot. Plant growth is usually severely restricted (approximately 50% reduction) before grazing animals or humans suffer serious consequences (Alloway 1995). Susceptibility varies: beans, onions, peas and cucumbers are very sensitive; strawberries and beet fairly tolerant; potatoes, carrots, tomatoes and grasses very tolerant. Douglas fir bioaccumulates arsenic, making it a potential bioindicator species. In animals, arsenic is an actual or potential carcinogen (Lepp 1981a, Nriagu 1994a, Nriagu 1994b).

Beryllium (Be) is a rare element, the major environmental source of which is fossil fuels. It has been little studied, but possibly achieves normal maximum soil and plant tissue concentrations of 7 and 1.0 ppm respectively. It appears to be toxic to plants growing in acid ecosystems, but beneficial at alkaline pH (Lepp 1981a). It causes a variety of pulmonary diseases in humans and is therefore of concern. However, it appears to be mainly sequestered in plant roots, thus minimising its impact on the food chain (Lepp 1981a).

Barium (Ba) occurs at fairly high concentrations in a number of naturally occurring soils. Plants absorb barium readily from the environment (even epiphytes which are not rooted in soil) and some species bioaccumulate, but it appears relatively inert in plant tissues (Lepp 1981a).

Cadmium (Cd) occurs in association with zinc and is found in soils, mud, humus and organic matter. It is a significant anthropogenic contaminant, but soils derived from carboniferous black shales may contain up to 200 ppm. Research interest in its environmental effects was only stimulated in the 1970s following the demonstration of effects of dietary intake in humans, especially after long exposure (Lepp 1981a). It is now regarded as being highly toxic to animals, particularly in water. Cadmium is readily taken up from the soil (especially by leafy plants and under acid pH) but, although the initial rate of uptake can be linear relative to soil concentration, it tends to tail off with time (Lepp 1981a, Vernet, 1992). Leafy vegetables (spinach, lettuce) are more susceptible than field crops, but phytotoxicity (reduced transpiration and photosynthesis) has mainly been demonstrated experimentally rather than in the field (Lepp 1981a). Unfortunately, cadmium is relatively mobile and shows potential for accumulation through the lower terrestrial trophic levels, although leaf crops are more problematic than root or seed crops from a human perspective (Lepp 1981a, Alloway 1995). It accumulates in the soft tissues of grazing animals where it is highly toxic, with pasture herbs being a more dangerous pathway of transmission than grasses.

Chromium (Cr) is a scarce mineral, but elevated levels are found in serpentine-derived soils and it enters surface waters from tanning, paint and drying plants. It is a trace element concerned with glucose metabolism in humans, but apparently not in plants. Cr III (chromide) is less toxic to plants than Cr VI (chromate) so Cr III-VI conversion in landfills etc. is of environmental significance. Uptake by roots seems fairly high in a range of species, but partitioning diminishes along the gradient roots – foliar parts – seeds. Lichens and mosses appear to bioaccumulate (Lepp 1981a, Langård 1982, Alloway 1995).

Cobalt (Co) is an essential element for nodulated nitrogen-fixing plants and for Vitamin B12 in mammals. Plant uptake correlates with soluble soil concentrations and species such as sweet clover bioaccumulate. It has variable and uncertain toxicity effects in plants, and is relatively non-toxic to animals, with Co deficiency being a greater problem in pastures than toxicity (Lepp 1981a, Alloway 1995). Cobalt has little effect in aquatic systems.

Copper (Cu) is also an essential micronutrient at low concentrations and has a relatively low inherent toxicity in plants although it is used to control algal blooms in water. Its toxicity levels vary with the hardness of a particular water and, if not properly handled, can cause fish kills. Copper availability to plants is influenced by factors such as the soil organic content, excessive uptake being associated with chlorosis and stunted growth (Lepp 1981a; Alloway 1995). Within limits, pig growth is stimulated by copper and it is often a commercial feed additive, but it is very toxic to sheep at 8-11 ppm in the diet (Kevin Dodd pers. comm.).

Lead (Pb) tends to leach from ores and strict limits on its presence in water have to be enforced as it is a toxic, cumulative poison. Lead levels in UK soils increased to 20 ppm since 1700, with leaded petrol contributing 3 ppm (rural) and 10 ppm (urban) to soils adjacent to roads. Lead uptake essentially correlates with soil concentrations (Alloway 1995), being linear in radish and greater than linear in alfalfa and some grasses. It may also be taken up by plant litter after the plant dies. Winter-grown cabbage, carrot, kale, leek, parsnip, spinach and sprouts in high-lead soils (13,000 ppm) had five to eleven times higher lead uptake than summer-grown forms. More atmospheric lead accumulated on hairy grasses and younger/faster-growing plants of various species (Lepp 1981a). Lead tends to accumulate in the bones of any grazing animals, thereby minimising its impact on the human food chain (Oehme 1979a).

Manganese (Mn) effects on plants, whether expressed as deficiency or toxicity, depend upon its solubility in the soil since it is essentially unavailable above soil pH 7 (Lepp 1981a, Alloway 1995). Attaining a neutral or alkaline pH on any contaminated site will therefore ameliorate any toxicity effects.

Mercury (Hg) is probably the best studied trace metal contaminant. It is non-essential and one of the most toxic metals within the food chain, being readily absorbed by animals, fish and shellfish. Mercury ore outcrops occur naturally, but the main sources are anthropogenic, following release from batteries, paints, plastics, and paper-making. Mercury in humified soils has been shown to range from 0.2-0.3 ppm, with peaks of 0.65-1.0 ppm. However, mercury compounds in soil are reduced to the metal form, which is released as vapour and transferred to the principal environmental sink in bottom sediments of aquatic systems. There is still scope to develop protocols using soil invertebrates to assess critical loads for species, communities or ecosystems, and identify acceptable limits for mercury in soil (Rundgren et al. 1992). Transfer to plants is limited and mercury tends to accumulate in the roots (Alloway 1995). Inorganic and methyl-mercury are bioaccumulated by different mechanisms, but standard tissue concentration ranges for plants and mammals are of the order of 0.1-10 ppm. Cats are very sensitive to mercury poisoning and are a good indicator species.

Molybdenum (Mo) is an essential trace element required in very small concentrations, the metabolism of which is closely related to that of copper. Molybdenum-deficient soils occur naturally and may restrict plant growth. Excessive soil concentrations also occur naturally; the plants may not be affected, but animals feeding on them suffer from an induced copper deficiency disorder at levels exceeding 15 $\mu\text{g.g}^{-1}$ (Jones 1991, Alloway 1995).

Nickel (Ni) contaminated soils occur naturally, and those derived from basic igneous and serpentine rocks can have 50-400 ppm Ni. Nickel is an essential trace element, which becomes toxic at external concentrations of 0.8-10 ppm (Lepp 1981a, Alloway 1995). There is a reasonable correlation between uptake and plant tissue concentrations, but there is species-specific variability amongst crops: wheat and barley tend to exclude nickel, but beans and turnips accumulate it, while oats are the most affected (Lepp 1981a, Lancaster 1988).

Platinum (Pt) and **Palladium** (Pd) have very similar chemistries. They are naturally rare and non-essential, and little is known about their biological impact except that they are concentrated by some plants, mainly in the roots (Lepp 1981a).

Rhodium (Rh) is listed as a trace metal constituent of incinerator flue gases, but there appears to be no literature on its potential toxicity in the environment.

Selenium (Se) is not a plant nutrient. It is an essential trace element for fish and mammals, although the range between dietary requirement (0.1 to 1 $\mu\text{g}\cdot\text{g}^{-1}$) and chronic toxicity (2 to 15 $\mu\text{g}\cdot\text{g}^{-1}$) is relatively narrow (Lo & Sandi 1980, NRC 1989, Combs & Combs 1986, Mayland et al. 1989, Frankenberger & Engberg 1998). Soil deficiencies of selenium are a major problem for livestock in New Zealand and occur in some areas in Ireland. Excessive selenium levels occur naturally in Ireland in soils derived from rocks such as marine black shales (Walsh et al. 1951), but the concentration can also increase by deposition from the air or migration from adjacent land, and soils are capable of reabsorbing volatile selenium compounds. Selenium has been shown to migrate through the soil capping layer on a closed fly ash landfill site and accumulate in the surface vegetation (Woodbury et al. 1999). Plant uptake correlates fairly well with soil concentrations, with the element being readily transported throughout the plant. Phytotoxicity problems can occur and appear to involve a disturbance of sulphur metabolism (Lepp 1981a). Toxicity symptoms are more severe in animals, especially in horses, and with cattle suffering characteristic loss of hair and a sponginess and splaying of the hooves. However, pig growth may be stimulated by selenium and it has been a dietary additive (Kevin Dodd, Faculty of Veterinary Medicine, UCD, personal communication).

Tellurium (Te) is found in a number of commercial products such as porcelain, glass and enamel, and may therefore escape to the environment from landfill or incineration. It is known to have emetic effects if digested by humans, but there appears to be no literature dealing with its other potential environmental effects or of its passage along the food chain.

Thallium (Tl) is often chemically associated with arsenic, and may also be concentrated in soils derived from weathered limestone (Lepp 1981a). The main anthropogenic source is flue gases, primarily from coal burning, non-ferrous smelting and cement production (Alloway 1995, Nriagu 1998). In this context, the contribution from MSW incineration seems negligible, but this may be understated since MSW and industrial wastes have been used to fuel cement kilns in France since 1986 (Porteus 1996). The forms of thallium found in flue gas are fairly soluble and affect both plants and animals (enzyme inhibitor), the toxicity to animals possibly being enhanced by microbial biomethylation (Lepp 1981a, Sager 1998). Rape and cabbage have high bioaccumulating abilities and are problematic crops in contaminated areas (Sager 1998). Although soil/plant exchange increases at acid pH, thallium mobility in the aquatic environment is largely independent of major water characteristics such as hardness. Aquatic food-source invertebrates such as *Daphnia* are affected at levels below the vertebrate toxicity threshold and therefore have indirect effects upon fish stocks (Nriagu 1998).

Tin (Sn) achieves a mean soil concentration of 3-4 ppm, being strongly absorbed onto the humus fraction. It is relatively immobile in natural waters (Alloway 1995). Some plants bioaccumulate (especially lichens and mosses) but not to such high levels as for arsenic or selenium. There is inconclusive evidence that it might be a plant trace element, but there is little evidence of its effects on animals and it causes little concern (Lepp 1981a, Alloway 1995).

Titanium (Ti) is another listed component of incinerator gases, but there appears to be no literature on its environmental effects and it apparently has no ill effects on mammals.

Vanadium (V) is a generally abundant element in nature. Relatively little is taken up by plants from soil, absorption being greatest in seleniferous or alluvial systems, and lowest in high calcium soils. After uptake the element is localised in the roots, where it may function as a plant trace element and appears to stimulate nitrogen fixation reactions. Concentrations of 10-20 ppm were toxic and 100 ppm lethal to some plants in experimental situations, but some nitrogen-fixing species were unaffected at 100 ppm and seem to act as bioaccumulators (Lepp 1981a, Alloway 1995).

Zinc (Zn) is an essential micro-nutrient at low concentrations, but is highly toxic to aquatic life. It transfers fairly directly from soils to plants, but uptake is restricted at alkaline pH. Plant deficiency and toxicity symptoms are fairly similar and involve chlorosis and stunted growth (Lepp 1981a, Alloway 1995). Plant tolerance to zinc tends to correlate with that to nickel, implying the operation of common genetic systems of resistance. It is relatively non-toxic to animals and tolerance can be enhanced by the presence of calcium, copper, iron, and cadmium in the diet.

Environmental risk assessment

Risk assessment is becoming an increasingly important discipline within overall environmental management. The reviews of the effectiveness of the first phase of formal EU Environmental Impact Assessment procedures introduced by Directive 85/337/EEC (CEC 1985) identified the general absence of probability analysis or risk assessment as a weakness of predictions for the projects covered. Therefore, some emphasis was placed in the amending Directive 97/11/EEC (CEC 1997) on the need for developing this area.

Risk assessment protocols are being developed for a range of practical applications, including use in technology assessment of new engineering applications. The techniques are also being extended to the area of environmental toxicology and contamination (CEC 1993a, CEC 1993b, Suter et al. 2000). The majority of these tend to address comparatively simple chains of events, for example the impact of a single pollutant or group of pollutants on one identifiable species or component process within an ecosystem (Ward 1978, Westman 1985, EPA (US) 1997). As an example, the discussion document on key Irish environmental indicators identifies the specific impact of tributyltin (TBT) on the marine environment, or the changes in the populations of Greenland white-fronted geese (Lehane 1999). Such methods need to be 'based on state-of-the-art understanding of the structure and function of ecological systems' (Bartell et al. 1992) but such understanding is sadly lacking for many species and for all but the simplest systems. Risk assessments carried out to date (and the related life-cycle analyses) have also been affected by a 'flavour-of-the-month' approach, with a large component of value judgement substituting for unavailable data.

In the Irish context, years of chronic under-funding for basic environmental surveillance have resulted in a significant lack of baseline biological data. Much of the most detailed data about the presence and environmental significance of individual species is either generated by amateur groups such as

Birdwatch Ireland (Irish Wildbird Conservancy) or is commissioned for environmental impact assessments of specific local areas. In view of this, it would not be surprising if any comprehensive survey undertaken for an EIS reported data, for example, on species previously considered to be rare or unknown in the country. The review of the technical quality of EISs submitted to the competent authorities is generally constrained by the same lack of financial resources and scientific expertise.

Despite a great deal of ecological expertise, the criteria for ranking ecosystems of a similar type and assessing their vulnerability is underdeveloped (Dahdoub-Guebas et al. 1998), and there is no formalised procedure for evaluating the relative merits of different ecosystems within a landscape complex. Significantly, there is no mention of risk assessment protocols in the current definitive text on ecological impact assessment procedures (Treweek 1999) and reference to it in a recent ecotoxicology test is confined to toxicity data (Walker et al. 1996). A new practical guide to environmental risk assessment for waste management facilities (Pollard et al. 2000) does refer to the need to address sensitive ecosystems. However, techniques are not yet available to assess the overall, and possibly interactive, impacts of a large project such as an incinerator or landfill with a complex ecosystem, and much of the work in this area remains experimental (Bartell et al. 1992), although recent work does attempt to address additive effects (Suter et al. 2000). The World Bank is in the process of integrating a biodiversity and environmental assessment toolkit into its planning procedures, but the finer details of the tools still have to be fleshed out by competent ecologists (World Bank 2001).

The problem of assessing possible synergistic effects between more than one project within reasonable geographic proximity are even greater, especially if this is undertaken retrospectively as in the case of the recent Askeaton inquiry (EPA 2001). There is no evidence that specific ecological risk assessment protocols were employed, or that anything other than simple engineering risk assessments were used in relation to any of the recent landfill or incinerator proposals covered by the Irish EIA Regulations.

Research is currently being undertaken in Ireland to quantify the risks associated with individual aspects of the problem created by BSE (Bovine Spongiform Encephalopathy). Although BSE risk material would be classed as hazardous and should not end up in either landfill or any proposed MSW incinerator, the components of the BSE assessment are relevant to the current study since this is probably the best developed risk assessment protocol relating to a waste product generated within the state (Box 5.7). It addresses the risk of movement of the contaminant (the infective BSE prion) through the environment as well as the risks associated with heat-treating, incinerating or landfilling potential contaminated animal products and the consequences for policy (Cummins et al. 2002a). Even in this area there is no single all-embracing model for risk assessment and the predictions that are being made have yet to be validated through monitoring (Cummins et al. 2001). Ultimately, a modification of this methodology may be applicable to addressing the broad spectrum environmental effects of new landfills or incinerators

However, presentations at a recent Irish environmental conference (ESAI 2002) suggest that these techniques are being actively pursued. Papers presented included a consideration of pyrolysis and gasification as alternative disposal mechanisms, the development of Geographic Information System (GIS) models to aid in site selection, the design of economic instruments associated with solid waste management, and the application of multi-criteria decision-making and life-cycle analysis techniques to the problems.

Box 5.7 Development of risk analysis for BSE in Ireland

The identification of meat and bone meal (MBM) as a significant factor in the spread of bovine spongiform encephalopathy (BSE) has resulted in the introduction of restrictions on the use and movement of MBM and tallow. This has led to a requirement for alternative uses for these products. With up to 4,000 tonnes of tallow being produced each year in Ireland, combustion with energy recovery represents a viable cost-efficient utilisation route. A stochastic (Latin Hypercube sampling) simulation model was developed for Ireland to assess the infectivity risk to humans associated with potential airborne exposure to the combustion products while using tallow as a combustion fuel in diesel engines (Cummins et al. (2002b)). The model simulates the potential infectivity pathways which tallow follows including its production from animals with potentially subclinical BSE and processing the tallow with segregation and heat treatments. The model uses probability distributions for the most important input parameters. The assessment takes into account a number of epidemiological parameters including tissue infectivity, species barrier, disease incidence and heat inactivation. Two scenarios, reflecting the infectivity risk in different animal tissues defined by the European Commission's Scientific Steering Committee (SSC), were performed. It is seen from the model results that the risk of a human contracting variant Creutzfeldt-Jakob disease (vCJD) from potential airborne exposure to BSE, resulting from the combustion of tallow, are extremely small even when model uncertainty is taken into account (mean values ranging from $10^{-7.3}$ to $10^{-6.67}$ per annum). The risks are less than the sporadic annual incidence level of CJD in Europe (approximately 10^{-6}).

The probability and severity of an adverse event can be analysed by quantitative risk assessment (QRA). This methodology was applied to model the human health risks associated with the combustion of specified risk material (SRM)-derived meat and bone meal (MBM) (Cummins et al. 2002b). A stochastic (Latin Hypercube sampling) simulation model was developed to assess the associated risks for a combustion facility in Ireland. The model simulates the potential infectivity pathways, which SRM-derived MBM follows including its production from animals potentially infected with subclinical BSE and processing the material with segregation and heat treatments. The model uses probability distributions to take account of inherent uncertainty in the input parameters. Similarly to the tallow risk assessment, two scenarios reflecting the infectivity risk in different animal tissues as defined by the SSC were performed with 100,000 iterations of the model. It is seen from the model results that the societal risks presented to human health from the combustion of SRM-derived MBM are extremely small (ranging from -7 log ID₅₀/year to -13 log ID₅₀/year). These risks are a number of orders of magnitude less than the sporadic incidence level of CJD (approximately - 6 logs). A sensitivity analysis revealed that the species barrier had the largest impact on risk calculations and hence should be the focus of further scientific investigation to reduce our uncertainty about this parameter. A separate model was run with no species barrier. The resulting societal risks were still small ($7.7e^{-6}$). The model predicts that material spillage into untreated effluent represents the biggest risk to humans, indicating that efforts for risk mitigation should be focused on reducing the potential for spillage in an effort to reduce risk estimates.

To date only a few risk assessments regarding BSE risk via environmental pathways have been done. Most have been done by Det Norske Veritas Technica (DNVT) for the UK Environment Agency (DNVT 1997a, DNVT 1997b). Specifically, they addressed risks to humans associated with the disposal of BSE-infected cattle and cattle slaughtered under the 'Over Thirty Months Scheme' in the UK. The results of these assessments were later incorporated into the scientific

report to the SSC on the risks of non-conventional transmissible agents and other hazards entering the human or animal food chains via fallen stock, dead animals or condemned materials (EA 1997).

Disposal of BSE-infected cattle or TSE suspect material in an uncontrolled landfill or by burying is not recommended by the SCC, primarily because of the possibility of contamination of the environment and water supplies by leachates or percolation. Incineration of whole carcasses or burning MBM in power plants after rendering can be done. However, handling the infected MBM prior to incineration would potentially increase the risk. Incineration or burning of BSE-infected carcasses or TSE suspect material at temperatures at or exceeding 850°C for 2 seconds is recommended (EA 1997). No infectivity was demonstrated when hamster-adapted scrapie agent was subjected to 1000 °C. Commercial incinerators, power plants, and cement kilns operate in excess of 850 °C. Incineration was not assumed to completely inactivate the TSE agents in the DNV risk assessments but this was due to potential failure of the operation, not the inability of the incineration process to inactivate the agent (DNVT 1997a).

The SSC recognised that there might be infectious material remaining in the ash and slag after incineration (up to 400 ID50s after incineration of 5000 BSE infected cattle) and recommended that the slag and ash be stored in a controlled landfill.

Comparative risk assessment

When trying to obtain a more balanced picture of relative risk, volumes of emissions can be calculated for each pollutant and related to local or national totals in each case. Landfill is estimated to be one of the most important global sources of methane emissions, but methane is also emitted in significant quantities from natural soils such as active peatlands (EA 2001) and in agriculture from land clearance, paddy fields and ruminant digestion (Leggett 1990, Conway & Pretty 1991). Hester and Harrison (1995) present comparative emissions of trace elements from a variety of industrial activities, and the EEA (2000) has data on the world-wide atmospheric emissions of trace metals from waste incineration as a percentage of total emissions. These emissions should be related to the output from trace metal mining, and to their increasing release from catalytic converters on motor vehicles (Lepp 1981a).

However an assessment of the risks of incineration or landfill comparative to other industrial processes is extremely difficult because of the complex composition of emissions from waste facilities and the likelihood of unique synergistic effects between these and other activities.

The best form of comparative risk evaluation would be to prepare an environmental balance sheet for non-treatment and the various alternative forms of waste treatment. In the short term, incineration will increase greenhouse gas emissions over and above those produced by landfill or no waste treatment due to the instantaneous creation of carbon dioxide. However, it has greater long-term benefits for carbon-based greenhouse gases over landfilling since incineration eliminates the production of methane, which, although transient in the atmosphere, is thirty times more active than CO₂ (Eduljee 1995). The relative merits of incineration versus landfilling in terms of emissions of greenhouse gases have been examined in the UK. The greenhouse effect of landfilling one tonne of MSW (without gas recovery) has been calculated as being equivalent to about 4.8 tonnes of carbon dioxide, as opposed to 0.8 tonnes of carbon dioxide released through incineration, a difference in potency of a factor of six (Hester & Harrison 1995).

Summary

Any attempt to evaluate the framework for environmental management in Ireland immediately encounters problems over a general lack of baseline information and monitoring data. Owing to severe deficiencies in our overall monitoring capability, accurate and reliable data are difficult to acquire. This undermines the validity of specific surveys undertaken for site selection purposes, since detailed investigations tend to identify complexities of the local environment that are difficult to evaluate in a national context. Far more support needs to be given to baseline monitoring of the Irish environment if legitimate conservation and development needs are to be adequately addressed and balanced. The *Directive Establishing a Framework for Community Action in the Field of Water Policy* 2000/60/EC (CEC 2000) should provide a partial stimulus for this since it requires the collection of basic information to set up references for aquatic ecosystems. To comply with the spirit of the directive it will be important to assess not only water quality, fish and aquatic invertebrates, but also phytoplankton, macrophytes and hydromorphology.

The Irish environment is suffering as a direct result of an inadequate waste management framework, which needs to be drastically overhauled in the immediate future. This necessitates not only proper planning for future developments guided by national and EU legislation, but also stringent enforcement of existing laws and the vigorous prosecution of unlicensed and illegal activities. Contingency plans should also be developed to enable response to the emergencies, incidents or breakdowns in environmental performance, which are being identified with increasing regularity.

Clear responsibility must be assigned to an appropriate government department to define (and fund) areas of research priority, introduce stringent sampling protocols and ensure their implementation, set goals and oversee progress, and publish annual reports. Responsibility for actual monitoring programmes could be assigned to the appropriate local authorities, most of whom are already directly involved with landfill sites. However, legal and moral responsibility must reside with the developer. In the USA, developers of lined landfills are trying to shift the burden of proof for protection of groundwater from the applicant to the regulatory agencies and/or public watchdogs. Such an approach is highly inappropriate.

Similarly, firms that undertake the production or review of Environmental Impact Statements for waste management projects must have the technical competence to make a truly independent analysis of the proposed design, construction, operation, closure and post-closure activities. If insufficient information is available to make a proper assessment, that should be explicitly stated and the applicant required to complete the necessary investigations to develop the information. This is implicit in the EIA and waste management legislation, but needs more rigorous and public follow up.

This report has highlighted the paucity and scattered nature of information specifically related to the impacts of solid waste disposal in Ireland. Apart from published data, some information remains untapped in theses in a number of third level institutions, and more is in the collective memory of academics and central or local government departments, several of which are currently investigating aspects of the problem. A significant effort should be made to catalogue and centralise this information, possibly focused by the organisation of dedicated research symposia/workshops.

It is clear that not enough consideration has previously been given to the impact of landfill leachate on water and the aquatic environment. Despite the apparent absence of published evidence for impacts of leachate on soil and surface water in Ireland to date, effects on groundwater are known.

Regrettably, groundwater monitoring systems typically have a low probability of detecting leachate before widespread pollution has occurred. Therefore, it must be concluded that leachate from existing facilities is already posing serious undetected problems which can only get worse. This pollution should be identified even if it cannot be easily rectified. Protection of water is a priority and existing landfill sites in close proximity to aquifers, water courses, rivers, lakes, estuaries and inshore marine locations should therefore be subjected to continuous, regular sampling. This sampling should include all the usual suite of parameters plus additional data on trace metals such as copper, cadmium, lead and zinc.

It is evident that any new waste management facility will require a thorough baseline survey and monitoring of its emissions. However, not enough is known about the impacts and fate of leachate and other emissions in soils or terrestrial ecosystems in Ireland. In particular, modelling of the transport of metals in soils and vegetation is not yet satisfactory, although work has started on a database for micropollutants in Irish soils (McGrath & McCormack 1999). Despite the difficulty in quantifying ecological effects, these are usually an aggregate of effects on individuals that can be extrapolated to populations through modelling of life history dynamics. Appropriate studies in these areas will have to be initiated if there is to be any possibility of gaining wider public support for new landfills or incinerators. On the assumption that studies related to the best available technology are reassuring, the results will have to be disseminated in non-technical and culturally appropriate forms since there is evidence of a clear deficit in risk communication to the public (Snary 2002). Communication campaigns adopted in other countries may not be adequate since the general attitude to waste management in Ireland is all but universally negative.

Water-quality monitoring increasingly involves a combination of chemical and biological approaches. Good chemical analyses provide an instantaneous snapshot of emissions, while bioaccumulating organisms reflect cumulative exposure and provide a passive record of previous pollution events. Further evidence of this is provided by differences in the ratio of sensitive to non-sensitive species in any population. This combined approach has also been utilised in monitoring dust deposition from modern trace metal mines and should be the conceptual basis of all industrial monitoring. In the case of a potential MSW incinerator, such monitoring must be supported by the rapid development of research on the sources, formation and fate of all significant pollutants contained in the emission. At the same time, best technology should be employed to minimise emissions, especially of the non-consistent pollutants. This must be reinforced by high standards of maintenance and management with appropriate risk management strategies to compensate for possible accidental emissions. No such facility should be created without a clear life-cycle analysis, which also addresses the controlled disposal or recycling of the ashes. The mitigation measures used in any waste management facility should themselves have a minimal contaminating impact.

All new landfills must conform to the requirements of the *Directive on the landfill of waste* (CEC 1999). Although some reliance can be placed on impermeable clay soils as 'natural' liners, these should only provide a back-up to synthetic liners cushioned by shock-resistant material to prevent the risk of perforation. Some advantage might be gained from exploiting a hydrological trap provided by a high watertable where this does not conflict with the requirement to protect groundwater.

The uncontrolled release of landfill gas can present fire and explosion hazards as well as constituting a source of greenhouse gases, which are the focus of compulsory emission reductions. Under the *Directive on the landfill of waste* (CEC 1999), provision for flaring or re-use of methane will be a planning condition for all new facilities. Support should be provided to ensure the collection and

flaring of methane (preferably with energy recovery) from old landfill sites wherever technically feasible, as there are no other existing measures to reduce the amount of gas emitted. Consideration could be given to design options like bioreactor landfill with methane recovery and utilisation, although (as previously noted) such designs become less effective as organic waste is increasingly diverted elsewhere.

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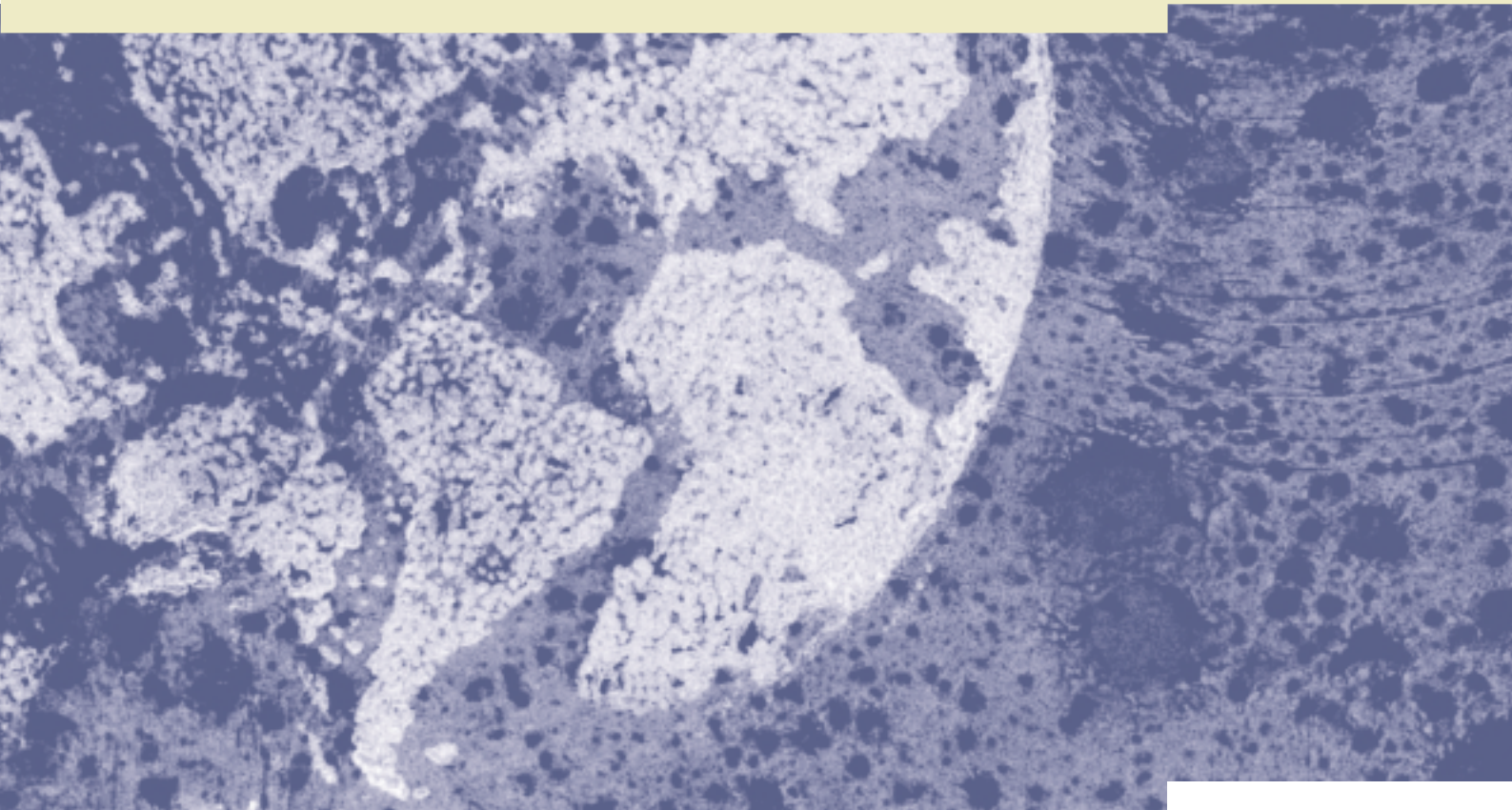
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Chapter Six: Methods of Human Health Risk Assessment



Chapter Six: Methods of Human Health Risk Assessment

Introduction

Health and quality of life depend largely on the physical, social, economic and commercial environment in which one lives. This environment is increasingly compromised by human activity, with few areas in the world left untouched by the direct and indirect effects of humans. Internationally, there is growing awareness of environmental pollution. In addition to the environmental effects of these activities, there is also growing concern about the potential effects on human health. Living or working near industrial or nuclear facilities has led to public anxiety and, in some cases, much media attention. In order to determine the nature and extent of the actual risks to health of such pollutants, a scientific approach is required. Health risk assessment is an approach that encompasses a wide range of disciplines and areas of expertise.

This chapter describes the principles of health risk assessment. Within the context of the risk assessment framework, the principles, strengths and limitations of epidemiology, which is crucial to the analysis of the relationships between population health and the environment, are outlined. While risk assessment is an objective scientific attempt to arrive at the best estimate of the potential hazard, risk management is the decision-making process that incorporates risk assessment outcomes with information from political, economic and social sources. The purpose of risk management is to decide the appropriate response. Integral to risk management is an understanding of the way in which risks are both perceived and communicated. Risk perception and communication are also discussed.

Risk assessment

Risk is the likelihood that a set of circumstances will produce some harm or adverse effect over a period of time. Risk assessment is any methodological approach that is used to predict the likelihood of an unwanted event in the presence of uncertainty (Gargas et al. 1999). The modern model of health risk assessment provides a framework with which to carry out a review of information required for estimating health and environmental outcomes (IPCS 1999).

The primary point of interest in health risk assessments is the health of individuals and human populations. Probabilities and risks of specific health outcomes can be defined for many specific environmental agents. In contrast, ecological risk assessments are concerned with protecting many populations (water snail, woodcock, sphagnum moss, etc.), communities (soil heterotrophs, stream fish, etc.) and ecosystems (forests, bogs, streams). As a result, ecological assessments, which are discussed in Chapter Five, must define a limited number of assessment endpoints. These endpoints are qualitatively very different from those pertaining to human health. For those wishing to take account of both types of assessment, additional challenges exist. The adverse effects of specific agents, and the extent to which remedial measures are required, differ greatly (Suter 1993).

In relation to human health, control of risks from exposure to environmental pollutants requires a scientific assessment of potential effects at given levels of exposure. A model developed by the US

National Academy of Sciences (NAS) in 1983 has formed the basis of much of the EU's new and existing chemicals legislation and is the predominant model used by policy makers and regulatory bodies (National Research Council 1983). The NAS model comprises (a) Hazard Identification, (b) Dose-Response Assessment, (c) Exposure Assessment and (d) Risk Characterisation.

Hazard identification

Hazard identification is identification of the inherent capability of a substance or practice to cause adverse effects. This involves the evaluation of scientific evidence for adverse effects reported in human, animal or *in vitro* studies.

There are two different sources of information to estimate the health hazards of exposure to specified levels of various chemicals. These are toxicological studies and studies of exposed human populations. A very detailed review of these issues is contained in the recent book from the International Agency for Research on Cancer (IARC), *Quantitative estimation and prediction of human cancer risks* (Moolgavkar et al. 1999).

Toxicological studies

These are laboratory-based biological studies carried out under carefully controlled conditions. Organisms, or tissues samples, are exposed to precisely measured levels of hazardous substances for well-defined periods of time, and the consequences of these exposures are measured. From these experiments, estimates of some of the acute, short-term, intermediate and long-term biological effects of the compounds studied can be derived. In addition, the specific effects on development, reproduction, the immune and nervous systems and the ability of the agents to cause cancer are often examined.

The conduct and interpretation of laboratory studies is not entirely straightforward. There are a large number of potential pitfalls in the design and conduct of these studies. The book cited above (Moolgavkar et al. 1999) includes some detailed discussion of the difficulties in analysis and interpretation. On the whole, it is easier to understand the results of laboratory studies than human studies, but perhaps harder to apply them to human exposures and outcomes.

Studies in which the route of exposure is similar to that in humans are of greatest use for the risk assessment process (IPCS 2000). All major organ systems should be examined for dose-related effects if the toxicological potential of the hazard is to be understood. In contrast to human and animal testing, *in vitro* testing uses isolated cells, tissues and organs maintained in cultures to preserve their living characteristics and properties. This method of toxicity testing is accepted by many scientists as ethically more acceptable than many animal testing methods, and will play a greater role in the future of toxicological studies.

Studies of exposed human populations

There are two principal groups of people whose health has been studied in relation to environmental exposures. These are workers exposed to various chemicals in the workplace, and people presumed to be at risk of exposure because of the place where they live.

Occupational studies

Workers in various industries are commonly studied to estimate the health effects of exposure to

chemicals. Workers are often exposed to quite high levels of very specific chemical compounds, and are therefore a good group to study to determine the specific health effects of individual compounds or groups of compounds.

While these studies can provide powerful tests of the human effects of high-level exposure to specific compounds, there are some problems. For example, it is quite common for workers to be exposed to many different compounds. The effects seen are then the result of the aggregate chemical exposure. Workers may change jobs frequently, both within one company and between companies, something perhaps less common in the past than it is now. Workers, by definition, tend to be healthier than the population as a whole. This is because sick people usually cannot work. This is especially important for certain types of employment that require high levels of physical fitness. As a result, studying people still working in a given industry may not detect those whose health has been damaged and who have had to leave that employment.

Some health effects of chemical exposure, especially certain cancers, may take decades to manifest. Other health effects tend to develop more rapidly. Fortunately, the level of exposure to chemical hazards in many workplaces is far lower now than it was in the past. This is due to the introduction and enforcement of workplace safety regulations. However, this reduces the ability of workplace studies to give definitive information on the health hazards of exposure.

Exposed population studies

These are studies of people living near putative sources of environmental pollution. Examples include studies of people living near factories, near nuclear facilities, most famously the Sellafield nuclear facility in the UK, and of people living near waste disposal facilities (Shaddick & Elliott 1996, Michelozzi et al. 1998, Dolk et al. 1998, Viel et al. 2000, Kokki et al. 2001, Elliott et al. 2001, Pukkala & Ponka 2001, Vrijheid et al. 2002).

These studies have a major problem in defining what the health of the population would have been had the facility not existed. Many industrial facilities are sited in areas with higher rates of poverty. Poorer people have substantially worse health than richer people, so people living near an industrial facility may have higher rates of many diseases than the general population. It is quite common for workers in a facility to live near their place of work. This means that the observed health effect of living near a facility may be a combination of the effects of working in the facility and the effects of exposure to off-site emissions.

In studies of workers at a facility, occupational health records, pension records, employment histories, exposure measurement, details of processes and many other items of information are available. These allow a detailed assessment of the likely level of exposure, and give many opportunities to identify some of the consequences of that exposure.

By contrast, in typical residential studies all that is known is that a person was recorded as living in a given location. Commonly, it is not possible to say how long they lived there, or precisely where they lived in relation to the source of exposure.

For example a person might be diagnosed with cancer within a short time of moving close to a facility; another person could live beside the facility for many years, move away, and then fall ill. In both of these cases the link between their residence and their illness would be obscured.

The use of epidemiological studies to investigate the effects of environmental agents

Epidemiological studies have provided much information about the action of hazards to which humans are exposed in their natural environment. In addition, these studies provide information that is directly relevant to human populations (unlike laboratory studies).

Epidemiology has been defined as 'the study of the distribution of a disease or a physiological condition in human populations and of the factors that influence this distribution' (Lilienfeld 1978). Environmental epidemiology may be defined as the study of environmental factors that influence the distribution and determinants of disease in human populations. Recent developments have resulted in a shift from a solely disease-based focus to include the study of exposures. This shift has brought epidemiology closer to the risk assessment process (Elliott et al. 1996). A brief description of the types of epidemiological studies is outlined below.

Epidemiological studies

Different types of epidemiological study are frequently mentioned in the hazard assessment literature. For ease of reference, we include definitions of each common type of study, illustrated with examples relevant to our subject area. Basic ideas relevant to all types of epidemiological study include the concepts of exposure, effect estimate, and outcome.

In the examples here, the exposure is typically a measure of proximity to a waste site, or a set of exposure estimates for a specific chemical. Effect estimates are quantitative, numerical estimates of the impact of exposure on disease occurrence. These might be measures such as the difference in incidence between exposed and unexposed people, or the ratio of the incidence of disease in the exposed group to that in the unexposed group. The outcome is the result of the exposure that one wishes to study. Common health outcomes studied in relation to exposures related to waste sites have included cancers, congenital malformations, and stillbirths.

Ecological study

This is a study with two specific features. First, exposure is measured in geographical terms, for example distance from a waste site. Second, exposure is linked to people by using their locations, typically their home address at the time of diagnosis. Other locations, for example school addresses, addresses at birth or addresses at some specific time before diagnosis can also be used. For several reasons, mainly the difficulty of measuring personal exposure to chemicals outside industrial and waste sites, this method of exposure estimation is often the best available. While ecological studies have significant limits, they are the only method commonly available for measuring the actual health effects of living near waste sites.

Case-control study

This is a study comparing two groups of people. The first group comprises people affected by a specific disease. The second group comprises people without this disease. Both groups are studied, and their characteristics compared. Typically, subjects are given questionnaires to complete, but it is increasingly common to take blood samples or other biological samples to assess exposure. This is discussed further under the topic of biomonitoring, below. The principle underlying this type of study is that, if a particular exposure causes disease, it should be more common in the group with the disease than in the group without the disease.

The main practical difficulty in the conduct of case-control studies is the selection of the control population. This group should represent people who, had they developed the disease under consideration, would have been identified as cases by the study. In practice this requirement can be hard to meet.

The main issue in the interpretation of case-control studies is known as recall bias. Participants in a case-control study usually have their past exposures estimated. As a result, any factor that affects the recollection of cases and controls can affect the results of this type of study. Unfortunately, people with serious chronic illnesses, the type most commonly studied using these techniques, frequently spend time wondering why they have fallen ill. Control subjects seldom do this.

Cohort study

This is a study of a single group of people. These people are identified and followed over a period of time. Their health outcomes are recorded. Common types of cohort study include the occupational cohort, where the cohort is defined to include employees of a particular factory. In this situation, the occurrence of disease is often detected using occupational health records of some kind.

Cohort studies often depend on the existence of past records. These records were seldom collected with the needs of future epidemiologists in mind, and must be interpreted cautiously. Assessment of exposure based on past occupational records may be of limited reliability.

Assessment of exposure

A problem common to epidemiological studies of landfill and incineration is the lack of information relating to human exposure. Although some work has been carried out, mainly in the US, on emission monitoring of specific sites, until recently, continuous or regular monitoring of many sites has not been carried out. Transport mechanisms and pathways that influence the risk of exposure off-site, and thereby influence the risks to local resident populations, have generally not been taken into account in epidemiological studies (Staff & Dolk 1998).

Proximity to the waste site has been used as a proxy measure for exposure in many studies. This can lead to misclassification of exposure (classifying those with low exposure as high and vice versa), which in turn can lead to biased estimation of effects. The US National Research Council (NRC) provides a guideline of the relative reliability of methods of estimating population exposure (NRC 1983). In this hierarchy, the most desirable option for exposure assessment is biomonitoring, whereas data on residence or employment in a geographical area are regarded as least reliable.

US NRC hierarchy of data values for exposure assessment (1983)

- Quantified individual measurements (biomonitoring)
- Quantified ambient measurements
- Quantified surrogates
- Distance and duration
- Distance or duration

- Residence or employment proximity
- Residence or employment in a geographical area

As populations living close to waste sites are likely to be exposed to low concentrations of pollutants (sometimes over long periods of time), the effects on health may be very subtle. Although one of the strengths of geographical population studies is the ability to detect small differences in measured health between exposed and unexposed populations, this measurement is very sensitive to other influences, such as lifestyle factors and other environmental exposures.

Health outcome measures

Epidemiological studies use measures of health that are routinely collected for the population under investigation. Examples of specific health outcome measures used in many epidemiological studies are summarised in Table 6.1.

Table 6.1 Summary of main health outcomes in epidemiological studies of waste sites

Health outcome	Possible difficulties	Comments
Mortality	Some misclassification of cause of death.	Generally a reliable outcome measure.
Cancer	Long periods of time often required to develop cancer after exposure.	Use of cancer registry data is very useful, particularly where coverage is high, and where data has been collected over many years.
Sex ratio	Other influencing factors difficult to establish.	Reliable and easy to measure.
Birth weight	Many other factors i.e. smoking, maternal nutrition, socio-economic status greatly influence this measure.	A sensitive marker of environmental effects. This information is usually collected on all babies.
Congenital abnormalities	Many different conditions may have different causes.	Unknown risk factors may play a part, but few known other factors.
Illness such as respiratory illness	The level of illness in the community of concern may be difficult to establish.	Difficult to be confident about representativeness when examining this outcome measure.
Symptoms of illness	Very subjective. Much variation in individuals perception of illness and in illness behaviour.	Often not routinely collected. Use health surveys to collect information.

A number of studies have investigated the possible association of cancer and exposure to pollutants from landfill sites and incinerators. As outlined in a recent report from the Committee on Carcinogenicity of the UK Department of Health, the factors listed below should be considered when deriving conclusions from these studies (Dunn et al. 2001). Although these recommendations were intended for use when appraising studies of incinerators, most of the points apply equally to studies of landfill sites:

- Accuracy of health statistics,
- Accuracy of cancer diagnosis,
- Potential confounding factors for individual cancers,
- Environmental variables particular to incineration such as type of waste burnt, geographical and meteorological conditions, and controls placed on the emission of pollutants.

In addition, the following points pose additional challenges to such research:

- Lag time for the development of cancers. Most solid tumours take ten years or more from onset to clinical diagnosis. This period is often shorter for cancers of the blood and lymphatic system.
- Other sources of exposure to the same pollutants, resulting in difficulty in identifying a putative source.
- Other agents influencing the process of carcinogenesis.
- Individual variations in susceptibility. Some people may be more susceptible to developing cancers, for example as a result of some genetic factors and age at exposure.
- Some cancers are uncommon or rare, so that few cases may be available for analysis over a given period of time.

Interpretation of epidemiological evidence

Recent guidelines have been produced by the World Health Organisation (WHO 2000) for the evaluation and use of epidemiological evidence for environmental risk assessment. This document sets out a set of processes and approaches for assessment of available literature. A systematic approach to evaluation will also facilitate international comparisons and the inclusion of epidemiological studies in risk assessments.

Causality

An important question in any epidemiological study is whether an association observed between exposure to a potential hazard, and an adverse health outcome is causal. To assist in the determination of a causal relationship between the potential hazard of concern and the observed adverse effect, a number of criteria have been developed (Hill 1965). Although not all criteria are required to be satisfied in every circumstance, these at least provide a structured and systematic way to assess the importance of an observed association (Table 6.2).

Table 6.2 Criteria for establishing a causal relationship

Causal criteria
Strength of the association
Consistency of the association
Temporal relationship between cause and effect
Dose response relationship
Specificity of the association
Biological plausibility of the association

(Source: Hill 1965)

Causality is a difficult concept, but operationally we can interpret it as meaning that removing the 'hazardous exposure' would reduce the risk of ill health. Note that we do not consider here the costs, or other adverse effects of such action, merely whether we can reasonably conclude that this exposure leads to an increased risk of disease. Unfortunately, for the reasons discussed below it can be very hard to establish causality from epidemiological studies. Experts can, and do, disagree vehemently about the most appropriate interpretation of the evidence, and in particular the question of the amount of evidence required to justify a particular action can be very divisive.

A useful rule of thumb is that no single study suffices to establish scientific causation, and that good evidence for causation requires several large, well-conducted studies from different countries. Scientific decisions on causation remain tentative and are liable to revision as new evidence becomes available. Decisions on causation for policy purposes are governed by different priorities. Scientists try to estimate the size of an effect, as precisely as possible, but from a policy perspective the financial and political costs of missing a real hazard may be much greater than the costs of overstating an effect.

Methodological issues in environmental epidemiology research

There are a number of issues to be considered when conducting research in environmental epidemiology, and when appraising literature on this topic. The principal issues are discussed below.

Issues of statistical power

A primary consideration in any study of the health effects of an exposure is the 'power' of the study. This is simply the chance that a particular study will detect a real increase (or decrease) in risk. This is influenced by two main factors. The first is the size of the risk. The higher the risk, the more likely any given study is to detect that risk. The second is the size of the study, in this context the number of people exposed. The larger this number, the more likely a study is to detect any given level of increased risk.

Good-quality epidemiological studies try to identify similar facilities and conduct a pooled study, where information from each of the facilities is used to make a reliable estimate of the average hazard. Recent examples of this study design include the Eurohazcon study of the effects of living near hazardous waste sites in several EU countries (Dolk et al. 1998, Vrijheid et al. 2002), and the SAHSU study of the effect of living near any type of waste site in Britain (Elliot et al. 2001). In both of these studies the health effects of living near a large number of similar sites were studied together.

A good example of the problems of power and precision is a study by Tollefson et al. (1990). The authors compared studies of humans exposed to methylene chloride with risk estimates derived from a set of animal studies. Methylene chloride had been shown to cause an excess of lung and liver cancers in exposed mice, but a large industrial cohort study, of just over 1,000 workers, had shown no evidence of any increase in risk among workers at the Eastman Kodak plant in Rochester, New York. The study showed that the human data were, in fact, entirely consistent with the animal data, but that the human studies had very little chance of detecting a real effect of the size suggested by the animal studies. Such studies do provide some reassurance that humans are not unusually sensitive to the specific exposure, a phenomenon well attested in comparative studies of chemical toxicity between species. The level of risks, at least of those of interest to policy makers, is quite low. This means that it is hard for even quite large epidemiological studies to detect such risks reliably, and to estimate them with any level of precision. Recent work (Tango 2002) suggests that the probability of epidemiological studies detecting modest risks of the type one would expect to see around modern industrial facilities is very low indeed. This has very serious implications for the use of epidemiological data in the assessment of the human hazards of industrial activity.

Issues of precision

For several reasons, the estimation of risk, whether based on epidemiological or engineering studies, is of limited precision. The evidence from a typical study is consistent with a wide range of possible risks. Some examples are presented below.

Cullen (1995) used very sophisticated statistical methods to evaluate the precision of estimation of human exposure to dioxins from municipal waste incineration. Her conclusion is that the estimates of risk to humans derived from these models are largely dependent on the underlying assumptions. This conclusion will not surprise anyone familiar with the types of modelling methods that have to be used to make these estimates. The complexity of these models is very high (see Walter (1999), for example).

Katsumata and Kastenberg (1997) used similarly complex statistical methods to assess the performance of US EPA estimates of the hazard to humans in proximity to Superfund sites. These are heavily contaminated industrial sites that are covered by certain US Federal legislation. Using the source, transport, exposure effects model, (the standard steps in a quantitative risk assessment) the authors found very large discrepancies between US EPA point estimates, and their anticipated distribution of the risk to workers and exposed members of the public. In most cases, the risk estimates that they derived were far smaller than the US EPA estimates.

Pukkala and Ponka (2001) studied the risk of cancer in people living in houses built on top of an old municipal dump in Finland. They identified 34 cases of cancer, compared with 21.2 cases expected on the basis of cancer incidence rates in Helsinki. They estimated that the relative risk of cancer was 1.6 in males, but the 95% confidence intervals on this estimate were from 1.11 to 2.24. In other words, their data were consistent with anything between an 11% excess to a 124% excess of cancer in males.

The Eurohazcon study (Dolk et al. 1998) studied the risks of congenital anomalies around 21 hazardous waste landfill sites in five European countries, comparing people living within 3 km of these sites to those living between 3 and 7 km away from the sites. They found a relative risk of all congenital anomalies of 1.33, with a 95% confidence interval from 1.11 to 1.59. This is an excess risk of between 11 % and almost 60%. For individual anomalies the precision of the estimates was much

less, for example for neural tube defects their estimate of the relative risk was 1.86, with a 95% confidence interval from 1.24 to 2.79, consistent with an excess risk ranging from 24% to just under 180%.

It is important to remember that the 'statistical' estimates of precision, which are all that can usually be obtained from epidemiological studies, represent upper limits on the actual precision, which is usually much worse. This is because the 'statistical' error only considers one source of imprecision in the estimates. This is discussed at more length in the glossary included in this report.

Issues of bias

Bias is the possibility of getting an estimate of the effect of a given exposure wrong. A biased result will not be improved by simply doing a larger study. Bias arises from many sources. Errors in estimating exposure are especially important. If people who were actually exposed are labelled as unexposed, or vice-versa, a study may miss real effects. The problems of people moving residence, the healthy worker effect, and other issues already discussed are example of this.

Another important source of bias is a failure to measure all of the exposures contributing to disease. It has been known for many years that smoking causes lung cancer. If a group of workers, or a group of people living in an area, smoke more than others, they will have higher rates of lung cancer. If the investigators are not aware of this, they might falsely conclude that the extra risk of lung cancer was due to their work, or to their place of residence. This is the problem of confounding.

A very important source of confounding in ecological studies arises because industrial facilities and waste facilities tend to be built in areas where poorer people live. As is well known, poorer people have substantially worse health than wealthier people. As a result people living in areas containing waste facilities and industrial facilities are likely to have worse health. This effect is large, usually significantly larger than any effect from exposure to chemicals. Because of this, ecological studies almost always use measures of the wealth and poverty of areas to adjust the estimates of the health effects of living near industrial sites (e.g. Dolk et al. 1998, Viel et al. 2000, Kokki et al. 2001, Elliott et al. 2001). It is unclear how reliable this adjustment is.

Errors in identifying disease outcomes are also very important. The poor quality of many systems of health records means that accurate measurement of health outcomes is very difficult. This can give rise to severe errors in the conclusions.

Dose-response assessment

Dose-response assessment involves the investigation of the relationship between the amount of the substance to which the subject is exposed and the frequency and severity of adverse effects. For many types of adverse effects, such as organ-specific effects, neurological, immunological, reproductive, developmental and non-genotoxic carcinogenesis, there often exists a threshold dose, below which the observed adverse effect will not occur. For these non-carcinogens, the highest observed dose for which no significant effect can be detected, called the No Observed Adverse Effect Level (NOAEL), is taken for purposes of setting exposure levels (Gargas et al. 1999). Where no NOAEL exists, the Lowest Observed Adverse Effect Level (LOAEL) is used.

Another method for deriving reference doses is the benchmark dose model. This is a technique which takes into account responses at a number of dose levels. This model has the advantage of using more

information from the dose-response assessment to estimate the reference dose and has less uncertainty attached to it. For other effects, such as damage to cells and genes that can result in the development of cancer, there is no threshold for effect, as it is expected that there is some probability of effect at any given dose, no matter how low.

Advancing technology has enabled the use of statistical modelling techniques to estimate the dose-response for certain effects, particularly for the low doses that are often observed in population exposures. These reference doses (RfD) are defined as the amounts (with associated uncertainty factors) that can be taken up each day by the majority of the population without producing an adverse effect. Differences between species and the variability of the human population introduce a level of uncertainty to this dose-response estimation. Extrapolation of responses in animal studies may not always be appropriate when subsequently applied to human populations.

Biologically motivated models for risk assessment have been developed which help to remove some of the uncertainty from this extrapolation process. These models incorporate data on the physiological and biochemical structure of the animal system being described (Clewell 1989). Safety factors have been derived for use when estimating these values (Renwick & Lazarus 1998). These factors, often a multiplier of 10, 100 or 1000, provide a safety margin when incorporated into estimations of effects in humans using animal data.

Exposure assessment

The main goal of exposure assessment is to quantify and describe the environmental agent's contact with and entry onto the human body. Knowledge of exposure to environmental pollutants is a vital part of environmental epidemiology, risk assessment, risk management and the analysis of specific population exposures over time (IPCS 2000).

Critical steps in determining exposure include identifying the release of a pollutant into the environment, how it is transported and the way in which it comes into contact with individuals or populations. Information on the distribution of exposures in a population and identification of specific sub-populations, such as children or older people, who are either more susceptible or at increased risk of exposure, can be acquired.

Assessing exposure also involves estimating the amount of the pollutant that (a) is actually absorbed and (b) is available within the body in a form that can produce an effect; identification of the effects produced then follows.

The basic calculation for estimating exposure is as follows (Gargas et al. 1999):

$$\text{Dose} = \frac{\text{EC} \times \text{IR} \times \text{AF} \times \text{EF} \times \text{ED}}{\text{BW} \times \text{AT} \times 365 \text{ days/years}}$$

Dose = exposure intake expressed in mg per kg per day

EC = the environmental concentration, expressed in units specific to the media analysed

IR = daily intake or contact rate expressed in kg per day for food and soil, litres per day for fluids, and square cm per day for skin exposure

- AF = absorption factor, expressed as percent absorbed for solids or mass absorbed per unit area per unit time for liquids
- EF = exposure frequency expressed in days per year
- ED = exposure duration expressed in years
- BW = body weight expressed in kg
- AT = averaging time; for evaluation of carcinogens, this value is set equal to 70 yrs; for evaluation of non-carcinogens, it is set to the actual duration of exposure.

Issues of interpretation

From the perspective of a policy maker, this reinforces the view that more reliance should be placed on toxicological and environmental dispersion studies. Also, a failure to demonstrate a health effect in epidemiological studies does not give grounds for asserting that the safety of an exposure has been demonstrated. A corollary of this is that it is futile to demand that safety be proven. It is, essentially, impossible to prove the complete absence of any risk. The best that can be done is to make a reasonable inference, based on available biological, environmental and epidemiological evidence, as to the likely magnitude of the health effects from any proposed activity.

As a rule of thumb, no single epidemiological study, no matter how well conducted, is an adequate basis for decision making. There are so many different sources of bias that many epidemiologists advise waiting to see if an observed health effect from a single study can be reproduced in another study of similar exposures in a different population. Final decisions on action are, fundamentally, political and not technical decisions. While such decisions must be technically informed, the high level of uncertainty inherent in the estimation of environmental risks has to be acknowledged.

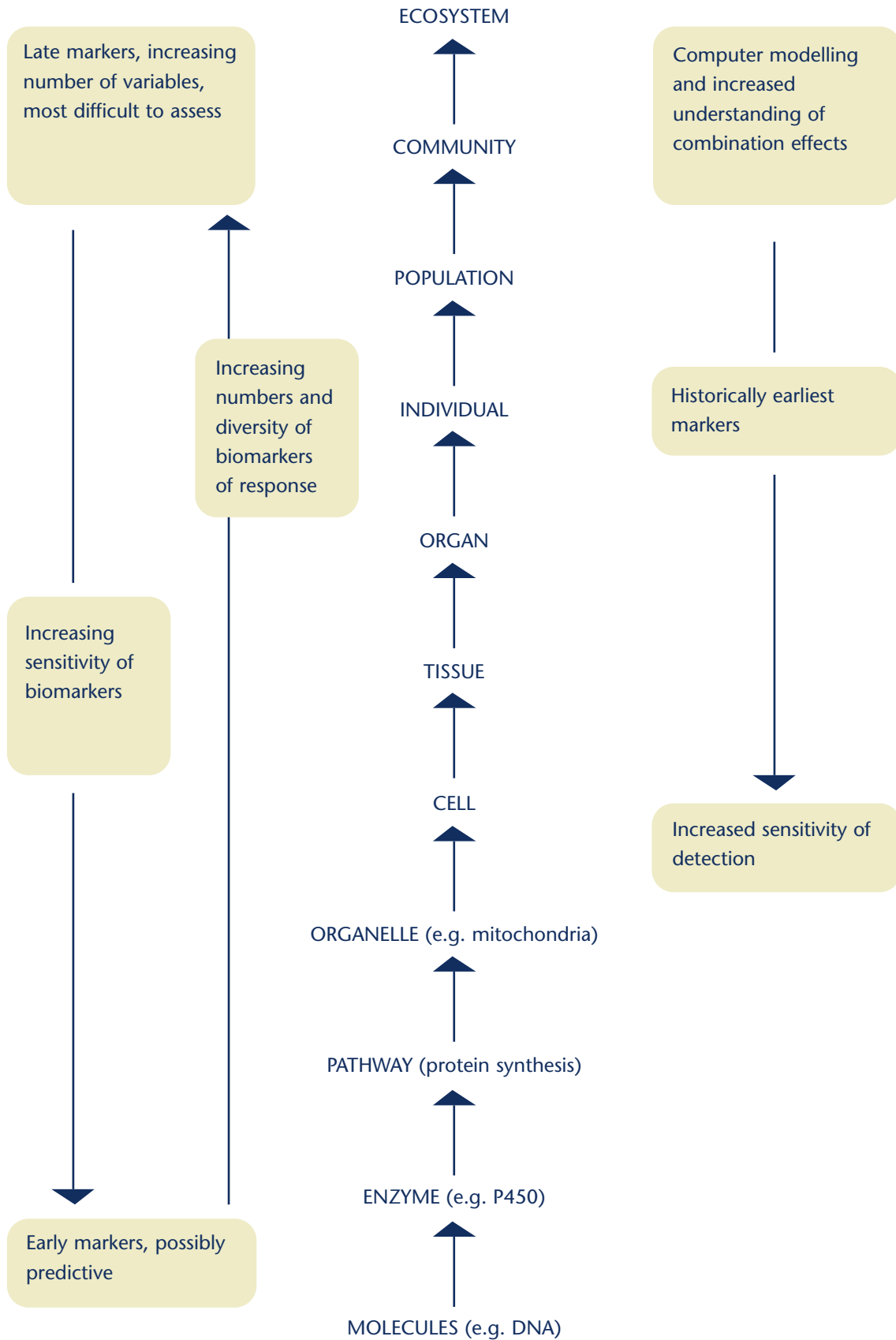
Biomarkers

Biomarkers can be identified at all stages of biological organisation (Figure 6.1) and can be categorised as follows (IPCS 2001):

- Biomarkers of exposure
- Biomarkers of response or effect
- Biomarkers of susceptibility

Biomarkers of exposure include the presence of a compound or one of its break-down products in blood or tissues. Such markers can be useful in epidemiological studies for categorising the level of exposure. Biomarkers of effect or response are those markers that are the result of a physiological or pathological reaction to the presence of the environmental agent within the body. The third type of biomarker is an indicator of an individual's susceptibility to the effects of the environmental exposure in question. Genetic variations can dramatically affect the response of an individual to many agents. This variability may result in greater or lesser adverse effects in those individuals, and may lead to variations in risk of acute, short-term, and long-term effects.

Figure 6.1 Biomarkers (adapted from Waterfield and Timbrell 1999)



The use of biomarkers in environmental health risk assessment

Biological monitoring can provide exposure information that is often complementary to the type of exposure information obtained from environmental monitoring (Pirkle et al. 1995). Although occupational biological monitoring has been carried out for many years, relatively few populations have been so monitored (Sampson et al. 1994). A prerequisite for biomonitoring is knowledge of the kinetics and stability of the marker, in addition to information on the sensitivity and specificity of the methods used to determine it (Tarkowski et al. 2000).

In a recently introduced US programme, such population surveillance is being carried out. The *National Report on Human Exposure to Environmental Chemicals* presents data for the civilian, non-institutionalised US population from the US Center for Disease Control (CDC) National Health and Nutrition Examination Survey (NHANES) (CDC 2002). Data for exposure of the general population to 27 environmental chemicals are documented (Table 6.3). This information provides routine surveillance biomonitoring data for the US. For the specific substances tested, this information serves as valuable baseline data for risk assessment.

Risk characterisation

The above information relating to hazards, exposure and subsequent effect is used to determine health risks. This characterisation of the risk is used to develop standards to protect both public health and the health of workers.

A definition of risk characterisation was published by the US EPA as 'a summary, integration and evaluation of the major scientific evidence, reasoning and conclusions of a risk assessment' (1997). Similarly, risk characterisation has been described by the International Programme on Chemical Safety (IPCS 1999) as 'an evaluation and integration of the available scientific evidence used to estimate the nature, importance and magnitude of human and/or environmental risk that can reasonably be estimated to result from exposure to a particular environmental agent under specific circumstances'.

Risk management

Many organisations with responsibility for managing environmental risks have adopted some form of risk management framework (Figure 6.2). The purpose of this framework is (a) to organise the activities required to support the development of sound environmental policies and (b) to improve the understanding of stakeholders (NERAM 2000). Risk management in its wider context incorporates the process of risk assessment. However, this assessment process should be based on sound science, and should be independent of the decision-making process. Specifically those undertaking the assessment should be independent of those devising and implementing the risk management strategies which will subsequently be informed by its findings.

Table 6.3 The national report on human exposure to environmental chemicals

Environmental chemicals listed in the Report

Metals

Lead

mercury

cadmium

cobalt

uranium

antimony

barium

beryllium

caesium

molybdenum

platinum

thallium

tungsten

Tobacco smoke

Cotinine (a metabolite of nicotine)

Organophosphate pesticides

Urine metabolites of 28 pesticides, including chlorpyrifos, diazinon, fenthion, malathion, parathion, disulfoton, phosmet, phorate, temephos, and methyl parathion:

dimethylphosphate

dimethylthiophosphate

dimethyldithiophosphate

diethylphosphate

diethylthiophosphate

diethyldithiophosphate

Phthalates

Urine metabolites of seven phthalates:

mono-ethyl phthalate

mono-butyl phthalate

mono-2-ethylhexyl phthalate

mono-n-octyl phthalate

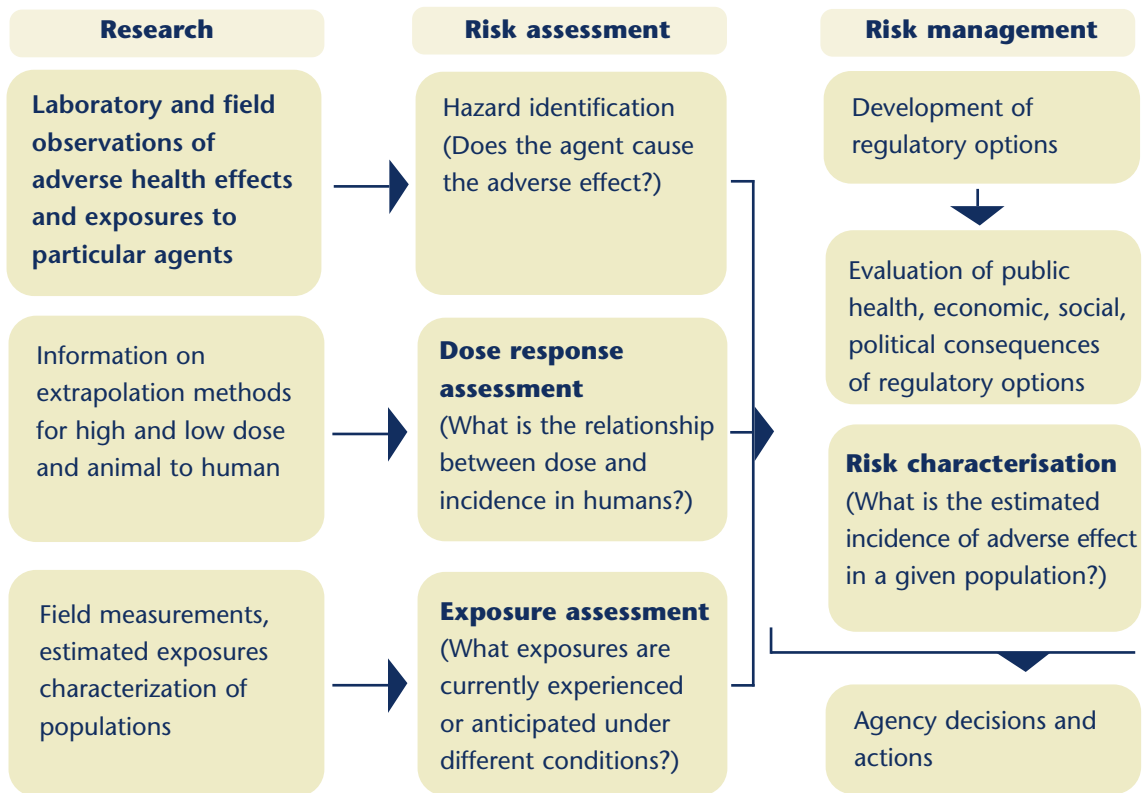
mono-isononyl phthalate

mono-cyclohexyl phthalate

mono-benzyl phthalate

(Source: Centre for Disease Control and Prevention 2001)

Figure 6.2 Elements of risk assessment and management



(Source: NAS/NRC 1983)

A slightly different approach was presented in the report of the Presidential/Congressional Commission on Risk Assessment and Risk Management (1997). This group proposed risk management as an alternative, or a supplement, to risk assessment. They defined risk management as

the process of identifying, evaluating, selecting, and implementing actions to reduce risk to human health and to ecosystems. The goal of risk management is scientifically sound, cost-effective, integrated actions that reduce or prevent risks while taking into account social, cultural, ethical, political, and legal considerations.

The Commission identified six stages in this process

- Define the problem and put it in context.
- Analyse the risks associated with the problem in context.
- Examine options for addressing the risks.
- Make decisions about which options to implement.
- Take actions to implement the decisions.
- Conduct an evaluation of the actions.

Risk evaluation, where the level of importance of the risk to those affected, those who create it and those who control it, has recently been added to the risk management process. The following section describes some methodological issues in relation to both risk assessment and risk management.

Sources of uncertainty in risk assessment and risk management

Different types of uncertainty should be taken into account when conducting a risk assessment. Four major sources of uncertainty are summarised below (McColl et al. 2000).

Model uncertainty

Risk assessment, as mentioned above, often relies on statistical models to estimate risks to human health and the environment. These models may be prone to a number of inaccuracies. A good understanding of the limitations and uses of the model, rigorous testing and an understanding that model results are *theoretical* predictions rather than actual measures, will enhance the value of the statistical model as a risk assessment tool.

Parameter uncertainty

Measurements such as body weight and amount of chemical absorbed into the body are values that can be used to calculate risks in relation to exposure to environmental agents. These numeric values are termed parameters and are subject to wide variation over time and between individuals. In some cases, a parameter cannot be measured and a proxy measure is taken instead (such as distance from site as a proxy for exposure). Specific statistical techniques are available for measuring the effects of these parameter uncertainties, which can contribute a great deal of uncertainty to the overall estimation of risk.

Decision-rule uncertainty

The course of action taken by decision makers in response to the findings of a risk assessment is influenced by many social, cultural and institutional factors (Davies et al. 1997). The precautionary principle is an example of how the EU responds to the potential for adverse environmental consequences arising from the use of a particular substance or process. The precautionary principle has been defined as 'when an activity raises threats of harm to human health or the environment, precautionary measures should be taken even if some cause and effect relationships are not fully established scientifically'. The 1992 Rio Conference defined this principle as 'where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation' (UNCED 1992).

Recently published guidelines for the application of the precautionary principle (CEC 2000) have proposed the following steps to be considered by those involved in risk management:

- Proportionality: 'Measures... must not be disproportionate to the desired level of protection and must not aim at zero risk'
- Non-discrimination: 'Comparable situations should not be treated differently and... different situations should not be treated in the same way, unless there are objective grounds for doing so.'

- Consistency: 'Measures... should be comparable in nature and scope with measures already taken in equivalent areas in which all the scientific data are available.'
- Examination of the benefits and costs of action or lack of action: 'This examination should include an economic cost/benefit analysis when this is appropriate and feasible. However, other analysis methods... may also be relevant.'
- Examination of scientific developments: 'The measures must be of a provisional nature pending the availability of more reliable scientific data... scientific research shall be continued with a view to obtaining more complete data.'

The risk assessment process should be used as a means to inform action based on the precautionary principle, rather than considered in opposition to it.

Natural uncertainty

Natural uncertainty arises from many factors that occur randomly, such as age and sex distributions in an exposed population, or individual variation in susceptibility to environmental agents. Natural variability cannot be reduced by additional data collection or analysis, but can be better understood by careful observational studies.

Risks assessments that do not include sufficient attention to uncertainty are vulnerable to a number of difficulties (Table 6.4).

Table 6.4 Difficulties associated with insufficient attention to uncertainties in risk assessment

Precludes the opportunity for identifying research initiatives that might reduce uncertainty.
Does not permit reliable comparison of alternative decisions, so that appropriate priorities can be established by policy-makers comparing several different risks.
Does not allow for optimal weighting of the probabilities and consequences of error for policy makers so that informed risk-management decisions can be made.
Failure to communicate to decision-makers and the public the range of control options that would be compatible with different assessments of the true state of nature. This makes informed dialogue between assessors and stakeholders less likely, and can cause erosion of credibility as stakeholders react to overconfidence inherent in risk assessments that only produce point estimates.

(Source: National Research Council 1983)

Risk perception and the social construction of risk

Risk is occasionally presented as a very simple matter. The risk associated with a process is often defined as the expected number of deaths, cancer, or other adverse events expected to arise from the operation of a site. This number is typically expressed as the probability of an extra adverse event per person per year. A popular belief is that this risk can be established with certainty from scientific studies and that there is therefore little ground for argument about the risks associated with waste disposal, or any other technology.

This view is erroneous. While risk includes what we refer to as hazard (the probability of adverse effects), risk encompasses a far wider range of ideas.* Attempting to engage in discussion about risk without fully grasping this point is likely to engender more heat than light. A major theme in this section is the difference between technical and professional meanings and the meanings of risk to individuals or to a community potentially exposed to a source of environmental pollution. We argue that risk itself, and arguments about risk, are the results of social processes. The stances people and groups adopt in debate about appropriate management of risk reflect these more fundamental social processes.

Policy makers often seek to use scientific evidence to settle a debate about risk. Leaving aside the very large uncertainties in all scientific assessments of exposure and hazard, and also the important political questions about the legitimacy of this approach, available evidence suggests that this is unlikely to be helpful. People objecting to proposals to handle waste in a particular way seldom do so solely on the basis of increased hazard to themselves and their families. The real issues are more fundamental. They revolve around the ideas of trust, social equity and justice. A reasonable case can be made that these issues are much more likely than any formal hazard assessment to determine the attitudes of a community to a proposed waste disposal site.

The professional social construction of risk

Professionals tend to define risk in these terms, and there is a view that other definitions of risk are inferior, irrational or otherwise unworthy of serious consideration. This is not to say that the professional construction of risk is in some sense objective. There can be very large disagreements between professionals, both between different groups and between members of the same profession working for different organisations (Lynn 1987).

Tarr et al. (1980) and Tarr and Jacobson (1987) report two typical historical disputes between professionals in the correct approach to acknowledged hazards. In the early years of the twentieth century there was a dispute between sanitary engineers and public health officials in the US. The point at issue was whether cities should build sewerage plants to treat waste before dumping it into rivers, or whether they should simply rely on effective treatment of drinking water by the cities downstream. Sanitary engineers argued for the cheaper alternative, boards of health for the more expensive. The sanitary engineers won the argument, partly for economic reasons. The debate was not resolvable on purely scientific grounds, so representing an early example of what Weinberg (1972) calls *trans-science* (see below).

Lynn (1987) studied the views of occupational health professionals, working in industry, universities and the government, on the guidelines for carcinogenicity assessment proposed by the US Occupation Safety and Health Administration. She found a strong relationship between the place of employment of these professionals and their opinions. Professionals working in industry were more likely to object to the use of animal data to assess carcinogenicity in humans, and more likely to advocate a threshold model for carcinogenicity than those working in the university sector. Dietz et al. (1989) in a study of environmental professionals in the US found a similar relationship between place of employment and ideas of risk.

* For the purposes of this section we distinguish between risk – the generic term for all aspects of the adverse consequences of waste disposal – and hazard – an estimate of the likely adverse effects of waste disposal as measured by the number of extra deaths, extra cases of cancer, or other adverse health outcomes.

Lynn (1987) argued that the available scientific evidence could not have resolved these different views. Weinberg (1972) introduced the useful term *trans-science* to describe such issues. He introduced the term in the context of a discussion on the biological effects of low-level radiation. He argued that 'this was a question which went beyond science. The matter could have been dealt with ... on moral or aesthetic grounds.' This seems to be a fruitful perspective for some of the questions that lie on the borderlands between science and policy.

Perhaps more important than disputes between technical experts is the discordance between the perspective adopted by professionals and that adopted by the public. This discordance, which can be very severe, is sometimes used by professionals as an excuse to belittle and ridicule opposing views held by non-experts (Dietz et al. 1989). From a risk communication perspective this is likely to be unhelpful. Condescension by experts will usually irritate the public. Such condescension predisposes people to reject the message, along with the messenger.

Citizens and the social construction of risk

While the immediate probability of mortality is one factor in the social construction of risk, it is often a minor factor. Available evidence suggests that this is not because citizens fail to understand the numerical levels of risk, but because other factors have far greater salience in the social processes underlying the definition of risk (Slovic 1987, Hohenemser et al. 1983, Lichtenstein 1978).

There are two distinct strands in the analysis of the perception of risks. The first group of studies used psychometric techniques, and their primary concern has been to examine the characteristics of specific risks, and how these influence their acceptability to the general public. The second group of studies, which have used anthropological and sociological techniques for the most part, have been more concerned with how groups in society identify, respond to, and deal with risks.

Psychometric studies

The study of risk perception began with a paper on revealed preferences published by Starr in 1969. He argued that industrial societies had arrived at an optimum balance between risk and benefit for ongoing activities. Hence, a study of actual risk and benefit data could reveal social preferences for risk. While a historical perspective on how actual societies have weighed risks would suggest that this was very naïve, (Wohl 1983, Tarr 1980, Tarr & Jacobson 1987 for counter examples), Starr's paper was an important start.

One of Starr's key conclusions, and one that remains significant today, is that people will accept far higher hazards if these are believed to be voluntarily assumed. For example, the hazard from smoking is far higher than any plausible hazard arising from non-occupational exposure to chemicals, but people accept it with little enough demur. Similar arguments can be put forward for the acceptability of other hazards, such as the use of cars, eating a high fat diet, and engaging in such sports as mountaineering and rugby.

Another very important piece of work on risk perception was published by Fischhoff et al. (1978) using an approach based on expressed, not revealed, preferences. The authors interviewed 76 Oregonians and sought their assessment of the risk and benefits of different technologies. They identified two factors associated with risk that influenced their acceptability. They labelled these factors *dread* and *knowledge*. The subjects found more dreaded risks less acceptable, where dread incorporated ideas of catastrophe and severity of outcome; they found risks that were more familiar, and voluntarily

assumed, more acceptable. Although the design of this study was open to criticism, a large amount of further work, by this group and other researchers, has tended to confirm their conclusions (see the collection of papers in Slovic 2000).

Slovic, in a very influential paper published in *Science* (1987) summarised many of the results from the psychological literature on risk perception. This work has shown that people find risks to which many people are exposed less acceptable than those to which few people are exposed. Otherwise, the findings from the earlier studies in relation to dread and knowledge have been largely confirmed. Slovic emphasised the importance to citizens of the catastrophic potential, a measure of the possibility of large loss of life, even from an unlikely event. Sandman and colleagues (1993, 1994) have studied and confirmed the importance of feelings of outrage to risk perception.

Anthropological studies

Mary Douglas and Aaron Wildavsky (1983) set the original parameters for this debate in their book *Risk and Culture*. While some of their conclusions, for example those about the social structure of environmental groups, have not been widely accepted, their basic ideas, and particularly the typology of world views which they introduced, remain very significant (Johnson 1987). Specifically, their clear exposition of the key role of culture in determining how people see risks, and how they respond to risks, remains central to much current thinking about risk and risk communication (Johnson & Covello 1987, Adams 1995, for example). Douglas and Wildavsky (1983) proposed a four-fold division of people along dimensions of differentiation or hierarchy and exclusivity (the grid/group classification). The four groups that result are given different names by different authors. Douglas and Wildavsky originally used the terms individualist, atomised subordination, hierarchist and sectarian. Adams (1995) labelled these groups slightly differently as individualists, fatalists, hierarchs and egalitarians. These descriptions represent, perhaps in caricature, four different world views. Douglas and Wildavsky (and Adams) argue that risk construction takes place largely among three of these groups-effectively the power elite-omitting the fatalists. These three groups have very different ideas about what risk is and how it should be dealt with. They have power to implement their ideas.

The poor old fatalists, the atomised subordinates, who are usually the people most vulnerable to damage, do not really participate in this process (Adams 1995). This idea, while it may be empirically false in Ireland today, has been an important component in the development of the idea of environmental equity. Further discussion of the idea of vulnerability, in a different context, can be found in Blaikie et al. (1994) and Staines (in press).

The Love Canal incident illustrates some of these points well (Fowlkes & Miller 1987, Tarr & Jacobson 1987). Love Canal, a disused canal basin, was used by a local chemical company to dump large amounts of hazardous waste. It was sold to the city for \$1 in 1953 and developed as a park. An elementary (primary) school was built on one corner of it, and a large housing development was built beside it. In 1975, possibly due to heavy rainfall, there were substantial leaks from the landfill site into the basements of local homes. In 1978, a report was released by the State Department of Public Health describing the dump as a major threat to public health and proposing relocation of families living close to it. The subsequent course of events was marked by a complex struggle over who should be relocated, and who should pay for it.

Tarr and Jacobson (1987) concentrated on the disputes between federal and state officials, and within professional groups. The main points at issue in these disputes were the allocation of responsibility for the costs of relocation and attempts to redefine the boundaries of the affected area and the

affected population. There was also a division between the sanitary engineering professionals, who concentrated on the threat to local water supplies, and the public health professionals who wanted to consider a much wider set of effects.

Fowlkes and Miller (1987) focused on the divisions within the local community, especially between those with children and older people, for whom the houses themselves were an important issue. Older people did not want to leave their homes, because their housing security would be very severely affected. Younger people with families were far more anxious to leave, both because of the perceived hazard for their babies and children, and because they had better prospects of re-establishing themselves in the housing market.

The main national impact of the Love Canal episode was to spur local environmental groups. It was the one of the first public environmental fights in the US. Some of the people involved with Love Canal, particularly Lois Gibbs, have had immense influence on the development of the environmental movement in the US and internationally. Gibbs later established the Centre for Health Environment and Justice, which is still very active in this work. A good short review of these developments can be found in Montague and Pellerano (2001).

Ostry et al. (1993) interviewed people living in two rural villages in British Columbia close to the main landfill site for Vancouver. They found that younger people, and people with children, were more likely to be concerned about the landfill. These findings echo those of Fowlkes and Miller (1987). Greenberg and Schneider (1994) studied the impact of waste site remediation under the superfund legislation, and reported some improvement in the perception of these areas, particularly among newer residents. In this study, most of the 'newer' residents had moved into the area after the remediation had begun. People who had lived there for longer, and who may have felt trapped in the area, had far less positive views.

Grandpre (2000) and Capek (1992), from different perspectives, emphasised the role of environmental equity and justice. These ideas affect both community attitudes to risk, and individual responses to proposed development. Capek, in a case study from Arkansas, explored how ideas about environmental equity and simple justice motivated citizen groups to oppose federal funding of 'community groups' with close links to industry. Grandpre analysed the responses of a poor black community to the discovery that their housing had been built on top of an old landfill. There are strong echoes of Love Canal in this case. Both of these studies illustrate the importance of outrage in the establishment and maintenance of opposition to state and corporate action (Sandman et al. 1993).

Fitchen et al. (1987) describe what may be a more common situation – where a community was largely disinterested in a potential water-borne hazard. The community that they studied, which is not identified in the report, had significant levels of groundwater contamination with tri-chloro-ethylene. On their analysis, people were not very concerned about this risk, because they became more concerned about the possible economic and personal impact of the clean-up process under the US superfund legislation. They also trusted local officials and felt that the pollution had arisen internally to their community. Many of them were very familiar with the chemical and did not fear it.

Gale (1987) reports similar attitudes in his case study of contamination in the Gas-Works Park in Seattle. These studies show the interplay between the psychometric ideas and the sociological context in practice. Fitchen et al. (1987) emphasise the dynamic nature of the community response to the incident, and suggest that the dynamics might have gone differently had the episode been mishandled by the officials or the companies involved.

Conclusions

These studies suggest certain common elements in the construction of risk. We would argue that both the psychometric and sociological theories are of value in understanding the dynamics of communities potentially exposed to chemical hazards. The importance of taking these theories into account is well illustrated by the comments of Stevenson (1991). Most of his paper is a technical review of likely discharges from incinerators, with estimates of the (small) adverse health effects to be expected from these discharges. His paper, which has the expressive title *Provoking a firestorm: Waste incineration*, ends with the following remark

The public is very concerned about the safety and health impacts of incinerators... Besides the physical aspects, the public may be more influenced by psychological, social, economic and political factors. As a result the siting of an incinerator has become a very difficult endeavour.

This is very true, but what needs to be added is that the public are right to do this. Health hazards should play a significant role in planning decisions, but the absence of significant hazard does not mean that the risks of a project will be publicly acceptable.

Risk communication

Communicating information about risks is an important part of the activity of many people in modern industrial societies. Employers have responsibilities to their staff, regulatory authorities have responsibility to their constituencies, industry organisations and trade unions have responsibilities to their members and to the wider community, and professionals have responsibilities to their clients and the population as a whole.

The routes by which people receive information are correspondingly complex. Messages about the risks, hazards and benefits of different activities are delivered through the media, through work, neighbourhood and kin networks, and through the Internet (Montague & Pellerano 2001, for example). Different groups of people perceive the same risk in different ways, as illustrated, for example, in the Love Canal case studies (Fowlkes & Miller 1987), and the British Columbia study (Ostry et al. 1993).

Covello and Allen (1988) drafted 'seven cardinal rules of risk communication', a short pamphlet from the EPA, suggesting a need to be open, trustworthy, accessible and organised. Present in their list, albeit only by implication, is the need to address the real concerns of the community who will be affected by the planned waste-handling facilities. This, in turn, implies a need to find out what those concerns actually are. At around the same time, a manual on risk communication by Covello et al. (1988) was published for the US chemical industry. This recommended setting unfamiliar risks in context by comparing them with other, better known, risks.

Roth et al. (1990) compared the responses of four groups of the general public to the examples provided in the manual. They found no correlation between the responses to particular categories of statement predicted in the manual and those observed in their study. Commenting on this finding, Slovic et al. (1990) suggested that the key message for risk communicators was 'test your messages'. They also noted that Roth et al. (1990) chose to exclude considerations of acceptability of risk from their scenarios, an approach that they endorsed.

Freudenberg and Rursch (1994) explored the idea of putting risks in context a little more fully. They used a staged approach, testing the responses of a class of university students to incremental information about a proposed hazardous waste facility. Their results suggest that direct numerical comparison of risks may be unhelpful.

Sandman (1994), who has written extensively about risk communication, has repeatedly emphasised the importance of respect for the targets of communication -the audience - as an integral part of the process of successful communication. His studies on the contribution of feelings of outrage to public risk perception are especially interesting. By outrage, Sandman and his colleagues mean the public response to non-technical aspects of risk, such as trust, fairness, control and courtesy. One of his studies (1993) was a simulation, based on presenting various pieces of information about putative risks to population samples. The main finding was that people's assessment of the seriousness of risk was heavily influenced by manipulation of outrage-related factors. In this study, these included reports of the responses of other groups to the hazard, and the behaviour of the agencies involved.

One passage from Sandman's (1994) article in the *Encyclopaedia of the Environment* sets many of the real issues in risk communication in perspective:

Risk communication guidelines for the proponents of controversial technologies are embarrassingly commonsensical:

- *Don't keep secrets. Be honest, forthright, and prompt in providing risk information to affected publics.*
- *Listen to people's concerns. Don't assume you know what they are, and don't assume it doesn't matter what they are.*
- *Share power. Set up community advisory boards and other vehicles for giving affected communities increased control over the risk.*
- *Don't expect to be trusted. Instead of trust, aim at accountability; prepare to be challenged, and be able to prove your claims.*
- *Acknowledge errors, whether technical or non-technical. Apologise. Promise to do better. Keep the promise.*
- *Treat adversaries with respect (even when they are disrespectful). If they force an improvement, give them the credit rather than claiming it yourself.*

Advice like this is not difficult to accept in principle. It is, however, difficult to follow in practice....It provokes the unacknowledged bitterness in the hearts of many proponents, who may ultimately prefer losing the controversy to dealing respectfully with a citizenry they consider irrational, irresponsible, and discourteous.

Petts (1992) studied opposition to plans to site waste facilities in different parts of Britain. Her study emphasises the relative failure of an approach to reducing opposition, based on public relations and public education. She argues that a far more sophisticated approach, based on rebuilding trust in regulators and in the waste industry, will be required. In the absence of such trust, educational initiatives from the industry are not likely to be accepted. Although she does not make the point explicitly, her observations are consistent with the proposal that the divergence between professional and lay understanding of risk is a significant obstacle to communication.

A more recent study from Petts and her colleagues analyses the role of the media and the public in developing risk, within the framework of 'the social amplification of risk'. They studied media reporting of risk, reviewed media reports and conducted a large number of focus groups, TV studies, and interviews to explore what people worry about, and where they get their information from. Their principal conclusion was that lay people play a very active role in constructing and making sense of risk. To quote:

Our evidence leads us to refute any suggestion that lay publics are passive recipients of expert risk knowledge. People want to feel that the risks that are meaningful to them are being attended to, and this may mean taking personal control. This necessitates that they rationalise information in a way meaningful to them to enhance their coping mechanisms. It is inevitable that this process of rationalisation requires them to draw upon multiple information sources and understandings, not just mediated information. It was evident that this rationalisation was not assisted by the use of statistical risk comparisons, very few examples being offered in people's discussion. (Petts et al. 2001)

They concluded that the media had an active and dynamic role in mediating and interpreting risk information. They found that the UK media were very effective interpreters of public concerns. The media did not function as a postal system, simply delivering messages to consumers, but had a role as a symbolic information system that responded to public interpretation of risk issues. They also found that different groups of people interpreted risk in different ways, with particularly striking differences between people with children and those without, a finding similar to previous studies. This report concludes with a substantial set of recommendations for best practice in risk communication, including the use of people-centred material, and approaching the media as an opportunity, rather than a problem.

Summary

This chapter has described in some detail the modern risk assessment process. Carrying out a risk assessment is a difficult and challenging task. Each of the four phases, hazard identification, dose-response assessment, exposure assessment and risk characterisation, pose distinct technical challenges.

Risk assessment requires some judgement, and there is a considerable role for interpretation. Because of this, there will always be considerable uncertainty in the results of a risk assessment. Furthermore most risk assessments are site-specific. The details of geography, geology and human inhabitation make each site unique.

Responding to this level of uncertainty is very difficult. It poses immense challenges for politicians, regulatory officials and the public. Evidence from a series of studies over the last thirty years has shown that people make wide-ranging value judgements, incorporating many different aspects of an issue, before making decisions on disputed environmental questions. Risk assessment is one component of this decision process, sometimes, perhaps often, a relatively minor component. This is not meant to suggest that risk assessments are pointless, but rather that they should be viewed in an appropriate perspective.

One of the responsibilities of public officials and elected representatives is to communicate clearly with the general public. This can be a difficult task, as much of the literature on these topics is written

in dense and technical language. Some common approaches to communicating risk information are demonstrably ineffective. Petts and her colleagues (2001) have shown the complex processes used by members of the general public in Britain to process information on environmental hazards, and her findings need to be taken very seriously by those charged with risk communication.

There is an urgent need to develop the skills and resources required to undertake health and environmental risk assessments in Ireland. This should be considered as an important element in building capacity in Ireland to protect public health in relation to environmental hazards. At present, Ireland lacks the information systems and the people needed to monitor human health around potential sources of pollution. This is a major deficiency, and should be remedied urgently. The recommendation in the *proposal for a National Environmental Health Action Plan* (Government of Ireland 1999) to establish a national centre for toxicology should be revisited.

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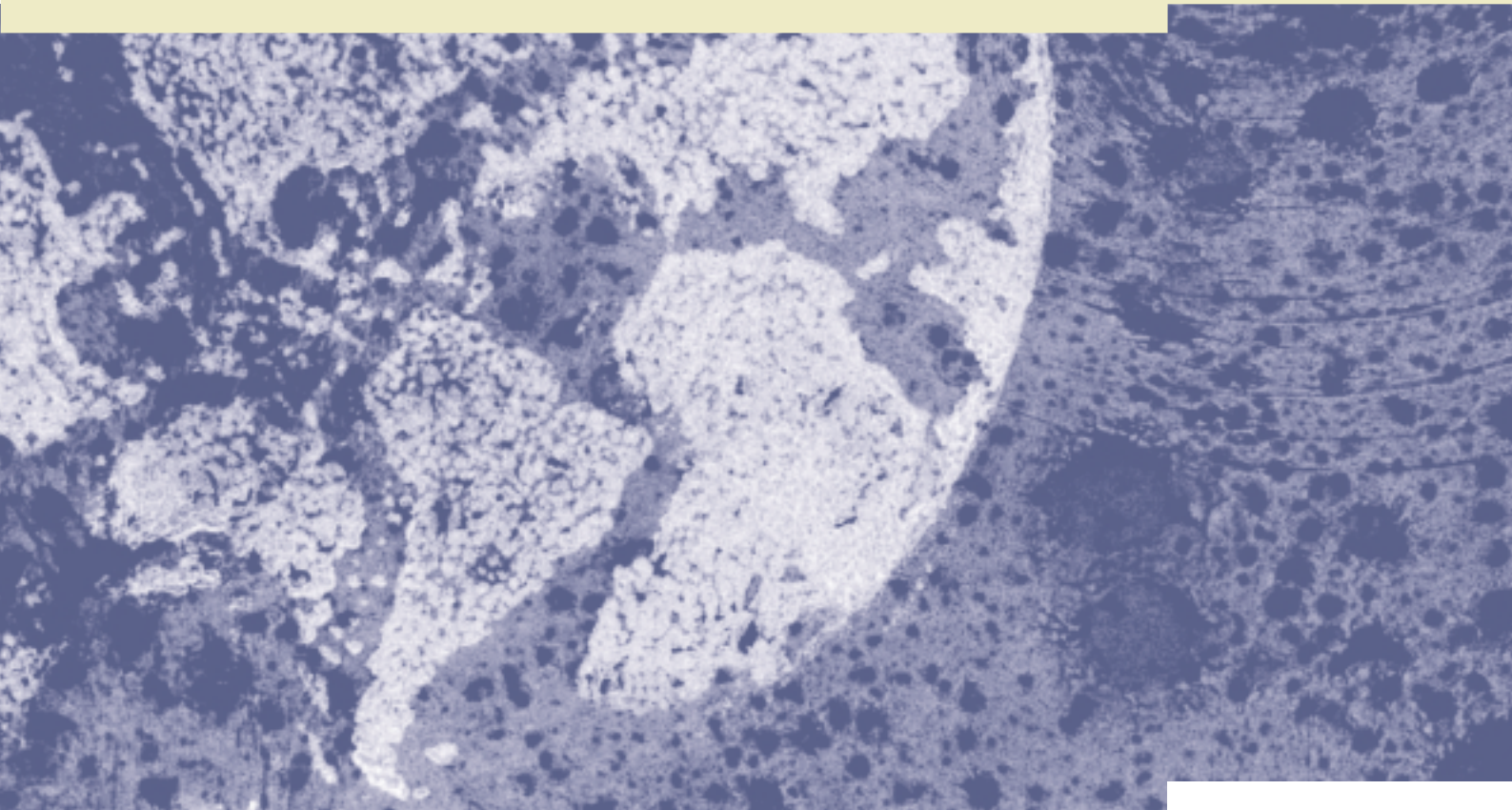
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Chapter Seven: Health Effects of Landfilling and Incineration of Waste



Chapter Seven: Health Effects of Landfilling and Incineration of Waste

Introduction

This chapter comprises descriptions of specific pollutants identified in emissions from landfills and incineration facilities. Biological monitoring to estimate exposure to specific pollutants has been carried out in populations living near waste sites and in those working in such sites. Most studies identified were of waste incinerator sites. This is followed by a review of the international scientific literature on the health effects of landfilling and incineration. Both population and occupational studies are discussed. The final section consists of examples of risk assessments that have been carried out on landfill and incinerator sites.

As there is a paucity of literature relating to modern landfill and incineration sites, nearly all of the studies identified in this chapter relate to older technologies. It can be assumed that as emission controls improve, risk of adverse effects diminish.

Characteristics of specific pollutants identified in emissions from landfill and incineration

This section contains a description of the basic toxicity characteristics of the substances likely to arise from either landfill or incineration waste disposal procedures. Table 7.1 is taken from technical report no. 38, *Dangerous Substances in Waste*, of the European Environmental Agency (2000). While it may be argued that other possible substances should be included, there is general scientific agreement that these substances represent the ones most likely to cause either environmental or health effects. The following discussion will focus on the possible health effects and, therefore, the potential toxicity of these compounds. Sources of information on the toxicological characteristics of these compounds include the International Programme on Chemical Safety (IPCS) Environmental Health Criteria (EHC), The International Agency for Research on Cancer (IARC), the IRIS database from the US EPA, the Agency for Toxic Substances and Disease Registry (ATSDR) database on toxic substances and The World Health Organisation (WHO) guidelines on air and water quality. Descriptions of some other possible toxic compounds, namely sulphur dioxide and particulate matter (PM₁₀), which may arise during waste disposal from either landfill or incineration will also be briefly outlined.

Before proceeding with the description of individual substances, it is worth emphasising a few general principles of toxicology. For a toxic or harmful effect to occur there must be interaction between the toxic compound and the biological system. It is true to state that almost all compounds can be toxic, even compounds which are essential for life, such as potassium and oxygen, if the biological system is exposed to levels that are greater than those that are necessary. An essential principle of toxicology is that a dose-response relationship exists for most toxic effects.

These dose-response relationships are usually established from experimental studies, mainly in animal models. From these studies, it may also be possible to establish levels at which no observed adverse effect (NOAEL) is detected. This NOAEL can then be used to establish minimal risk levels (MRLs) for

hazardous substances. These MRLs are established by dividing the NOAEL by a safety factor to take into account uncertainty factors such as species variation. The seriousness of the toxic effect is also an important factor in determining the level at which the MRL is set. For compounds which are carcinogenic, and particularly for genotoxic carcinogens, it may not be possible to establish NOAELs and MRLs. MRLs can be set for drinking water, ambient air and food. MRLs for ambient air and water for certain compounds of relevance to waste disposal are shown in Table 7.2.

The release of substances from landfill sites or incinerators does not always result in human exposure. A person can only be exposed to the substance if they come in contact with it. Contact can be by breathing, skin contact or eating or drinking food or water contaminated with the substance. If there is no contact there can be no toxicity. Another important factor to take into account is the fact that a person may be exposed to the compound from other sources. The contribution from the waste site, either landfill or incinerator, may be relatively minor to the overall exposure.

If a person is exposed to a harmful substance from a waste management site, a number of factors will determine whether a harmful or toxic effect is likely to occur. These factors will include the dose (how much), the duration (how long) and the route of exposure. Other factors to be considered include age, sex, diet, family traits (possible genetic susceptibility), lifestyle, state of health and consideration of other chemicals to which the person may be exposed.

Dioxins and furans (PCDDs and PCDFs)

PCDDs and PCDFs are a family of chemically related compounds. As is outlined in Chapter Four, these compounds are mainly by-products of industrial processes but can also result from natural events, such as volcanic eruptions and forest fires. These compounds are also unwanted by-products, formed when thermal processes produce chlorine-containing organic substances.

Dioxins are found throughout the world in practically all media, including air, soil, water, sediment, and food, especially dairy products, meat, fish and shellfish.

One of the most toxic of these compounds, 2,3,7,8-TCDD, has been extensively studied. This substance was a contaminant in some batches of the herbicide Agent Orange used during the Vietnam War. 2,3,7,8-TCDD was also released, accidentally, in Seveso, Italy in 1976, resulting in extensive population exposure. More recent dioxin incidents include the Belgian dioxin crisis which resulted in contamination of poultry, eggs, meat and dairy products.

Exposure to PCDDs and PCDFs is mainly from the consumption of food, primarily meat, dairy products and fish, and this constitutes about 90% of intake of the general population. Animal studies have shown that dioxin can effect the immune system and cause reproductive damage and birth effects. Animal studies have also shown an increase risk of cancer from exposure to dioxin. In humans, exposure to dioxins at high doses can produce chloracne, and may adversely affect human metabolism, development and reproductive biology (IPCS 1989a). Current evidence suggests that dioxins may be a cancer hazard to humans and the World Health Organisation has classified 2,3,7,8-TCDD as a human carcinogen (IARC 1997). Detailed information on dioxins and furans can be obtained from the following website: <http://www.who.dk/envhlth/dioxin/dioxin.htm>.

It is important to note that PCDDs and PCDFs are found in the environment together with other structurally related chlorinated chemicals, such as polychlorinated biphenyls (PCBs) (ATSDR 1998).

PCBs

Polychlorinated biphenyls are mixtures of up to 209 individual chlorinated compounds (known as congeners). There are no known natural sources of PCBs. They do not readily break down in the environment and may remain there for very many years. Information on the health effects of PCBs has come mainly from people exposed through heavy PCB contamination of their food. Few adverse effects have been definitely associated with low-level, long-term exposure (IPCS 1992a, 1993). At the moment there is not enough evidence to conclude that PCBs cause cancer in humans but the indications are that they are probably carcinogenic in humans (IARC 1987a); the current concern over human exposure to PCBs is due to their undoubted toxicity in animals and their persistence in human tissues.

PAHs

Polycyclic aromatic hydrocarbons (PAHs) are a group of over a hundred different chemicals that are formed during the incomplete burning of coal, oil and gas, waste or other organic substances like tobacco or charbroiled meats (IPCS 1998a, 1999). Cigarette smoking is a major source of human exposure to PAHs. Animal studies have indicated lower birth weights and some birth defects in exposed animals, but it is not known if these effects occur in humans. Epidemiological evidence indicates elevated risks for lung, skin, and perhaps bladder and gastrointestinal cancers in certain groups of people exposed to mixtures containing PAHs, such as coke-oven workers and tobacco smokers. Animal experiments on individual PAHs have shown some to be carcinogenic, and the International Agency for Research on Cancer has classified a number of PAHs as probably carcinogenic to humans (IARC 1986). Owing to the variation in composition and concentration of individual compounds in PAH mixtures, the general risk of cancer resulting from environmental exposure is not quantifiable.

Arsenic

Arsenic is a naturally occurring element widely distributed in the Earth's crust. Inorganic arsenic compounds are mainly used to preserve wood. Inorganic arsenic causes both acute and chronic toxicity in a number of organs, including the respiratory tract, skin, liver and peripheral nervous system (IPCS 2001). However, arsenic's most serious toxic property is carcinogenicity (IARC 1987b). This may follow ingestion or inhalation, the main target organs being the skin and the lungs, but these effects have been demonstrated only at relatively high occupational exposures and not at levels likely to be encountered in the Irish environment.

Cadmium

Cadmium is a natural element in the Earth's crust. All soils and rocks contain some cadmium. Cadmium does not corrode easily and has many uses, including the manufacture of batteries, pigments, metal coatings and plastics. Cadmium particles can travel long distances in the air and can enter water and soil from waste disposal. Fish, plants and animals take up cadmium from the environment. Cadmium can accumulate in the body and build up from many years of exposure to low levels. People can be exposed to cadmium from many sources, including breathing contaminated air, drinking contaminated water and eating contaminated foods. Breathing cadmium in cigarette smoke is a major source of exposure and doubles the average daily intake. Animals given cadmium developed high blood pressure, kidney damage, liver disease and nerve or brain damage. Long-term exposure to levels of cadmium can lead to build up in the kidneys and possible kidney disease (IPCS

Table 7.1 Ranking of dangerous substances from landfill and incineration.

Dangerous substances	Source	Category	Remark
Organic Compounds especially PCDD/F	Incineration and landfill	Human toxicity, Ecological toxicity	Very important, incineration is a major contributor
Methane	Landfill	Greenhouse gas	Very important
Volatile heavy metals HG, Cd, Pb	Incineration	Human toxicity, Ecological toxicity	Very important because of transboundary movement
Total N, NH ₄	Landfill	Eutrophication	Important because of the local contamination of surface and groundwater
HCl	Incineration	Acidification	Important
Heavy metals As, Cd	Incineration	Human toxicity	Important, carcinogenicity
Salt, e.g. chloride	Landfill and incineration	Ecological toxicity	Important, high loads to surface and groundwater
Organic emissions	Landfill	Human toxicity nuisance	Important for employees and neighbourhood
Heavy metal Cd, Ni, Cu, Zn Pb, Hg	Landfill and incineration	Ecological toxicity, Human toxicity	Less important because little contribution to total emissions, assumed to be stable in the landfill body

(Source: EEA 2000)

1992b, 1992c). Other possible effects are lung damage and fragile bones. Occupational exposure to high levels of cadmium has been associated with an increased risk of lung cancer and a number of non-carcinogenic effects, including effects on the lungs (emphysema) and kidneys (IARC 1993a). The threshold for renal effects has been shown to be above current EU occupational exposure limits.

Mercury

Mercury is a naturally occurring metal which has several forms. Mercury combines with other elements, such as chlorine, to form salts or inorganic mercury compounds. Mercury can also combine with carbon to form organic mercury compounds. The most common one, methylmercury, is produced mainly by microscopic organisms in the soil or water. Methylmercury can build up in the tissues of fish (IPCS 1989b). Exposure to mercury results from breathing contaminated air, eating fish or shellfish contaminated with methylmercury and release of mercury from dental work and medical treatments. The key health effects of low-level exposure to mercury are renal damage and subtle behavioural effects. The nervous system is very sensitive to mercury. Urinary thresholds for mercury excretion and associated exposure levels in air have been proposed for both nephrotoxicity and behavioural effects (IPCS 1991). Mercuric chloride has been shown to cause increases in several types of tumours in rats and mice. There are inadequate human cancer data available for all forms of mercury (IARC 1993b).

Chromium

Chromium is a naturally occurring element found in rocks, soil, plants and animals. Chromium is present in the environment in several forms. Chromium (III) occurs naturally and is an essential nutrient. Chromium enters the air, water and soil mostly as chromium (III) and chromium (IV). Exposure to chromium is mainly from drinking contaminated water and eating food containing chromium (III). Several studies have shown that chromium (VI) can increase the risk of cancer (IARC 1990a). Some people are extremely sensitive to chromium (VI). Allergic reactions consisting of severe redness and swelling of the skin have been noted. Occupational exposure to relatively high levels of hexavalent chromium (VI) causes damage to the nasal septum, dermatitis and lung cancer. Trivalent chromium (III) is in general far less toxic and is not considered to be a carcinogen (IPCS 1988). Current occupational exposure limits for hexavalent chromium protect against nasal damage, and personal hygiene (skin care) protects against dermatitis. At much lower environmental exposure levels, the most serious health outcome to be considered is lung cancer, for which a small risk cannot be excluded.

Nickel

Nickel is a very abundant element and is found in all soils. Nickel can be combined with other metals to form alloys. These alloys are used in the making of metal coins and jewellery. Nickel in the environment is found mainly with soil and sediments. Nickel does not appear to collect in plants, fish or animals used for food. Exposure to nickel occurs mainly by breathing air or smoking tobacco containing nickel, drinking water or eating food containing nickel or handling coins or jewellery. A small amount of nickel is probably essential for humans. Nickel can cause respiratory, gastrointestinal and renal effects, but the health effect of most concern is the carcinogenicity of inorganic nickel compounds (IARC 1990b, IPCS 1991). The cancer risk resulting from environmental exposure to these compounds is likely to be very small. Allergic sensitisation, particularly contact dermatitis, to nickel and its salts is also a recognised problem. This affects people who work with nickel and some people who wear jewellery that contains nickel.

Table 7.2 Air and water quality guidance values

Waste component	Water quality guideline value (WHO 1996, 1998)	Air quality guideline value (WHO 2000)	International Agency for Research on Cancer (IARC) classification of carcinogenic risk
Metals			
Cadmium	0.003mg/litre (based on an allocation of 10% of the provisional tolerable weekly intake (PTWI) to drinking-water.)	No safe level recommended <i>Increased risk of renal dysfunction and lung cancer at air conc. (continuous lifetime) of 0.3 µg/m³</i>	Group 2A carcinogen
Mercury	0.001 mg/litre (As the main exposure is from food, a 10% allocation of the PTWI to drinking-water was made).	1 µg/m ³ (inorganic mercury vapour)	
Lead	0.01 mg/litre	0.5 µg/m ³ (annual)	
Arsenic	0.01 mg/litre. (provisional) The estimated excess lifetime skin cancer risk associated with exposure to this concentration is 6 x 10 ⁻⁴ .	No safe level recommended <i>At an air concentration of 1 µg/m³ excess lifetime risk of cancer is 1.5x10⁻³ µg/m³</i>	Group 1 carcinogen
Chromium	0.05mg/litre (provisional value)	No safe level recommended (Chromium (VI)) <i>At an air conc. of 1 µg/m³ excess lifetime risk of lung cancer is 14x10⁻² µg/m³</i>	Chromium(VI) = Group 1 carcinogen and chromium(III) = Group 3.
Nickel	0.02mg/litre (provisional value)	No safe level of exposure recommended. <i>An incremental risk for cancer of 3.8x10⁻⁴ µg/m³ can be given for a concentration of 1 µg/m³</i>	Inhaled nickel compounds are carcinogenic to humans (Group 1) and metallic nickel is possibly carcinogenic (Group 2B). However, there is a lack of evidence of a carcinogenic risk from oral exposure.

Table 7.2 (continued)

Waste component	Water quality guideline value (WHO 1996, 1998)	Air quality guideline value (WHO 2000)	International Agency for Research on Cancer (IARC)
Polycyclic Aromatic Hydrocarbons (PAHs)			
Benzene	10 µg/litre	No safe level of exposure recommended <i>Excess lifetime risk of leukaemia at an air concentration of 1 µg/m³ is 6 x 10⁻⁶</i>	Group 1 carcinogen
Toluene	700 µg/litre (allocating 10% of the TDI to drinking-water this value exceeds the lowest reported odour threshold for toluene in water)	0.26mg/m ³	
Styrene	20 µg/litre	0.26mg/m ³	Group 2B carcinogen (little evidence of carcinogenicity)
Benz[a]pyrene	0.7 µg/litre	No safe level recommended <i>An air concentration of 1.2ng/m³ produces an excess lifetime cancer risk of 1/10,000.</i>	
Trichloroethylene		No safe level of exposure recommended <i>Excess lifetime risk of 1:10,000 corresponds to an air concentration of 4.3 x 10⁻⁷ per µg/m³</i>	Group 2A carcinogen (probably carcinogenic to humans)
Dioxins and related compounds			
Polychlorinated dibenzodioxins (PCDDs), polychlorinated dibenzofurans (PCDFs) and polychlorinated biphenyls (PCBs)		No guideline values as direct inhalation exposures constitute only a small proportion of total exposure. <i>Air concentrations of 0.3 pg/m are indications that local emission sources need to be identified and controlled.</i> <i>TDI (Tolerable daily intake)–1-4pg TEQ/Kg/bw/day</i>	

Lead

Lead is a naturally occurring metal found in small amounts in the Earth's crust. Lead can be found in all parts of the environment. Much of it arises from human activities, including burning fossil fuels, mining and manufacturing. Lead usually sticks to soil particles when it falls on the soil (IPCS 1989c). Because of health concerns, lead has been removed or drastically reduced from petrol, paints, ceramics, and pipe solder. Exposure to lead is via eating food or drinking water that contains lead, and spending time where lead-based paints have previously been used and are deteriorating. Lead can affect many organs and systems in the body. The central nervous system is very sensitive and organic lead may be especially toxic as it can penetrate the blood brain barrier more readily. Lead also damages the kidneys and the reproductive system (IPCS 1995). While there are some studies in animals indicating that lead can cause cancer, there is inadequate evidence to determine clearly the possible carcinogenicity of lead in humans (IARC 1987c).

Copper and Zinc

Copper and zinc are listed in the table of selected toxic substances that occur naturally in the environment and in plants and animals. Copper and zinc are essential elements for all living things. Toxicity is only likely to occur with exposure to very high levels. Neither copper nor zinc have been shown to cause cancer (IPCS 1994, 1998b).

Particles (PM₁₀)

Small particles are always present in the ambient air. Some of these are small enough to penetrate deep into the lungs. They are therefore of concern in that the particles can also contain substances of a toxic nature. Inhalation is the major route of exposure to airborne particles and those particles that can reach deep down into the lungs are of greatest concern in terms of toxicity. The so-called PM₁₀ fraction consists of those particles that pass through a size-selective orifice. Exposure to PM₁₀ particles is associated with both acute and chronic health effects and increased mortality from a variety of causes in the general population, particularly in susceptible subgroups. These effects are dose-dependent and do not appear to have a threshold (WHO 2000).

Sulphur dioxide

The main source of sulphur dioxide (SO₂) is the combustion of sulphur-containing fossil fuels, predominantly coal and heavy oils. Short-term occupational exposure to high levels of SO₂ irritates the upper respiratory tract. Both occupational and environmental exposure levels can produce bronchial constriction in sensitive subjects. Epidemiological studies have shown that long-term environmental exposure is associated with increased cardio-respiratory morbidity and mortality. Ambient exposure may also increase sensitisation to environmental allergens (WHO 2000).

Biomonitoring studies of populations living near waste incinerators

As discussed in Chapter Six, the purpose of biological monitoring is to protect human health and the environment. Biomarkers can be used to detect environmental exposure to pollutants and measure their biological effects before overt disease develops (Staessen et al. 2001). Biomonitoring studies have been carried out around specific waste sites to estimate the level of exposure to specific emissions from these sites. An important point to note in the use of biomonitoring is that tests appropriate and sensitive to the detection of the actual exposures are required (Favata & Gochfeld

1989). The majority of studies identified examine exposure to emissions from incinerators.

An investigation was conducted in the US to assess the potential levels of neighbourhood exposure to a municipal incinerator bottom ash landfill (Stern et al. 1989). This site received ash from a single incinerator without pollution control devices from 1954 to 1973. Soil was sampled for ten heavy metals, polychlorinated dibenzodioxins, polychlorinated dibenzofurans, 2,3,7,8-tetrachlorodioxin and furan congeners, polychlorinated biphenyls, and polycyclic aromatic hydrocarbons. Soil concentrations for these substances were converted to estimates of exposure, health effects, and/or cancer risk by the application of statistical models. The results of soil analysis and modelling indicated that the level of lead detected on the site was considerably above the recommended national levels and may lead to lead poisoning in children. The potential for health effects resulting from exposure to other substances measured in the soil on this site was considered to be small, and there was no significant increased cancer risk. Comparison of levels of various substances obtained at this site with levels obtained in fresh bottom ash in other studies suggested that these results may be applicable to exposures from other municipal incinerator bottom ash landfills.

In an evaluation of the potential for health effects due to short-term emissions of metals from incinerators, Hasselris and Wood (1998) estimated ground level concentrations for hazardous waste, municipal waste and medical waste incinerators. Worst-case scenarios were assumed for the statistical modelling and results indicated that metal emissions were not found to produce acute health risks, even in the worst-case medical waste incinerator. The authors recommended that regulators focus on chronic effects of metals. Continuous sampling with periodic analysis or statistically determined grab samples were reported to be valid for demonstrating metals compliance.

In a study of chromium (Cr) exposure, Taioli et al. (1995), measured biomarkers of chromium exposure in residents living near a waste site containing chromium in New Jersey. The DNA-Protein crosslink was used as a biomarker of biological effect of chromium exposure. The authors examined the levels of DNA-Protein crosslinks in peripheral blood mononuclear cells of 33 individuals determined to be at risk for chromium exposure by virtue of their residence in Hudson County and their urinary Cr levels. These data were compared to the levels of DNA-Protein crosslinks among 49 controls who resided in non-contaminated areas. A complete clinical examination and urine analysis did not show any Cr-related abnormalities among the exposed population. The mean DNA-Protein crosslink level in the lymphocytes of the exposed group was significantly higher than in the unexposed group, after adjustment for age, gender, race, smoking, and weight. The authors report that long-term exposure to low levels of chromium in the environment may induce biological effects of unknown significance. This observation was reiterated in a recent report by Rowbotham et al. (2000). In a review of available exposure data and known health effects, the authors evaluated the potential risks to human health from chromium. This report also states that there is no clear evidence to relate exposure to environmental levels of chromium with adverse health effects in either the general UK population or subgroups exposed to chromium around industrialised or contaminated sites.

Kurttio et al. (1998) examined the levels of exposure of residents living in the vicinity of a hazardous waste incinerator in Finland. A baseline survey of the local population and the environment had been carried out before the incinerator began operation in 1984. These subjects were followed up ten years later. Researchers focused on mercury exposure because mercury concentrations were present in the stack emissions, and environmental monitoring revealed mercury concentrations near the plant. In

1984 and 1994 the median hair mercury concentrations were 0.5 mg/kg and 0.8 mg/kg, respectively. During the ten-year period, median hair total mercury concentrations increased by 0.35 mg/kg in workers, by 0.16 mg/kg, 0.13 mg/kg, and 0.03 mg/kg in individuals who lived 2 km, 2 to 4 km, and 5 km from the plant, respectively; and by 0.02 mg/kg in the reference group. Mercury exposure increased as distance from the plant decreased, but this increase in exposure was minimal and was not considered to pose a health risk.

A study by Llobet et al. (1988) also investigated human exposure to metals in Tarragona, in Spain. Blood samples were obtained from 72 men and 72 women living in three residential areas in the vicinity of a municipal waste incinerator and petrochemical plants. A new hazardous waste incinerator was being built at the time of the study. The study aimed to provide baseline values for these metals, for use in further biomonitoring activities. The samples were tested for arsenic (As), beryllium (Be), cadmium (Cd), chromium (Cr), mercury (Hg), manganese (Mn), nickel (Ni), lead (Pb), tin (Sn), thallium (Tl), and vanadium (V) analyses. Results were analysed in terms of age, sex, and specific place of residence. The levels of As, Be, Tl, and V levels were below the respective detection limits. The mean concentrations and ranges ($\mu\text{g/dl}$) of the remaining elements were the following: Cd 0.70, Cr 0.02, Hg 0.68, Mn 1.90, Ni 1.39, Pb 3.83, and Sn 1.14. No differences in relation to gender were observed. Only Cr (men) and Hg (men and women) concentrations were significantly increased with age. However, significant differences depending on the place of residence of the subjects were noted in the blood concentrations of Cd, Hg, Mn, and Pb. The reported blood levels of Cd, Mn, and Pb varied from those found in previous surveys, with levels of Cd and Mn being higher and Pb being lower than previously measured.

A study in Spain by Gonzalez et al. (2000) comprised 104 subjects who lived at two distance zones from an incinerator (0.5-1.5 km, and between 3.5 and 4.0 km). Seventeen workers at a new municipal solid waste incinerator were also included in the study. Dioxins, furans, and polychlorinated biphenyls were studied in pooled blood samples and individual blood and urine samples were analysed for the detection of lead, chromium, cadmium, and mercury. At the beginning of the study, in 1995, dioxin blood levels were low, both among those living close to the incinerator (mean = 13.5 ng international-dioxin toxic equivalents/kg fat) and among those living far away (mean = 13.4 ng international-dioxin toxic equivalents/kg fat). In 1997, dioxin and polychlorinated biphenyl levels had increased in both groups of residents by approximately 25% and 12%, respectively. (The increase in dioxin levels was about 10% when the authors took into account the mean of two repeated quality-control analyses.) Blood lead levels decreased, but no difference was observed for chromium, cadmium, and mercury. As the blood dioxin levels did not depend on distance of residence from the incinerator and because the dioxin stack emissions from this plant were low, the authors concluded that it was unlikely that the small increase in dioxin blood levels resulted from the incinerator's emissions.

Potential public health effects in the US, associated with exposure to metal emissions from hazardous waste incinerators through non-inhalation pathways, were evaluated by Sedman et al. (1991). Changes in soil and water, As, Cd, Hg, Pb, Cr, and Be concentrations that result from incinerator emissions were determined. Estimates of changes in human exposure due to direct contact with shallow soil or the ingestion of surface water were then ascertained. Projected changes in dietary intakes of metals due to incinerator emissions were estimated based on changes from baseline dietary intakes that are monitored in the US Food and Drug Administration total diet studies. Changes from baseline intake were considered to be proportional to the projected changes in soil or surface water metal concentrations. Human exposure to metals emitted from nine hazardous waste incinerators

were then evaluated. Metal emissions from certain facilities resulted in measurable human exposure through non-inhalation pathways. However, further analysis indicated that the deposition of metals from ambient air would result in substantially greater human exposure through non-inhalation pathways than the emissions from most of the incinerators.

In a study of the dioxin body burden of residents living in the vicinity of a municipal waste incinerator, Deml et al. (1996) measured the concentrations of chlorinated dibenzodioxins and dibenzofurans (PCDD/F) in human blood and in milk from non-occupationally exposed residents. As compared to background levels in the general population in Germany, the results give no indication of an enhanced body burden of PCDD/F.

Staessen et al. (2001) recruited 200 seventeen-year-old adolescents from two suburbs of Antwerp polluted by a lead smelter and two waste incinerators, and from a rural control area. The subjects were all life-long residents of their areas. Heavy metals (lead and cadmium), TCDD dioxin, volatile organic compounds (VOCs) (benzene and toluene), polycyclic aromatic hydrocarbons (PAHs) (hydroxypyrene), were measured in blood or urine. Markers of kidney function and DNA damage were also measured. Sexual maturation was assessed by medical examination. Internal exposure was mostly within current standards. Concentrations of lead and cadmium in blood, PCBs (polychlorinated biphenyls) and dioxin-like compounds in serum samples, and metabolites of VOCs 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 and VOCs.

Another study conducted in the same area near Antwerp (Nouwen et al. 2001), examined environmental emissions and levels in soil, water, vegetation, milk and meat. These were examined to assess local exposure to dioxins and dioxin-like compounds. The number of congenital abnormalities occurring in the area was ascertained by active case finding. In order to look for chromosomal damage, blood samples were taken from 24 children living in the area and a similar number in a nearby area without an incinerator. There was no evidence of enhanced exposure to substances causing chromosomal damage. Using mathematical modelling of exposure scenarios, the authors reported that living in the vicinity of the waste incinerators did not result in an increased risk unless locally grown produce was consumed. Children were identified as being potentially at increased risk of exposure to dioxins because of their eating habits and lower body weight.

Biomonitoring and studies of specific occupational exposures

Exposure to organic substances emitted from a German municipal waste incinerator was examined in 53 municipal waste workers and 431 controls (Angerer et al. 1992). Blood and urine samples were taken to measure polychlorinated biphenyls (PCBs) and hexachlorobenzene (HCB), and mono- (MCPs), di- (DCPs), tri- (TCPs), tetra- (TCEPs) and pentachlorophenol (PCP) and hydroxypyrene. Significantly higher values for the workers were found for the excretion of hydroxypyrene and for the HCB level in plasma. For the concentrations of 4-MCP and 2,3,4,6/2,3,5,6-TECP, the controls had significantly higher concentrations in urine than did the workers in the incineration plant. No significant differences between workers and controls were detected with respect to benzene in blood, 2,4,6-TCP and PCPs in urine or the levels of PCB congeners in plasma. The investigators felt that the elevated levels of hydroxypyrene, 2,4/2,5-DCP, 2,4,5-TCP and HCB in biological material may be related to the incineration of the waste, but that they were not a cause for concern in relation to occupational health.

In another German study, exposure of 122 waste incineration workers to a large number of organic and inorganic substances was examined (Wrbitzky et al. 1995). Subjects were categorised into three groups according to risk of workplace exposure. Blood and urine analysis of the workers was carried out for lead, cadmium, mercury, benzene, toluene, ethylbenzene and m-xylene (in blood), chromium (in blood cells), polychlorinated biphenyls, hexachlorobenzene and pentachlorophenol (in plasma), and arsenic, chromium, nickel, vanadium, chlorophenols and hydroxypyrene in urine. Results of these tests were compared between each exposure category and against reference values for the general population. The biological exposure limits valid in Germany (BAT values) were not exceeded in any cases. Compared with the background levels of the German population, certain parameters were exceeded in several employees. Significantly higher levels of toluene were reported in the high-exposure category workers in comparison to both periphery workers and management. For the lead and cadmium levels in blood and for the urinary excretion of arsenic, 2,4-dichlorophenol and tetrachlorophenols, statistical differences were found only between the high-exposure workers and one of the other groups. However, in all cases the elevations were very small and of interest more from the environmental than from the occupational point of view. The incinerator was reported to be a modern one and the authors proposed that for some of the older facilities levels of exposure may be greater.

In 1989, the New York City Office of Occupational Safety and Health examined air levels of metals in New York City incinerators and found that workers were exposed to air lead levels as high as 2500 mug/m³ while cleaning the electrostatic precipitators in the plants. In order to determine the biological significance of these exposures to the workers, Malkin et al. (1992), took blood samples from 56 incinerator workers and 25 controls and analysed for lead and erythrocyte protoporphyrin levels. Incinerator workers were found to have a mean blood lead level of 11.0 mug/dl as compared to the control group level of 7.4 mug/dl. Risk factors for increased blood lead levels were analysed using multiple regression analyses. Significant predictors for blood lead levels were found to be: the wearing of a personal protective device ('always' or not at all); smoking; and cleaning the precipitator more than seven times in the past year. These results indicate that the effects of lead exposure may be minimised by wearing personal protective devices, not smoking, and rotating the work force to minimise precipitator ash contact.

A study by Schecter et al. (1995) was undertaken to examine dioxin levels in incinerator workers. Concentrations of PCDDs and PCDFs were determined in the blood of ten workers from an old municipal waste incinerator without adequate pollution controls, 11 workers from a newer incinerator with modern pollution controls, and 25 controls from the general population, group matched for age (+/- 10 years), gender, and race. In addition, dioxin levels were measured in the slag and fly ash from the older incinerator. Significant increases of certain PCDDs and PCDFs were found in the blood of the workers from the older incinerator compared with that of the controls, as follows: The workers from the older incinerator with the greatest exposure were found to have the most significant increases of the blood PCDDs and PCDFs, and the pattern of increased PCDD and PCDF congeners in the blood corresponded to the pattern in the incinerator slag and ash. No significant differences were found between the blood concentrations of the workers at the newer incinerator and the controls. The authors concluded that modern pollution-control technology in new incinerators may be able to minimise potential exposure to slag and fly ash, and thus the absorption of PCDDs and PCDFs from this source.

A more recent Japanese study of waste workers heavily exposed to dioxins was carried out by Kitamura et al. (2000). Ninety-four workers underwent a physical examination, biochemical and

immunological investigations and blood dioxin measurements. Information on working history, life-style, and dietary habits was obtained by questionnaire and interview. Dioxins found in the soil around the incinerator had the same profile as those found in the biological samples of the workers. The relationship between dioxin concentrations and work history in the factory showed that the fluidised incinerator and fly ash treatment areas were high-risk work areas. Although certain health effects were noted to be associated with higher levels of exposure, a follow-up study is planned to determine the health effects of chronic exposure. Personal exposure limits of eight heavy metals in respirable dust were not exceeded in any case. Significantly higher levels of copper were found in the maintenance group in comparison with both other groups. The biological exposure index of cadmium and chromium in urine were exceeded in seven and five cases, respectively. In all cases, however, the elevations of heavy metals were very small and of interest more for environmental reasons than for occupational health.

Hoffman et al. (1997) studied workers in ten unprocessed refuse incinerator facilities in the US. These incinerators were in continuous operation, requiring shift work to maintain operations. Handling and working around the ash could result in worker exposures to metals such as inorganic lead and cadmium. Although overall lead and cadmium exposures to workers in the industry were generally quite low, a small number of dusty jobs, such as ash handling resulted in exposures that exceeded the permissible Occupational Safety and Health Administration exposure limit for lead. Biological monitoring in this study demonstrated that personal protective equipment and hygienic work practices programmes were effective in controlling worker exposures to lead and cadmium. This benefit was recently reiterated in a Finnish study of exposure to airborne micro-organisms and volatile organic compounds (VOCs) in different types of waste-handling (Kivaranta 1999). During summertime, micro-organisms were collected as stationary samples, while for VOCs both personal and stationary sampling was conducted. The exposure at the waste handling facility was considerably greater than at landfill sites or in waste collection. Exposure to VOCs in the waste handling facility was three times higher than at the landfill sites, being at highest 3000 $\mu\text{g}/\text{m}^3$. The concentrations of viable fungi were maximally 105 cfu/m^3 , and the concentrations of both total culturable bacteria and Gram-negative bacteria exceeded the proposed occupational exposure limit values (OELV).

As reported by Scarlett et al. (1990), mutagenic airborne particulates have been identified in the working areas of a municipal waste incinerator that incompletely burns waste. If such particulates are inhaled or ingested by workers, urinary excretion of mutagens may occur. The frequency of urinary mutagens was measured by the Ames test in a sample of 104 refuse incinerator workers in seven US incinerator plants during 1988. Samples were compared to those observed in 61 water-treatment employees in 11 municipal water treatment facilities during the same period. Incinerator workers had a significantly higher risk for urinary mutagens and promutagens as compared to water-plant workers after controlling for age. Among incinerator workers, increased risk of urinary mutagens was associated with workers who wore protective clothing (defined as clothing other than masks or gloves) or whose job classification was equipment repair. It also showed a weak positive association with increasing age. There was an increased risk of urinary promutagens associated with not wearing gloves. The presence or absence of mutagenicity in workers' urine varied with plant location.

A follow-up study by Ma et al. (1992), reported on a smaller number of these workers and controls (37 and 35 respectively). Although there were differences between the study and control groups for the first urine mutagen testing, there was no significant difference for risk of urinary mutagens or promutagens between the two cohorts when comparing, respectively, the second and third urine samples from each cohort. The poor repeatability of demonstrating urinary mutagens in individual incinerator workers suggests that their exposure was highly variable. As a result of participating in the

study, workers may have changed their work practices and thus influenced the subsequent urine test results.

Toxicity to genes as a result of exposure to hazardous chemicals was examined in workers at a hazardous waste site in Mexico (Gonsebatt et al. 1995). The 12 workers employed at the site had been in contact with hazardous chemicals for several months without any protective clothing or equipment. Seven residents of the local village served as controls in this study. Chromosomal aberrations and sister chromatid changes were examined as markers of genotoxicity. The workers exhibited significantly higher frequencies of chromosomal damage, the magnitude of which was related to exposure time. The authors proposed that, when high-risk exposure is suspected, determining biomarkers of genotoxic damage (e.g., chromosomal aberrations) can be a useful component of a risk assessment.

In conclusion, biomonitoring studies of communities living near waste sites have indicated that certain exposures can be identified. These are valuable tools for risk assessment and can demonstrate exposures to specific substances. Most studies identified examined possible exposures to trace metals, volatile organic carbons and dioxins and dioxin-like compounds. Other markers of adverse health effects have been described; these include markers of kidney function and markers of DNA damage.

Literature review of the health effects of landfilling and incineration

In this section, the human health effects of environmental emissions from landfill and from incinerators are described. The search to identify relevant research papers was performed as follows:

The electronic database MEDLINE was used to identify relevant publications in the international peer-reviewed literature. The search terms including, 'landfill', 'incineration', 'waste', 'waste management', 'thermal treatment', 'health effects', 'pollution', 'emissions', 'environmental hazards', 'risk assessment', 'exposure assessment' and 'environmental monitoring' were used. From the primary search, 253 articles were identified. Additional articles were identified through secondary searches. Internet searches of websites of national and international government and academic organisations were also conducted. This resulted in identification of reports that were not available through the electronic medical database.

Landfill waste and human health

Introduction

As outlined in Chapter Three, most waste in Ireland is currently consigned to landfill. The constituents of landfill have changed over time in terms of waste that is deposited and also in terms of biological degradation in existing sites. Although modern landfill sites are superior in terms of containment and emission reduction, emissions from landfill continue to give rise to concerns about the health effects of living and working near these sites, both new and old.

This section describes the scientific literature in relation to landfill. Most studies examining the health effects of living near landfill sites have been carried out in relation to specific single geographic sites. Several studies have also examined a number of different sites. An advantage of these multi-site studies is a larger population base, which is particularly useful when studying health outcomes that

occur infrequently in the general population. Congenital malformations and rare forms of cancer are examples of such outcomes. However, a disadvantage of multi-site studies is that the waste sites being studied may vary according to what sort of waste is deposited, how the sites are managed and differences in pollutant transport and population exposure pathways (Vrijheid 2000). Where available, the mode of transport of the pollutant is described. As discussed in Chapter Six exposure may be via direct contact, inhalation or ingestion of contaminated food or water. Drinking water contamination has been identified as the source of exposure to harmful substances in many studies (Griffith et al. 1989, Berry & Bove 1997, Adami et al. 2001, ATSDR 1994, 1997).

Specific health outcomes that have been examined in epidemiological studies of the health effects of landfill sites include (a) congenital malformations, (b) birth weight, prematurity and child growth, (c) cancers, (d) symptoms of illness. Identified studies will be discussed according to these categories.

Congenital malformations

One of the most publicised incidents of environmental pollution from landfill took place in New York State in the 1970s and 80s. The Love Canal landfill was comprised of a sixteen-acre area, which contained approximately 21,800 tons of chemical wastes that had been deposited over a twenty-year period from the mid-1940s. This land was subsequently developed for housing. Local residents were exposed to a variety of hazardous chemicals that migrated through the soil and into surface water and local ground water. Drinking water was not contaminated, and exposure was either through inhalation, direct skin exposure or through ingestion. Hazardous chemicals identified in high concentrations included chlorinated hydrocarbons, organic solvents, dioxin, toluene and tri-chloro- and tetra-chloroethylene (Stark 2000). Among the earlier investigations of the Love Canal residents was a study of low birth weight, prematurity and birth defects (Goldman & Paigen 1985). Children born in the Love Canal area were reported to be at three times greater risk of low birth weight than children born in a different unexposed area. Birth defects were also reported to be increased. However, the information on birth defects was that reported by parents rather than data contained in a congenital malformation register. This result could have been subject to recall bias, with parents living in the study area more likely to remember minor defects than those parents living in the comparison area. This does not account for the association found for major birth defects.

In a later multi-site study of residents of New York State, a 12% increased risk of congenital malformations in children born to families within one mile of hazardous waste sites was reported (Geschwind et al. 1992). Exposure risk was quantified using the US EPA scoring system of waste sites, in addition to information on off-site leaks. Higher malformation rates were associated with a higher exposure risk. Higher risks were found for malformations of the nervous and musculo-skeletal systems and for malformations of skin, hair and nails. A dose-response relationship was reported with higher estimated hazard potential being associated with higher risk of malformation. Selected toxic waste sites containing specific chemical groups were studied separately. Pesticides were associated with musculo-skeletal anomalies, metals and solvents with central nervous system anomalies, and plastics with chromosomal anomalies. Smoking and alcohol consumption, occupational factors (both maternal and paternal) and the effect of other sources of emissions were not taken into account in this study. In addition, miscarriages and foetal deaths were not included. These factors may also be influenced by exposure to certain hazards in waste. However, a follow-up study found no relation between central nervous system and musculo-skeletal malformations and residential proximity to a hazardous waste site. The researchers examined specific types of hazards, and found an association between central nervous system defects and metal or solvent emitting industrial facilities (Marshall et al. 1997).

A case-control study conducted in California investigated whether maternal residential proximity to waste sites increased the risk of neural tube defects (NTDs), heart defects and oral cleft defects (Croen et al. 1997). Separate proximity measures were used, residence in a census tract containing a waste site and distance of residence from a site. No significant increases in risk were found with either measure of exposure. Risks for NTDs and heart defects were increased two- and four-fold, respectively, for maternal residence at a quarter of a mile from a site. The small number of cases and controls meant that these risks did not reach significance.

A multi-site European study, called EUROHAZCON, was carried out in ten European regions (Dolk et al. 1998). A 33% increase in non-chromosomal birth defects was reported for residents living within 3 km of the 21 hazardous waste landfill sites studied. The increased risk of neural tube defects and certain heart defects was small but statistically significant. This observed increase may have been a chance finding. This study examined very different types of hazardous waste sites. Some sites were uncontrolled dumps, whereas others were subject to modern control measures and management. The authors concluded that further work was required to investigate whether their reported associations are causal.

Budnick et al. (1984) examined birth defect incidence rates to investigate the effects of the Drake Superfund site in Pennsylvania. This site was contaminated with the carcinogens beta-naphthylamine, benzidine, and benzene. The authors reviewed type-specific birth defect incidence rates for the six-year period from 1973 to 1978. There were no statistically significant excesses in birth defects found.

Another recent study of birth defects, reported in 2000, compared health outcomes in a population living near a large landfill site in South Wales (Fielder et al. 2000). Populations in five electoral wards near the landfill site were compared with a similar population in 22 other wards in the same local authority for frequencies of deaths, hospital admissions, and indicators of reproductive health, such as low birth weight and congenital malformations. In addition, records of environmental monitoring of emissions were collected, where available. Although there were no differences in deaths, hospital admission or low birth weight rates between the study and comparison areas, there was an increased risk of congenital malformations. This difference was found to be present before the site was opened as well as during operation. Possible reasons for this observation may have been the effect of a nearby waste incinerator which was closed prior to opening of the landfill site. Other potential causes of both the pre-existing increase in risk of congenital malformations, and the observed risk since the landfill site was opened, include the existence of other alternative pollutant sources (Roberts et al. 2000).

In response to the publication of the EUROHAZCON study, government departments in the UK commissioned a national epidemiological study of the health effects of landfill sites in the UK. The Small Area Health Statistics Unit (SAHSU) at Imperial College London conducted a study around 19,196 known, open or closed landfill sites in Great Britain (Elliott et al. 2001). It was found that approximately 80% of the population of Great Britain live within 2 km of a landfill site. Therefore the study population was much larger in size than the comparison population. The 9,565 sites that were eventually included in the study comprised hazardous waste, non-special waste sites and sites handling unknown wastes. Residents living within 2 km of one of these sites were compared to those who lived further away. Small increases in risk of neural tube defects, abdominal wall defects and low birth weight were reported.

Chromosomal congenital anomalies were studied in a further report from the EUROHAZCON group (Vrijheid et al. 2002). Vrijheid and her colleagues examined 245 chromosomal anomalies and 2,412 controls living near one of 23 hazardous waste sites in 17 study areas in Europe. After adjusting for

confounding by maternal age and socio-economic group, the investigators reported a higher risk of chromosomal anomalies in those who lived within 3 km of a hazardous waste site when compared to those in the study population who lived between 3 and 7 km from one of the study sites. The risks for chromosomal anomalies were similar to those in the earlier EUROHAZCON study discussed above (Dolk et al. 1998). As the influence of socio-economic factors on the risk of non-chromosomal and chromosomal anomalies is in opposite directions, it was surmised that residual confounding was not responsible for the increased risks reported.

Birth weight, prematurity and childhood growth

Goldman and Paigen (1985) reported a three-fold increase in risk of low birth weight in children born in the Love Canal area over that in children living elsewhere. Homeowners and renters were examined separately and homeowners only were found to have a significantly increased risk. This factor could not be explained, as no known differences in exposure risk were identified for the two groups.

The Lipari Landfill in New Jersey was the site of a study of the effects of environmental emissions on nearby residents (Berry & Bove 1997). Leachate, containing volatile organic chemicals, was reported to have contaminated water supplies in the area. Inhalation of volatile organic chemicals directly from the landfill and from water was considered to be the most significant environmental concern. Birth certificate information for the 25-year period, 1961 to 1985, was used to identify maternal residence. For the period of highest potential exposure to environmental emissions, the number of low birth weight babies born to mothers living within a 1 km radius of the site was significantly increased. Although the investigators did not have information on other influencing factors, such as smoking, alcohol consumption and socio-economic status, birth certificate information showed that mothers born in the study area were more highly educated than those in the comparison area. As education is closely linked to socio-economic status, the study population was assumed to be less deprived than that of the comparison area. As a result, higher birth weights in the exposed population would be expected. This difference in birth weight was observed for babies born both before and after the periods of maximum pollution. This lends further weight to the study findings.

Birth weight was also examined in a study of a large hazardous waste site in Los Angeles, California (Kharrazi et al. 1997). Frequency and location of odour complaints from the site were considered to be more reliable estimates of exposure than proximity to the site. Although there were no overall differences in birth weight between the study and comparison areas, the time of greatest dumping activity was associated with a significant but small decrease in birth weight.

Goldberg et al. (1995a) looked at the Miron quarry, a municipal waste site in Montreal containing domestic, commercial and industrial waste. Biogas emitted from the site was found to contain a number of hazardous chemicals, which were the main cause for concern. No reliable information was available to determine resident exposure to these gas emissions, but exposure zones were defined according to proximity to the site and prevailing wind direction. Using information on birth registration, the authors examined infants born to mothers living near the site, which, at the time of reporting, was the third largest in North America. Babies born in the high-exposure zone had a greater than 20% increased risk of low birth weight. Babies born in this zone were also reported as being small for their gestational age, but this was not a statistically significant difference. Although education and maternal age were taken into account in the analysis, some other potentially important confounding factors, such as smoking, were not examined in this study.

One of a number of studies carried out on the Love Canal reported a reduction in stature in children who had spent at least 75% of their lives in the Love Canal area (Paigen et al.1987). The observed differences could not be accounted for by factors such as parental height, socio-economic status, nutrition, birth weight or chronic illness.

Cancers

Using information from the New York Cancer Registry, Janerich et al. (1981) investigated the risks of cancer in residents of the Love Canal area. Cancer rates associated with living near the Love Canal toxic waste burial site were no higher than those calculated for the entire state outside of New York City. Rates of liver cancer, lymphoma, and leukaemia, were not consistently elevated. Although a higher rate of respiratory cancer was noted, this was not consistent across age groups and appeared to be related to a high rate for the entire city of Niagara Falls. The authors reported that there was no evidence that the lung cancer rate was associated with the toxic wastes buried at the Love Canal site. Confounding factors such as socio-economic status and smoking were not examined.

In a further study of lung cancer in areas of New York State containing 12 toxic-waste disposal sites, Polednak and Janerich (1989) examined death certificates of 339 lung cancer cases (decedents) and 676 controls who died of other causes. There was no association between death from lung cancer and residence in the selected census tracts. Analysis of mail questionnaires from relatives of 209 cases who died from lung cancer and 417 controls showed no significant association between lung cancer and a history of ever having resided in the selected areas (response rate approximately 60%). In addition, there was no significant association with cigarette smoking. Duration of residence in the selected census tracts did not differ between cases and controls.

The Miron quarry, a municipal landfill site in Montreal, Quebec, was mentioned in the section on birth outcomes. Using data from the Quebec Tumour Registry, Goldberg et al. (1995b.) evaluated whether cancer incidence among persons who lived near the site was higher than expected. Proximity to the site was used to define exposure. Reference areas, with roughly similar sociodemographic characteristics, further from the site were selected for comparison. Among men living in the exposure zone closest to the site, elevated risks were observed for cancers of the stomach, liver and intrahepatic bile ducts and trachea, bronchus, and lung. Among women, rates of stomach cancer and cervix uteri cancer were elevated. Prostate cancer was also elevated in men living in one of the zones closest to the site.

In a further study of the Miron Quarry, Goldberg et al. (1999) investigated whether men who lived near the landfill site were at higher risk of developing cancer than individuals who lived at a distance from the site. Subjects were selected from a previously completed population-based, interview, a cancer case-control study of men who lived in metropolitan Montreal. Thirteen sites of cancer (n = 2,928 subjects) and a population-based control group (n = 417) were analysed. Street address at the time of diagnosis was used to classify subjects by geographic zones and distance from the landfill site. In the exposure zone nearest to the site, elevated risks were found for cancers of the pancreas, liver and prostate. A high risk was also found for pancreatic cancer and the non-Hodgkin's lymphomas in a sub-exposure zone approximately downwind from the site. When distance from the site was examined, higher than expected risks were found for pancreatic cancer liver cancer, kidney cancer and the non-Hodgkin's lymphomas. These increases in risk were weak and for most conditions were not statistically significant.

Griffith et al. (1989) identified 593 waste sites in 339 US counties in 49 states with analytical evidence

of contaminated ground drinking water providing a sole source water supply. Age-adjusted, specific cancer mortality rates in counties with one or more of these hazardous waste sites (HWS) were compared with those from counties not containing sites. Significant associations between excess deaths and all the HWS counties were shown for cancers of the lung, bladder, oesophagus, stomach, large intestine, and rectum for white males; and for cancers of the lung, breast, bladder, stomach, large intestine, and rectum for white females when compared to all non-HWS counties. Similarly to Janerich et al. (1981), this study did not adjust for confounding factors such as smoking and socio-economic status. Results are therefore difficult to interpret.

An ATSDR study of cancer incidence surrounding 38 municipal waste landfills in New York State (State of New York Department of Health 1998) specifically targeted sites where landfill gas exposure may have occurred. The New York Cancer Registry was used to identify cases among nearby residents. These were compared with controls, taken from a random selection of deaths from causes other than cancer, and matched for age and sex. Cancers which were thought to be sensitive to the effects of chemical exposures were selected. These included lung, liver, brain and bladder cancers, leukaemia and non-Hodgkin's lymphoma. Significant results reported were an increase, in women, of bladder cancer and leukaemia. No information was available on smoking status and duration of residence near landfill sites.

The Drake Superfund site in Pennsylvania was the site of a study of cancer incidence. This site had been contaminated by a number of carcinogenic chemicals, including beta-naphthylamine, benzidine, and benzene (Budnick 1984). In addition to the data on birth defects mentioned above, county-wide, age-adjusted, sex-, race-, and site-specific cancer mortality rates for three decades (50s, 60s, 70s) were examined. During the 1970s, a significantly increased number of bladder cancer deaths occurred among white males in the county, and a significantly increased number of other cancer deaths occurred in the general population of Clinton and three surrounding counties.

Symptoms of illness

Many studies of symptoms conducted in communities living near landfill sites rely on self-reported symptoms. The knowledge of and concern about possible exposure to hazards present in the landfill may introduce some bias into the results of these studies. When compared to populations living further away from such sites, individuals in proximity to landfills may be more likely to recall minor complaints and symptoms, which they may attribute to landfill exposures.

The Drake Superfund site was the subject of another study in relation to exposures of the local population (Logue & Fox 1986). This study was carried out in response to public concerns about adverse health effects possibly related to the site. A questionnaire survey was carried out on a cross-section of residents who had lived in the area for ten years or more. A control group of residents was selected randomly from a surrounding area. No serious chronic health conditions in the exposed group of residents were found. Significantly more individuals in the exposed group complained of skin problems and sleepiness for at least one month prior to the survey, indicative of a possible association between direct human exposure to toxic chemicals from the site and the manifestation of symptoms. The authors acknowledged that the observed increased prevalence of the two symptoms might also have been caused by factors other than contaminants at the Drake site, such as stress, occupational exposure, or other etiologic agents. This association may also have been a chance finding, or due to differences in recall of symptoms in the two groups.

A study of morbidity to assess the short-term health impacts of a hazardous waste landfill was conducted in Montchanin, France, by Zimrou et al. (1994). The site released volatile organic compounds (VOCs) into the air and provoked intense health concern in the community. The landfill was closed in 1988. Subjects were 694 inhabitants residing in three different parts of town. Individual exposure was estimated using a dispersion model of volatile air pollutants and information on the daily activity patterns of each individual within the area under investigation. Instead of self-reported symptoms and illness as used in the Drake Superfund study, the investigators used information on the consumption of medications prescribed for specific ailments over a three-year period (18 months before and 18 months after the site was closed). Although differences were not statistically significant, the most exposed subjects had been prescribed more medications, for diseases possibly linked to emissions from the site before it closed, than had the least exposed individuals. There was a suggestion of a slight trend in the consumption of medications for ear, nose, and throat and pulmonary ailments with individual exposure levels.

In a case control study of the residents of Montchanin, France, conducted during the same period, Deloraine et al. (1995) used the same exposure information as that reported in the above study. The study was designed to reduce bias introduced by the high degree of public concern locally. Seven participating GPs selected patients according to two categories of ailments thought to be associated with landfill emissions. Controls were patients who consulted their doctor for conditions not associated with these emissions. Associations were reported between exposure and frequency of respiratory illnesses and also frequency of psychological disorders. The bias may not have been fully controlled for, as GP consultation may be associated with increased concern about the effects of the landfill emissions.

Levels of morbidity were more recently examined in a telephone survey in New York. Berger et al. (2000) examined the levels of respiratory symptoms and illness among Staten Island residents living adjacent to the Fresh Kills landfill. These were compared to symptoms of residents living on the other side of Staten Island. An increase in respiratory symptoms was reported among residents living near the landfill site. An association was also reported between the odour emitted from the landfill site and the occurrence of eye nose and throat irritation.

A study of a Polish population living near a large mixed (hazardous and municipal) waste site near Warsaw was reported by Zejda et al. (2000). A self-administered questionnaire survey was conducted in tandem with a physician-administered questionnaire. Exposure was estimated by three measures: distance from the waste site; area of residence; and intensity of transport traffic to the waste site in the vicinity of the subject's house. No control group was identified. The response rate was very poor (11% overall), with the highest rate among residents living nearest to the site. Although the investigators reported an increase in psychological complaints, respiratory and gastrointestinal disorders, and in allergic symptoms, the results are unreliable due to the methodological problems with the study.

Incineration and human health

Introduction

The introduction of waste incinerators has resulted in numerous studies of the effects of this process on human health. As is the case with studies of the effects of landfill, research on incineration of waste has been carried out in either the occupational or community setting. Studies of communities

situated near incinerator sites are presented below. Occupational studies of waste workers are discussed separately. The health outcomes that have been examined include respiratory symptoms and illness, reproductive effects and the development of cancer. In addition to studies of the possible consequences of non-specific exposure to emissions from waste incinerators, research has also been conducted to determine the presence or effects of exposure to certain substances known to be present in incinerator emissions. It is important to bear in mind that many studies were based on older incinerator facilities, which would not have had the same emission control standards as those applied today.

Respiratory symptoms and illness

Respiratory symptoms are one of the most sensitive markers for adverse health effects associated with air pollution (Hall 1995). Shy et al. (1995) examined three separate populations living near a biomedical incinerator, a municipal incinerator and a hazardous waste incinerator. The investigators measured air quality, respiratory symptoms and respiratory function in these populations. Results were compared with three matched-comparison communities. Environmental air quality measurements included those of particulates, and gases. No differences in concentrations of particulates were detected among the three pairs of communities. For the municipal incinerator, it was reported that emissions accounted for 2% of the fine particulate mass detected at the monitoring station. Symptoms of respiratory illness, such as chronic cough, wheeze and sinus trouble, were significantly greater in those living near the hazardous waste incinerator than in their control community. However, this difference did not remain when all three incinerators were combined and compared with their comparison populations.

Respiratory symptoms in over 4000 residents living in four communities near waste incinerators were compared to those in similar but separate nearby populations (Mohan et al. 2000). A higher prevalence of self-reported respiratory symptoms was reported in one community near a hazardous waste incinerator than in its control population. However, the investigators also reported that this community was located the greatest distance from its comparison population, and that respondents in this community showed more concerns about air quality. In addition, the socio-demographics of these areas were not directly comparable. This may have led to the introduction of a number of biases and confounding factors. This study combined data from two separate cross-sectional studies to determine the significance of previously reported respiratory symptoms in the hazardous waste incinerator site. Although these two studies were conducted using similar methodologies, control communities located upwind of the study communities were added.

In another cross-sectional study, the frequency of respiratory symptoms was examined in children living near two sewage-treatment facilities with high-temperature sludge-burning incinerators in Sydney (Gray et al. 1994). The results of lung function tests and the prevalence of asthma, symptom frequency and atopy were not significantly different between the study and control populations. Socio-economic status, however, was not taken into account when comparing the two regions, nor was parental cigarette smoking or indoor air quality.

In a study by Wang et al. (1992), lung function was measured in 86 primary school children living in an area of air pollution resulting from wire reclamation incineration, and in 92 schoolchildren in an un-exposed area. A higher incidence of lung function abnormalities was reported in children in the polluted area than those in the non-polluted area. There was no significant difference in the prevalence of respiratory symptoms between these two areas when surveyed by a questionnaire. Bronchial responsiveness tests were conducted on children from the non-polluted and polluted areas

(26 and 28 respectively). Nine (35%) of the 26 children in the polluted area were responders, compared to only one of the controls. The authors concluded that their results indicate that air pollution resulting from wire reclamation can produce a detrimental effect on both pulmonary function and bronchial responsiveness in primary school children who are continually exposed to air pollutants from the time of their birth.

Reproductive effects

Lloyd et al. (1988) reported an increase in the frequency of twinning in human and cattle populations in an area in central Scotland at increased risk from incinerator emissions. The findings of this study were reported to be consistent with the hypothesis that PCHs (polychlorinated hydrocarbons) or other agents with oestrogenic and fertility-related properties were introduced into the local environment. This study, however, was an analysis of the geographical distribution of twinning and did not analyse environmental emissions. In addition, the authors acknowledged that the genetic component of twinning was not examined. Although maternal age was taken into account, other social factors that may have influenced human twinning rates were not examined. Four years later, in an analysis of the same area in Falkirk, in central Scotland, a similar study reported a significant excess of female births in an area at risk from emissions from two incinerators (Williams et al. 1992).

A later study, carried out in Sweden, examined whether spatial clustering of twin births was associated with 14 incinerators constructed during the study period (Rydhstroem 1998). Between 1973 and 1990, 1,224 municipalities, with 17,067 twin deliveries, were examined. No clustering of twin deliveries was evident in time or in geographic areas, including the areas in which incinerators were built.

A study of open chemical combustion in Zeeburg, Amsterdam, during the years 1961 to 1969 was reported by ten Tusscher et al. (2000). This study was carried out to investigate the incidence of orofacial clefts in the region and to determine any association with the local combustion facility. Birth records for the 1960s from two maternity hospitals, the Zeeburg and Wilhelmina Clinics, were collected. Both clinics were situated in Amsterdam, but varied in distance and direction from the incineration works. Maternal address at birth was obtained from the records and plotted on a map of Amsterdam. The addresses of the mothers of the cases born in the Zeeburg Clinic were grouped primarily to the northwest (and a smaller group to the west) of the incineration works. The average incidence of non-syndromal orofacial clefts in the Zeeburg Clinic was 2.4 per 1000 births. That for the Wilhelmina Clinic was 0.66 per 1000 for the study period. Within the study period, the incidence in the Zeeburg Clinic rose dramatically to a peak at 7.1 per 1000, before reaching a plateau at an average incidence of 1.68 per 1000 births. This was still 155% higher than that in the Wilhelmina Clinic. The authors concluded that these results inferred an association between the incinerator and the increased local incidence of orofacial clefts. Although this increase was probably a true finding, the possibility of other influencing factors, such as alternative sources of exposure, could not be ruled out.

Cancer

In an analysis of childhood cancers, Knox (2000) examined migration patterns around 70 municipal waste incinerators, 460 landfill sites and 307 hospital incinerators. Birth and death addresses of affected children who moved house were mapped and examined. Although there were no significant association related to landfill sites, there was a highly significant excess of migration away from birthplaces close to incinerator sites. The author comments that these findings may be the result of age-related circulation around available housing stock, with, for example, young mothers living with their inner-city parents and moving out to less industrial areas over time.

The Small Area Health Statistics Unit (SAHSU) analysed the incidence of cancers of the larynx and lung near the incinerator of waste solvents and oils at Charnock Richard in Lancashire (which operated between 1972 and 1980) and nine other similar incinerators in Great Britain, after reports of a cluster of cases of cancer of the larynx near the Charnock Richard site (Elliott et al. 1992). Post-coded cancer registration data was used to calculate cancer rates within 3 km, and between 3 and 10 km, of each site. Lag periods of 5 and 10 years were used between start-up (or first registration) of the incinerators and cancer incidence. Standardised cancer ratios were assessed within 3 km and between 3 and 10 km of each site and then aggregated over all sites. Zones of exposure were also drawn concentrically around each site to test for trend in cancer rates with distance. For Charnock Richard, none of the cancer rates within 3 km or between 3 and 10 km differed significantly from those of the general population. No increase in cases of cancer of the larynx was detected near the Charnock Richard former waste site.

In a study of over 14 million people, Elliot et al. (1996) examined cancer incidence in Great Britain, using cancer registry data and proximity to one of 72 municipal solid waste incinerators. Although a statistically significant decline in risk was reported for all cancers combined, and individually for stomach, lung, colorectal and primary liver cancers, this was thought to be largely due to residual confounding by socio-economic factors. Liver cancer was the most strongly significant (37% excess risk within 1 km of municipal waste incinerators) but, on review of cancer registration data, this cancer category was reported to be frequently misclassified or misdiagnosed (mainly secondary liver tumours). In a recent study to investigate the validity of these liver cancer diagnoses, Elliot et al. (2000) attempted to determine the size of any true excess in the vicinity of municipal waste incinerators. In a sample of cases subjected to histological and medical record reviews, over half were reported to be true primary liver cancer. This resulted in a re-estimation of the calculated excess risk previously reported (from 0.95 excess cases 10^{-5} /year to between 0.53 and 0.78 excess cases 10^{-5} /year). The strong association between deprivation and primary liver cancer was thought to remain an influence on this result.

Analysis of deaths from cancer was undertaken in a densely populated suburb of Rome with multiple sources of pollution (Michelozzi et al. 1998). These included a large waste disposal site, an oil refinery plant, and a waste incinerator. Specific cancers examined were liver, lung, laryngeal, kidney and cancers of the blood and lymphatic system. Cancer risks were estimated for increasing distances from the plants. No excesses of cancer were found in the study area. However, a significant finding was that the risk for cancer of the larynx in men decreased with increasing distance from the plant. Kidney cancer in women living between 3 and 8 km of the plants was also found to be increased. This, however, was not influenced by increasing distance from the site. Factors such as deprivation were taken into account in this analysis, as zones near industrial areas are generally socio-economically disadvantaged. Limitations of this study include the use of mortality statistics as a proxy for cancer cases. For those cancers such as laryngeal cancer, which have long survival times, this could influence the findings of this study as many cases may be alive at the time of the study. In addition, as this study area contained a number of sources of pollutants, any excess in cancer risk could not be attributed to any one site.

Dioxin emissions from a municipal solid waste incinerator were the specific focus of a study of soft tissue sarcoma and non-Hodgkin's lymphoma in a region of eastern France (Viel et al. 2000). Cases registered with the local cancer registry between 1980 and 1995 were analysed to determine if a cluster of cases existed in the study period, and if any clusters of cases could be detected around the incinerator site. The incinerator was found to be the centre of a spatial cluster of cases of these

cancers. In comparison, cases of Hodgkin's lymphoma, thought not to be associated with dioxin exposure, did not demonstrate any clustering. Socio-economic confounding was thought not to be of importance as these cancers have shown no clear association with social class. Urbanisation as another potential confounder was also unlikely, as other local densely populated areas did not show the same excesses of these cancers. Other pollutants from the incinerator could also have contributed to the overall exposure of this population.

Biggeri et al. (1996) reported a case-control study of lung cancer around four sources of environmental pollution (shipyard, iron foundry, incinerator, and city centre) in Trieste, Italy. Seven hundred and fifty five deaths from lung cancer and 755 controls were identified through the local autopsy registry. Information on smoking habits, occupational history, and place of residence were obtained from the subjects' next of kin. Spatial models were used to evaluate the effect of sources of pollution on lung cancer after adjustment for age, smoking habits, likelihood of exposure to occupational carcinogens, and levels of air particulate. The models were based on distance from the sources and enabled estimation of the risk gradient and directional effects separately for each source. The risk of lung cancer was strongly associated with residence near the city centre and near the incinerator. In each of these two locations, as distance increased from the source, risk was reduced. The observed effects in relation to the city centre may have been influenced by the close proximity of two of the other sites, namely the shipyard and, to a lesser degree, the iron foundry.

Occupational effects of exposure to emissions from landfill and incineration sites

Introduction

When studying population health effects resulting from emissions from landfill and incineration sites, important information can be obtained by including occupational studies. The activities of waste workers are associated with a variety of physical, chemical, and biological hazards. Risk of fatal and non-fatal occupational injuries is much higher than that observed in the general workforce. Among this group of workers, non-fatal injuries are mainly musculo-skeletal. Other common injuries are those to the eye, bites, skin and respiratory complaints and gastrointestinal disorders, (Gelberg 1997, Boswell and McCunney 1995). As has been discussed in Chapters Three and Four, a large and diverse quantity of chemical substances are emitted from landfill and incineration processes. For those populations residing close to such facilities, exposures were generally described as being at low levels, albeit over long periods of time. In contrast, workers at landfill and incineration sites may be exposed to greater concentrations and to a greater variety of hazardous emissions. Multiple exposures may be more common, with workers involved in transporting waste, sorting, operating machinery, and maintenance of incinerators and landfill sites. The waste worker presents unique exposure problems to anyone attempting to undertake an occupational health assessment. Exact identification and measurement of ambient concentrations of hazardous chemicals prior to exposure is often not possible. Historically, there has been a strong reliance on the individual waste worker's use of personal protective equipment rather than environmental control measures (Favata & Gochfeld 1989). Primarily as a result of environmental constraints, recent developments in the waste-collection and processing industry in Europe have placed greater emphasis on separate collection, processing, and recycling of waste. It is likely that this will lead to an increase in the number of workers involved in the handling and processing of municipal waste, and an increase in the number of workers exposed to organic dust and other potentially hazardous substances (Van Tongeren et al. 1997).

This section outlines scientific research on the health of waste workers. In addition to studies of traditional health outcomes (such as illness, death, and development of cancer), this area has

prompted much research in the area of biological monitoring of exposures and of the effects of such exposures. Biological monitoring studies were discussed earlier in this chapter. As all waste worker reports are presented together, the type of site being examined is mentioned when discussing individual studies.

Morbidity studies

Gustavsson (1989) investigated mortality among 176 male workers employed at a municipal waste incinerator in Sweden. The incinerator handled municipal waste, although earlier in its 60 years of operation it had dealt with both municipal and industrial waste. Excess deaths were reported for lung cancer and for ischaemic heart disease. The excess deaths from ischaemic heart disease were significant for those workers with 30 or more years of employment, but not for lung cancer deaths. This might have been because there were too few lung cancer deaths in the study sample. Although no particular chemical exposures were implicated, exposure to combustion products and polycyclic aromatic compounds were reported to be common. Potential confounders such as smoking were examined and were felt not to have contributed to the excess deaths reported.

A cohort of 86 incinerator workers was the subject of an evaluation of health and exposure details in Philadelphia (Bresnitz et al.1992). Using work-site analysis, workers were categorised into high- and low-exposure groups. Lifestyle questionnaires, detailed medical examinations and blood and urine analyses were undertaken. Results of personal environmental sampling indicated that only four samples were above government standards: one for lead, one for phosphorous, and two for total particulates. Because samples were taken during limited operations (only one of the two incinerators was operating), the results may under estimate historical exposures at this site. Eight individuals had at least one elevated biological index indicating exposure to a heavy metal. These elevations, however, were not related to the workers' exposure categories. Furthermore, no clinically significant mean blood or serum measurements were noted. Thirty-four per cent of the workers had evidence of high blood pressure. This was not related to exposure group. Changes in lung function related only to smoking status. Although there was some evidence of an increased risk of exposure to products of incinerator waste, the authors could not relate the few elevated biological tests to exposure classification.

As a result of employee health concerns, Gelberg (1997) carried out an occupational health study of sanitation workers in New York City. Questionnaire surveys were carried out on 238 landfill and 262 off-site male employees to determine workplace exposures and health symptoms experienced in the previous six months. Higher rates of work-related skin, neurological, hearing, and respiratory symptoms, and sore and itching throats were reported among landfill employees than among off-site employees. The respiratory and skin symptoms were not associated with any specific occupational title or work task, other than working at the landfill. Off-site employees experienced more neuromuscular symptoms and injuries. The use of protective masks did not influence the frequency of reported respiratory symptoms. However these masks were paper and were not mandatory equipment for employees. This study relied on self-reported exposures and did not examine environmental monitoring or biological monitoring data. In addition, significant socio-economic differences were reported between the two groups.

Exposure to dust and high levels of airborne, non-infectious micro-organisms is recognised as a cause of respiratory symptoms and disease among workers handling biological materials, such as farmers, sawmill workers, and workers handling municipal waste and fuel chips (Eduard & Heederick 1998, Rahkonen et al. 1987, Fedorak & Rogers 1991, Yassaa et al. 2001).

Exposures to organic dusts, endotoxins and micro-organisms, were examined in a study conducted in the waste collection and processing industry in the Netherlands (Van Tongeren et al. 1997). The sites included in the study were a compost-screening facility, a resource-recovery facility and two waste-transfer facilities. Levels of exposure to inhalable organic dusts were highest in the waste-processing facilities (compost-screening and resource-recovery). Personal endotoxin exposure was highest in the resource-recovery facility during manual separation of waste. High concentrations of micro-organisms were found in all facilities. The highest levels for both total fungi and bacteria were recorded in the dumping pit at the resource-recovery plant and in the dumping pit at one of the waste-transfer plants. It is concluded that high levels of exposures to micro-organisms, and to a lesser extent to organic dusts and endotoxins, are likely to occur in many processes and activities in the waste-transfer and waste-processing industry, and that the possibility of health effects due to these exposures cannot be excluded.

A Danish study by Ivens et al. (1999) explored the relationship between gastrointestinal problems and measurements of bioaerosols to which waste workers are exposed in the course of their work. A job-exposure matrix was constructed from a combination of questionnaire data and field measurements. The questionnaire data were collected from 1,747 male waste collectors and a comparison group of 1,111 male municipal workers. In addition, a total of 189 personal environmental samples were collected for characterising the bioaerosol exposure described by viable fungi, total count of fungal spores, micro-organisms, and endotoxins. An exposure-response relationship was found between both nausea and diarrhoea and endotoxin exposure. Diarrhoea was also found to be associated with exposure to fungi. The risk of reporting nausea or diarrhoea decreased with decreasing exposure. The same pattern existed for exposure to fungi, for which high exposure resulted in the most reports, and for diarrhoea, for which low exposure resulted in the fewest reports.

In a cross-sectional study of work-related health complaints, Bunger et al. (2000) examined specific immune reactions to moulds and bacteria. These immune reactions served as markers of exposure to bioaerosols in waste. Fifty-eight compost workers, 53 biowaste collectors and 40 controls were interviewed and subjected to detailed medical examination and baseline immunological investigations. Knowledge of specific moulds and fungi was obtained from routine workplace monitoring. Health complaints from biowaste collectors did not differ from those of the control group, but compost workers had significantly more diseases of the skin and airways than the controls. Significantly increased levels of antibodies against fungi and moulds were found in compost workers. These levels were not raised in the biowaste collector group, when compared to controls. A significant association was found between reported diseases and raised antibody levels in compost workers. Differences in the two waste-worker groups may have been partially due to the duration of employment, with biowaste collectors having a shorter period of employment and thus shorter exposure time.

Mortality studies

In a study of mortality and incidence of cancer among Swedish workers exposed to combustion by-products, Gustavsson et al. (1993) reported an excess of deaths from oesophageal cancer in all categories of workers studied. The groups comprised 5,542 chimney sweeps, 695 bus garage workers, 296 gas workers and 176 waste incinerator workers. Routine mortality and cancer statistics were examined for the forty-year period since 1951. The excess deaths were considered most significant in the chimney sweep group. This study did not take account of other contributory factors, such as alcohol and smoking, which are both strongly related to oesophageal cancer risk. The authors

propose that carcinogenic and mutagenic substances produced in the combustion process contribute to the development of oesophageal cancer.

A retrospective study of deaths, in a cohort of 532 male waste workers, was carried out in Rome by Rapiti et al. (1997). Over five hundred male waste workers were employed at either a waste recycling plant or a municipal incinerator. All workers ever employed at the plants since 1962 were enrolled and followed up from 1965 to 1992. Standardised Mortality Ratios (SMRs) were calculated using regional population mortality rates. Deaths from all causes were significantly lower than expected. Looking at deaths from all categories of cancer together, results were comparable with those of the general population. However, mortality from lung cancer was reduced. Increased risk was found for gastric cancer, in subjects where more than ten years had elapsed since first exposure. Although no significant excesses in deaths were reported in this cohort, the authors suggested the need to investigate further the role of occupational exposure to organic dust and bacterial endotoxins generated in waste management processes in the development of cancer.

Public health risk assessments

Most of the formal public health risk assessments involving landfill and incineration have not been published in the peer-reviewed scientific literature. However, many of the epidemiological and environmental investigations which inform specific risk assessments are available. The literature reviews presented in this chapter have identified many of the publications relevant to landfill and incineration. Information on many formal public health risk assessments is available from those government organisations with responsibility for health or the environment.

In Ireland, a recent risk assessment was conducted in Askeaton, Co Limerick (Kelleher et al. 2001, Staines et al. 2001). A summary of this assessment is presented below.

The Askeaton studies

Askeaton is a rural district in County Limerick, close to the Clare border. There are two large industrial sites close to Askeaton, the Aughinish alumina plant and the Moneypoint power station. Following on reports of severe ill health amongst animals on two farms in Askeaton, ill health attributed by locals to industrial pollution, an extensive series of environmental studies was established. Studies on human health included a questionnaire-based survey of almost 2,500 people, studies on cancer, school attendance, deaths, births and stillbirths, and a study of symptom diaries. These studies showed no substantial differences between the health of the population in Askeaton and people living in other rural parts of County Limerick. This episode showed clearly the severe lack of capacity for the assessment of human health in relation to environmental exposure in Ireland. This is still a major problem. The series of studies was very expensive, and took almost seven years from the start to publication of the report. This delay led to considerable, and understandable, concern among the local people.

In the US, the Agency for Toxic Substances and Disease Registry (ATSDR) is the agency of the US Department of Health and Human Services with responsibility for conducting public health risk assessments. This agency provides toxicological, environmental and epidemiological information to inform public health protection in the US.

The following section has been adapted from the ATSDR description of the public health risk assessment process (ATSDR 1994, 1997).

As the first step in the evaluation, ATSDR scientists review environmental data to see how much contamination is at a site, where it is, and how people might come into contact with it. Generally, ATSDR does not collect its own environmental sampling data but reviews information provided by the US EPA, other government agencies, businesses, and the public. When there is not enough environmental information available, the report will indicate what further sampling data is needed. If the review of the environmental data shows that people have come or could come into contact with hazardous substances, ATSDR scientists then evaluate whether or not there will be any harmful effects from these exposures. The report focuses on public health, or the health impact on the community as a whole, rather than on individual risks. Again, ATSDR generally makes use of existing scientific information, which can include the results of medical, toxicological and epidemiological studies and the data collected in disease registries. The science of environmental health is still developing and, occasionally, scientific information on the health effects of certain substances is not available. When this is so, the report will suggest what further research studies are needed. The report presents conclusions about the level of health threat, if any, posed by a site and recommends ways to stop or reduce exposure in its public health action plan. ATSDR is primarily an advisory agency, so usually these reports identify what actions are appropriate to be undertaken by EPA, other responsible parties, or the research or education divisions of ATSDR. However, if there is an urgent health threat, ATSDR can issue a public health advisory warning people of the danger. ATSDR can also authorise health education or pilot studies of health effects, full-scale epidemiological studies, disease registries, surveillance studies or research on specific hazardous substances.

Extracts from ATSDR public health assessments

Two extracts from ATSDR public health assessments are presented below. These and other similar reports can be viewed on the ATSDR website, <http://www.atsdr.cdc.gov>.

1. Barkhamstead – New Hartford Landfill

Connecticut.

The Barkhamstead-New Hartford Landfill (BLS) has been operating since 1974 as an unlined landfill. The 97.8 acre property contains a 10 acre municipal landfill which also functions as a recycling and reclamation center. From April of 1974 to August of 1988, BLS was used for solid waste disposal, and received municipal and industrial waste including but not limited to oily sludge, metal grindings, and degreasers (solvents). This sludge contained cadmium, chromium, copper, lead, manganese, nickel, and zinc, as well as solvents. The Barkhamstead-New Hartford Landfill also conducted a barrel crushing operation from which reclaimed metals were obtained. Bulky waste continued to be accepted for disposal until October of 1993.

On October 4, 1989, the Barkhamstead-New Hartford Landfill was placed on the National Priorities List (NPL) by the United States Environmental Protection Agency (EPA). On December 16, 1991, the Agency for Toxic Substances and Disease Registry (ATSDR) completed an interim preliminary health assessment. The interim preliminary health assessment concluded that the Barkhamstead-New Hartford Landfill Site was an indeterminate public health hazard. At that time insufficient data were available to determine whether exposure to contaminated groundwater at levels of public health concern occurred. The interim preliminary health

assessment recommended additional environmental sampling to further characterize the extent and magnitude of contamination.

A remedial investigation (RI) was conducted at the site between October of 1992 and October of 1993. The RI included sampling of residential drinking water wells, air, groundwater, surface soil, surface water, leachate seeps, and sediments.

A community group was formed in the 1980's: Barkhamstead Residents Acting to Conserve the Environment (BRACE). Community concerns in the past included: odor complaints, migrations of site-related contaminants, and the potential for private well contamination. The community group is now disbanded and citizens' concerns appear to be greatly reduced.

Employees who drank water from the Barkhamstead Landfill office well (up to four years) or from the Barkhamstead Town Garage, (also up to four years) were exposed to volatile organic compounds (VOCs). All exposures to site-related contaminants in these wells represent no apparent public health hazard. The exposure period for the landfill office well was approximately 1980 - 1984 (well closing date). The exposure period for the Town Garage well was approximately 1986 - 1990, when an alternative water source was initiated.

Private well sampling was first conducted in 1988, and private well quarterly monitoring program is ongoing. No wells were identified with VOCs. Two wells contained arsenic, antimony, and selenium, however these levels represent no apparent public health hazard. The CT DPH will continue to review monitoring reports from the three private wells nearest the landfill that are included in the quarterly monitoring program.

Low levels of contaminants detected in the surface soil of the landfill have also been detected in surface soil of two adjacent properties. However, these low levels represent no apparent public health hazard to either young children, older children, or adults. Lead was detected in water from five private homes. The source of lead is probably from plumbing fixtures in the individual homes not their well water. Therefore the potential exists for persons to be exposed to lead through ingestion. Based on the above information, the Agency for Toxic Substances and Disease Registry and the Connecticut Department of Public Health have concluded that this site represent No Apparent Public Health Hazard. No follow-up health activities have been recommended for this site.

2. Pollution Abatement Services (PAS)

City of Oswego, Oswego County, New York.

The Pollution Abatement Services (PAS) site is in an industrial and commercial area on the north-eastern edge of the City of Oswego. The site was listed on the National Priority List (NPL), also known as Superfund, in September 1983. Pollution Abatement Services, Inc. (PAS) operated a chemical waste incinerator at the site from 1970 to 1977.

Between 1977 and 1982, the United States Environmental Protection Agency (US EPA) completed several removal actions and clean-up activities at the site. A remedial investigation (RI) and feasibility study (FS) was completed between November 1982 and January 1984. A record of decision (ROD) was issued by the US EPA in June 1984 and provided for excavation and removal of contaminated soil, subsurface tanks and drums; construction of a perimeter slurry wall; capping; groundwater recovery and leachate collection, with on-site treatment and

groundwater monitoring. Installation of the slurry wall and cap was completed in 1986. The New York State Department of Environmental Conservation (NYS DEC) has overseen long-term monitoring at the site since 1989. In September 1988, the Agency for Toxic Substances and Disease Registry (ATSDR) completed a health assessment for the PAS site. The health assessment evaluated public health concerns, on- and off-site contamination, physical hazards, environmental and human exposure pathways and associated public health implications.

Public Health Implications

A. Toxicological Evaluation

An analysis of the toxicological implications of the human exposure pathways of concern is presented below. To evaluate the potential health risks from contaminants of concern associated with the PAS site, the NYS DOH has assessed the risks for cancer and non-cancer health effects. The health effects are related to contaminant concentration, exposure pathway, exposure frequency and duration.

1. Past potential ingestion, dermal and inhalation exposure of workers and trespassers at the PAS site to waste leachate and waste lagoons.

In the past, workers and trespassers at the site could have come in contact with contaminated leachate seeps and waste lagoons for a period of about 16 years (from 1970, when PAS went into service, to 1986, when remedial measures were taken). Among the organic contaminants selected for further evaluation, several are human or animal carcinogens. Benzene is a known human carcinogen (ATSDR, 1993a), whereas carbon tetrachloride, 1,1-dichloroethene, dimethylaniline, methylene chloride, tetrachloroethene (or tetrachloroethylene) and trichloroethene (or trichloroethylene) are known to cause cancer in laboratory animals exposed to high levels over their lifetimes. Chronic exposure to dimethylaniline at the highest concentration found in waste lagoons could pose a high increased cancer risk, whereas, exposure to the other contaminants could pose a low increased cancer risk. The potential health risk to workers and trespassers from past exposures to these chemical contaminants would most likely be less because contact would have probably been infrequent and for short periods of time.

Contaminants in the former on-site leachate and waste lagoons that were selected for further evaluation of non-carcinogenic toxic effects are benzene, dimethylaniline, trichloroethene and chromium. Benzene is known to cause damage to blood-cell forming tissues and to the immune system. Trichloroethene can produce noncarcinogenic toxic effects, primarily to the liver, kidneys and central nervous system. The primary toxic effects associated with ingestion of large amounts of chromium have been kidney damage, birth defects and adverse effects on the reproductive system. Exposure to dimethylaniline is associated with central nervous system depression. Chronic exposure to benzene and dimethylaniline could pose a moderate risk of adverse noncarcinogenic health effects, whereas chronic exposure to trichloroethene and chromium could pose a low risk of adverse health effects. Again, the potential health risk to workers and trespassers would most likely be less because exposures would have probably been more infrequent than the assumptions we used in our evaluation.

2. Potential ingestion, dermal and inhalation exposure of persons engaged in recreational activities in White and Wine Creeks.

People who used White and Wine Creeks for recreational purposes may have been exposed to surface water contaminants. In addition, trespassers on the PAS site also may have been exposed to surface water contaminants. The potential adverse health effects from exposure to these contaminants would probably be minimal, since contact is likely to be infrequent in occurrence and for short periods of time.

B. Health Outcome Data Evaluation

Evaluation of health outcome data may present a general picture of the health of a community and may confirm the presence of adverse health outcomes. However, elevated rates of a particular disease may not be due to hazardous substances in the environment. Similarly, a contaminant may still have caused adverse health effects even if elevated rates are not found. Pre-existing health outcome data are usually reported for much larger population units, such as counties, than are likely to be affected by the contaminants associated with a particular site. Any evidence of adverse health effects on the smaller population may be hidden within the larger population. Also, when populations are small, the number of people who have a particular adverse health effect is also small. Small changes in the number of affected people from year to year can cause a large change in the rate, so the rate is considered 'unstable'. For those reasons, health outcome data must be evaluated with caution.

Findings of the 1986 cancer incidence investigation by the NYS DOH did not detect a statistically significant excess in cancer incidence among workers at the Eastside Sewage Treatment Plant when compared with either Westside Sewage Treatment Plant workers or the general population. Four different types of cancer were observed, two of which are quite common among men in the age group examined. The remaining two types of cancer have no known risk factors in common. Furthermore, the occurrence of all four cancers arose in relatively short intervals from the beginning of employment at the Eastside Sewage Treatment Plant to the time of diagnosis of cancer (all less than 10 years). This is inconsistent with what is known about the long latency period for most adult cancers (10 to 20 years).

C. Community Health Concerns Evaluation

In response to past odor complaints reported by residents near the site, the NYS DOH investigated the site area and determined that strong, nauseating odors from the site were migrating to nearby residential properties. The NYS DOH determined that air sampling would be conducted when the odors were next reported.

In response to community concerns about possible health risks associated with the PAS site, the ATSDR completed a health assessment of the site in September 1988. This PHA updates information about site conditions, investigation and remedial activities at the site, site contamination, exposure pathways and community concerns related to the PAS site.

In response to concerns about the occurrence of cancer in young male employees at the Eastside Sewage Treatment Plant who might be exposed to industrial wastes during plant processing or contaminants at the nearby PAS site, the NYS DOH completed a cancer incidence investigation in 1986.

The US EPA completed a supplemental remedial investigation at the site in August 1993. In December 1993, the US EPA signed a Record of Decision (ROD) for the third part of site

remediation. This ROD addressed contamination outside the existing containment system. The primary objectives of this ROD were to control the source of contamination at the site as well as minimise migration of contaminants in groundwater, thereby increasing the effectiveness of earlier remedial actions at the site. The ROD called for a well survey, extending public water to those residents using private wells in the Smith's Beach area downgradient of the site, and institutional controls on groundwater use through deed restrictions. The ROD also called for a supplemental pre-remedial design study (SPRDS) to investigate the bedrock aquifer; investigate pesticide and polychlorinated biphenyls (PCBs) in surface water and sediments in the adjacent creeks and wetlands; and evaluate potential leachate treatment processes.

Based on the information reviewed and ATSDR's criteria for classifying sites, the site currently poses no apparent public health hazard. Past remedial actions, including installation of a slurry wall, an impermeable cap and fencing, have eliminated the potential for current and future exposures to site contaminants in soil gas, on-site soils and air. As outlined in the December 1993 ROD, those homes in the Smith's Beach area that were still using private wells for drinking were connected to public water in July 1995. Although volatile organic compounds have been detected in groundwater in the bedrock aquifer off-site, groundwater monitoring data collected in May 1996 showed a decrease in contaminant levels within the bedrock aquifer since the SRI was completed. There are no known potable supply wells downgradient of the existing groundwater contaminant plume and the area is served by public water. The PAS site posed a public health hazard in the past. Prior to August 1977, when the US EPA initiated cleanup activities at the site, numerous physical and chemical hazards existed at the site. On-site workers, residents and people working near the site are believed to have been exposed to contaminants in air, although there is insufficient information to characterize these past exposures. Workers at the site were most likely exposed to on-site wastes, leachate and contaminants in surface soil at levels of public health concern. Past remedial actions have eliminated the potential for exposure to contaminants on-site.

It is not known if people eat fish from White and Wine Creeks or wetland areas near the site. However, the potential for exposure to site contaminants through ingestion of fish is limited, given that the creeks are small and intermittent.

Summary

Emissions from waste management sites

Emissions from landfill or incinerator sites do not always lead to human exposure. Exposure can only arise if individuals come into contact with the harmful agents in emissions. Contact can be by breathing, skin contact or eating or drinking food or water contaminated with the substance. If there is no contact there can be no toxicity. Another important factor to take into account is the fact that a person may be exposed to levels of the compound from other sources. If a person is exposed to a harmful substance, a number of factors will determine whether a harmful or toxic effect is likely to occur. These factors will include the dose (how much), the duration (how long) and the route of exposure. Other factors to be considered include age, gender, diet, family traits (possible genetic susceptibility), lifestyle, state of health and consideration of other chemicals to which the person may be exposed.

Landfill sites contain many different potentially toxic substances. Potential and actual hazardous emissions from these sites have caused concern to both local populations and regulatory bodies. This has resulted in numerous studies examining different potential adverse effects. These studies indicate that residence near certain specific sites is associated with risks to health. Although a great number of studies have been carried out, evidence of a causal relationship between specific health outcomes and landfill exposures is still inconclusive. Methodological difficulties make determination of cause and effect very difficult. Difficulties in assessing and categorising exposure, and difficulties in controlling for other confounding factors, limit the ability of such studies to detect these adverse effects.

Health effects of landfilling

At present there is insufficient evidence to demonstrate a clear link between cancer and exposure to landfill. Excesses of bladder, lung, leukaemia and stomach cancer have been reported in some studies and not in others. The association between adverse birth outcomes such as low birth weight and birth defects is more compelling, but as yet cannot be described as causal. Further studies are required. In particular, examination of specific types of defects, which may be related to exposure to specific environmental agents may serve to clarify these questions. Reports of increased risk of respiratory, skin and gastrointestinal illnesses are based mainly on self-reported symptoms. Although this evidence must not be dismissed, consideration should be given to the strong possibility of bias and the influence of fears and worry related to the waste sites.

Health effects of incineration

There is some evidence that incinerator emissions may be associated with respiratory morbidity. Acute or chronic respiratory symptoms are associated with incinerator emissions. Reproductive effects, such as an effect on twinning or sex determination, have been described. These findings however are not conclusive. A number of studies have reported associations between developing certain cancers and living close to incinerator sites. Specific cancers identified include primary liver cancer, laryngeal cancer, soft-tissue sarcoma and lung cancer. Although some results are conflicting in this area, other well-designed studies indicate a possible link between cancer risk and residence near incinerator sites. The influence of other sources of pollutants continues to prove difficult to separate and, as a result, evidence cannot be described as conclusive.

Further research, using reliable estimates of exposure, over long periods of time is required to determine whether living near landfill sites or incinerators increases the risk of developing cancer. Studies of specific environmental agents and specific cancers may prove more definitive in the future.

Biomonitoring studies

Biomonitoring studies of communities living near waste sites have indicated that certain exposures can be identified. These are valuable tools for risk assessment and can demonstrate exposures to specific substances. Most studies examined possible exposures to trace metals, volatile organic carbons and dioxin like compounds. Other markers of adverse health effects have been described, including markers of kidney and liver function and markers of molecular or chromosomal damage. The prediction of cancer risk may be possible in the near future by using such biomarkers.

Occupational studies

Occupational exposures to hazardous emissions in waste workers are due to a combination of factors. Of primary importance is proximity to numerous hazardous constituents of waste. Exposures may result in an increased risk of illnesses such as respiratory, skin and gastrointestinal complaints. Evidence of exposures to, and cellular and genetic effects resulting from, certain chemicals such as trace metals, dioxins and other organic substances is strong. Although increases in risk of gastric, oesophageal and lung cancers have been reported in separate studies of waste workers the effects of contributory factors such as smoking were not always taken into account.

Exposures in the occupational setting, although undesirable, present an opportunity to study the health effects of higher concentrations of specific agents than would be observed in the general population. Both to protect waste workers and to understand more about the possible health effects of landfill and incineration, research should be conducted in this area. Biomonitoring and environmental monitoring should be incorporated into such studies.

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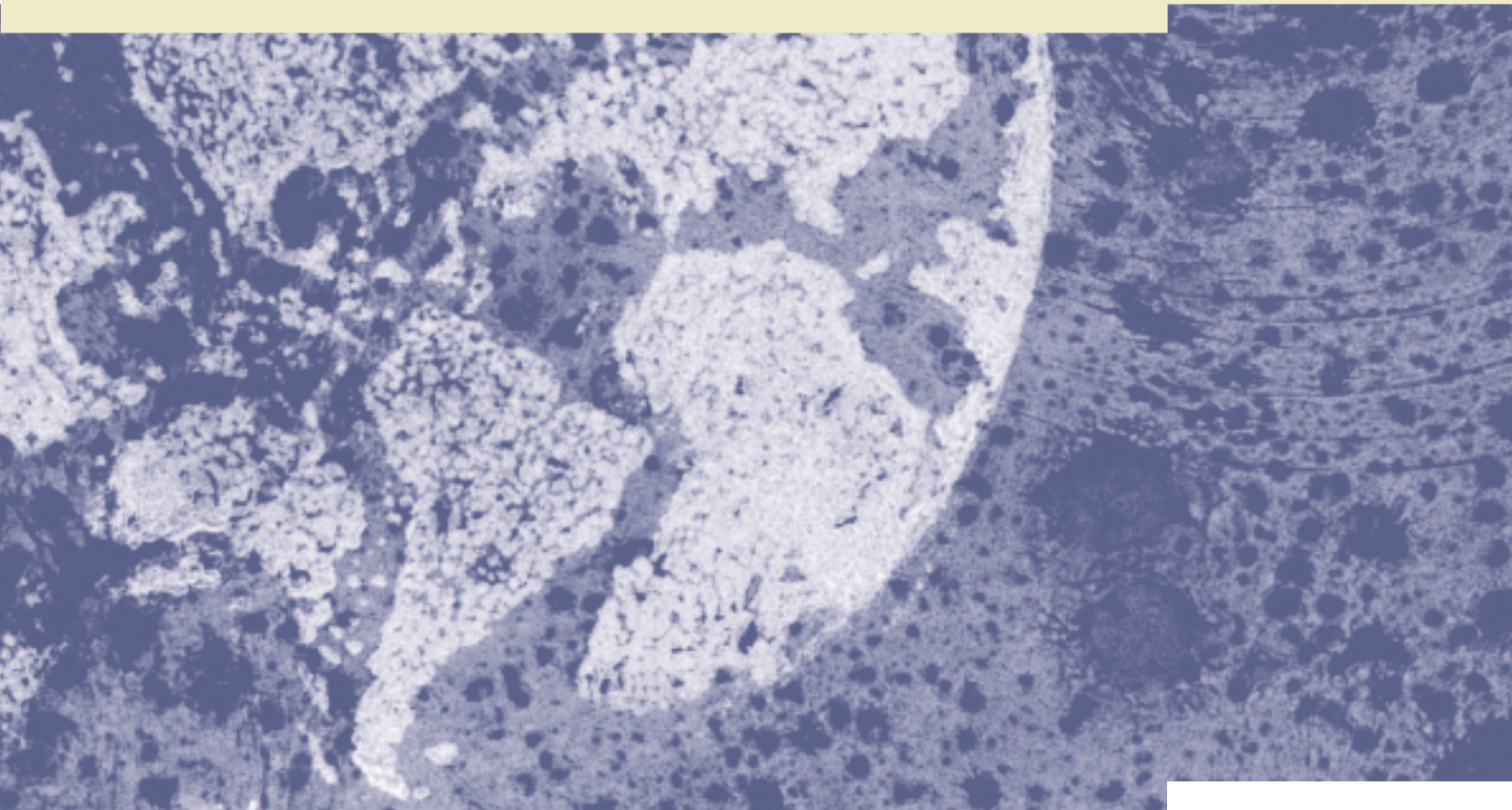
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Chapter Eight: Knowledge and Perceptions of Waste Management Options and their Associated Effects



Chapter Eight: Knowledge and Perceptions of Waste Management Options and their Associated Effects

Introduction

Focus groups and semi-structured in-depth interviews (either face-to-face or by telephone) were conducted with waste management service providers, environmental health officers and the general public. Focus groups and in-depth interviews are a qualitative methodology used extensively in the social sciences. Such an investigation is concerned with gaining an understanding of issues and accessing people's attitudes. It does so using the respondents' own language and criteria.

The issues explored with the informants included concerns in relation to current waste management practice in Ireland, perceived risks from landfill and incineration, sources of information and level of involvement and control in decision-making processes. The topic guide used is shown in Appendix D. An invitation to submit open comments was also published in the national press (See Appendix D). This provided the general public and any other interested party with the opportunity to contribute.

Content analysis and theme identification were used to analyse and interpret the qualitative findings. Examples to illustrate the theme identified are given in the text.

The length and detail of the sections below are representative of the response received from the various contributors, in addition to the data-collection methods employed. The first section represents the input from seventeen interviews or focus groups with service providers and industry; the second section represents the input from twelve telephone interviews with environmental health officers; the third section represents the input from four focus groups with the general public; and the final section represents the input from invited submissions. The limited time-frame for the project permitted only an ephemeral study of the views of the general public. Public knowledge, attitudes and perceptions are complex in their formation. Some a priori conclusions are drawn, but these require more rigorous testing within the context of a more intensive study devoted to this area. The chapter concludes with a summary of the above four sections.

Qualitative research permits one to go beyond quantitative statistics and to look at peoples' attitudes, opinions and beliefs. Most importantly, it does this using the respondent's own language and criteria. A qualitative investigation is concerned with the "what", "why" and "how" rather than the "how many".

Results for service providers and industry

Description of informants

Seventeen semi-structured interviews/focus groups were held with a variety of bodies identified by the research team as being relevant to waste management in Ireland. Representatives from these organisations participated in a focus group, a face-to-face in depth interview or an in-depth telephone

interview, depending on the number of representatives in the organisation available to meet with the interviewer and the time restrictions of the representatives. The representatives interviewed are listed in Appendix D.

Organisational mapping

When asked where organisations would place themselves within the waste management hierarchy, responses varied considerably depending on what sector and role respondents occupied.

The Department of the Environment and Local Government identified its role as the policy driver and financier of waste management strategy at a national level. It flagged market development for delivering and collecting of recoverables as an area it wanted to develop.

The Department of Health and Children did not view itself as a major influencer, noting that:

'We haven't been working within any well-defined environmental health framework but that is an issue we will be addressing during the current year.'

There was a desire for a higher profile 'once we agree our national environmental health action plan and once it is signed off by government'. They saw themselves collaborating 'hand in glove' with health boards as their executive agencies. This department also expressed a desire for more integrated working inter-departmentally and also between health boards and local authorities.

Local authority contributors saw themselves as vital players in the implementation of county and regional waste management plans. One local authority spoke of the fact that they now had waste charges in place, which transformed their ability to be effective. They felt that their approach, a public-private partnership, 'affords us the opportunity to develop long term our plans rather than just from year to year depending on the funding'.

The agricultural advisory body felt that it had a 'central role', although not a regulatory one, in advising farmers and offering them technical support and assistance with regard to waste management issues. This role was seen as primarily one of leading behaviour change in farmers and influencing them to engage in better practice in relation to agricultural waste management.

The health board contributor was clear that, as a director of public health, the role included 'monitoring the health status of the population' and operating as a 'watchdog and advocate' regarding population health in dealing with local authorities and developers. The dearth of data, information and research, which resulted in a 'lack of baseline data', precluded the role from being more proactive than that. There was a strong recommendation for ongoing surveillance systems, which are a deficit in the Irish health research context. There was a sense that a balance needed to be sought between 'risk assessment and risk communication'.

An Taisce saw a role for itself in attempting to engage local people affected by waste management issues to engage in the decision-making processes relevant to them, as in Agenda 21. It saw itself as 'promoting best practice in relation to waste management'. Despite their prescribing role 'we don't think we have very much influence in relation to waste management'.

The EPA clearly saw itself as having four roles: as a regulator, an information source, as an intermediary with the public and as an advisor. The amount of work generated by the interactive role was thought to be considerable-'...for example we have had about 14,000 submissions on waste licences to date,

-which must be responded to and dealt with'. There was a sense that the public wanted the EPA 'to physically go and do the work that licences are often meant to do'. The EPA did not feel it was 'practical or realistic to expect any organisation to be on site to that extent'. It was felt this would result in the regulating authority being responsible for the operation of the facility.

The Food Safety Authority Of Ireland (FSAI) saw itself 'not at the centre but near it' in terms of the waste management hierarchy in Ireland. It has contracts with over 40 government agencies, all health boards and all local authorities, and is a publicly funded body. It considered itself influential and stated that the EPA viewed it as an audit body, especially in relation to water quality. It would welcome closer links and a more proactive relationship with the Department of the Environment and Local Government and other health agencies.

The Institution of Engineers saw itself as 'having a key advisory role as a neutral independent body which had a vested interest in quality waste management in the country'. This body stressed the width and breadth of technical expertise it brought to bear on the issue but was clear that it did not have a regulating role. It regretted the fact that in Ireland, unlike other countries, it was not a legal requirement 'that the consulting engineer has to employ a qualified chartered engineer to actually build the design' (of a waste facility). It did not see an operational role for itself but offered learned advice to the government, construction industry and relevant working groups.

The Health and Safety Authority saw its waste brief as protecting the health and safety of those who operate sites and, in a general sense, protecting the health of those affected by waste further up stream. It saw itself as 'outside the hierarchy but liaising with or indeed acting on all elements of the hierarchy'. The authority has close contact with the EPA, especially in relation to biological agents regulations. It also concerns itself with the transport of dangerous substances, roads and works, with the Gardaí manning roadblocks to check drivers' compliance with health and safety training in relation to chemical tankers. As a statutory body it can enforce fines. Resources allowing, it would wish to be more proactive in the health care waste sector, with staff specialising in the area of biological agents.

Industry viewed itself as being near the bottom of the waste management hierarchy in Ireland. It did view itself as an influencer and wanted to lobby and inform policy makers; but, 'for example, there's been two major task forces on waste management in this country and there has not been a representative from a waste facility at either of those'. Waste companies saw cowboy skip operators as detrimental to their sector, 'tipping in the nearest hole in the ground'. They saw the lack of differentiation between bad and good practice as a problem for their industry sector. This group saw itself as 'promoting landfill but looking at different infrastructures as well'. They wanted to improve their status and credibility with policy makers and the general public.

The collective body for waste companies, the Irish Waste Managers Association (IWMA), is a new entity set up at the end of 1999. It felt that it was influential, to a degree, in that it has written submissions, and it has had meetings where some of its recommendations have been taken on board in new policy developments. It does, however, think that 'people are reluctant to listen to the waste management industry' due to its 'bad reputation'. The IWMA saw itself as being effective in its representative role as its various members would not themselves have gained access to policy makers on an individual basis.

IBEC did not view itself as a player 'apart from giving advice', although it felt business in general would be seen as a player in that it 'both produces products and places them on the market which become waste in other peoples' hands'. The IBEC contributor saw part of the business community as

‘providing solutions to the hazardous nature of waste’. This contributor stated that government needed to be more open to its ideas and proposals.

The representative grouping from IBEC affiliates ranked itself fourth or fifth in the influencing hierarchy, but felt that other groupings, such as environmental groups, had a larger presence in the media. It favoured adapting its strategies and policies to what government was already working on, to ‘make the best of what you’ve got and try and support that strategy’.

Figure 8.1 presents a *Position Map* of the representatives of the service providers and of industry that were interviewed. In a number of cases where organisations were not directly interviewed, their positioning has been interpolated. The map employs two dimensions. Vertically, organisations are positioned in relation to their interest in waste disposal issues. Those for whom the management of waste is a core issue are placed to the top of the map; those for whom health and environmental considerations are core are placed to the bottom. Horizontally, organisations are positioned in relation to their centrality to the issues of waste disposal. Key actors are positioned in the centre of the map; service providers, for whom waste is not a primary concern, are placed to the left of the map; and, advisory bodies, (depending on the nature of their advisory responsibilities) are placed to the right of the map. Academics have been included in a nominal position, as their positioning is often an issue of individual alignment.

Superimposed on the *Position Map* is a *Policy Network Map* (Figure 8.2). This shows the alliance of interests and, where they exist, the statutory relationships between organisations. Thus, a close policy relationship exists between IBEC and IWMA, the latter having been established by the former to represent the interests of their members within the waste management industry. (Though IBEC would also stress their responsibility to the wider business community, who are largely customers of the waste disposal companies). Such formal relationships are represented with a solid line. Relationships, which exist by virtue of *presumed* policy consistency, such as those between different governmental departments or between the Department of Health and Children and the World Health Organisation, are shown in dotted lines.

Waste management in Ireland-general concerns and challenges

Many contributors expressed a concern about the finite capacity of landfills as an ongoing method of waste management in Ireland. The decrease in capacity from an excess of 300 landfills in the mid 1980s to less than 50 currently was noted. The dependency on landfill was a cause for concern, allied to the long-term issues with regard to managing and maintaining landfills after their life-span had expired. Exporting waste out of Ireland was considered to be a ‘form of madness’ and it was thought that the general waste management situation was ‘on the brink of total collapse’.

It was felt that there was not a holistic approach to the challenges of waste management and that technology in itself would not offer adequate solutions. Those expressing this view felt that the ‘application of science...the interaction between everything’ must be promoted.

Many informants spoke of the absence of an appropriate waste management infrastructure as a concern. In particular, this view was expressed by the private sector informants.

‘Currently the infrastructure in Ireland is not sufficient to deal with the quantities or the type of waste that’s generated in the business community in Ireland.’

‘We came to the conclusion pretty rapidly that the current structures that are in place won’t deliver the infrastructure that’s necessary, we’ve got a lot of plans but we have no delivery.’

Figure 8.1 Position map of service providers and industry

(Organisations shown in italics were mentioned in interviews but not themselves interviewed)

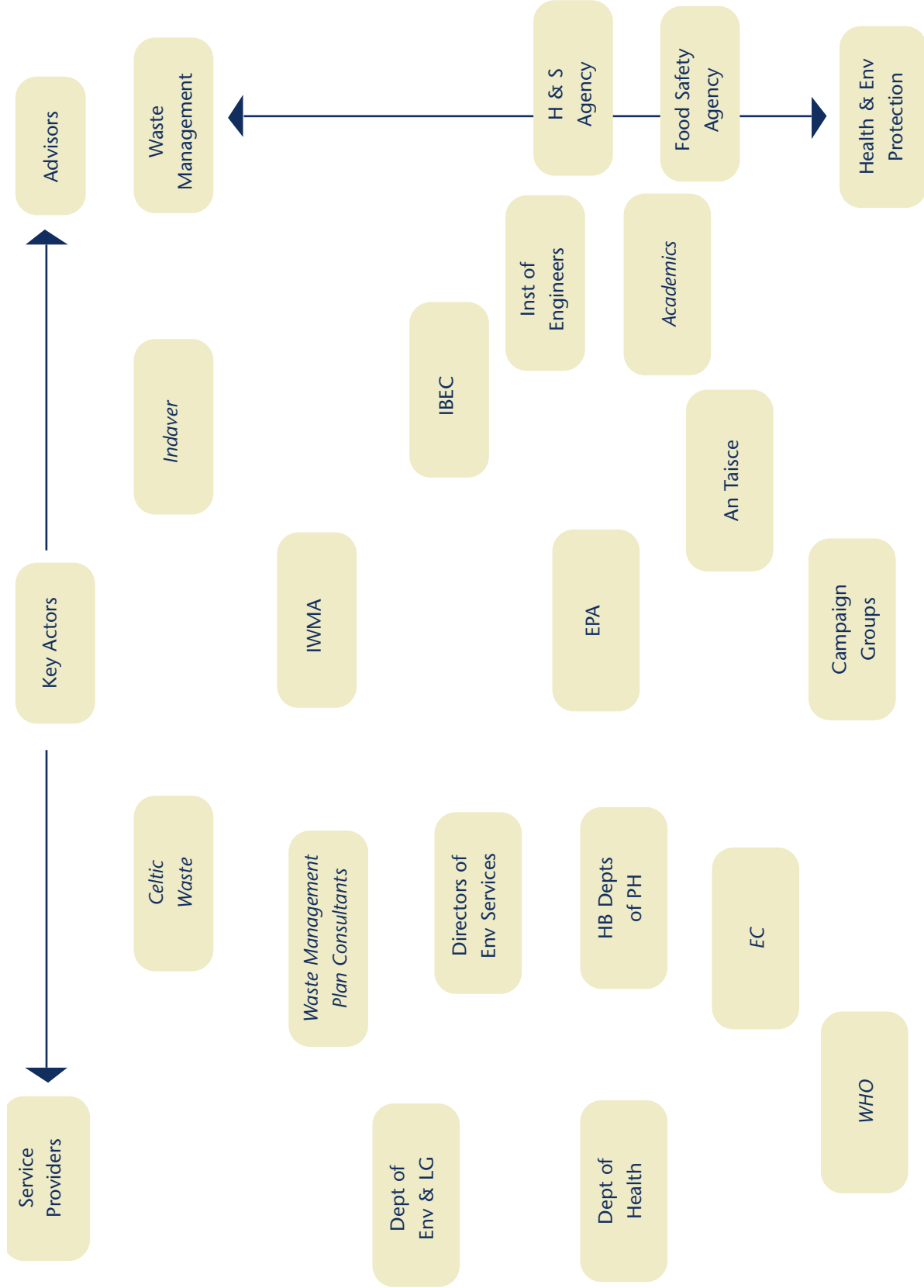
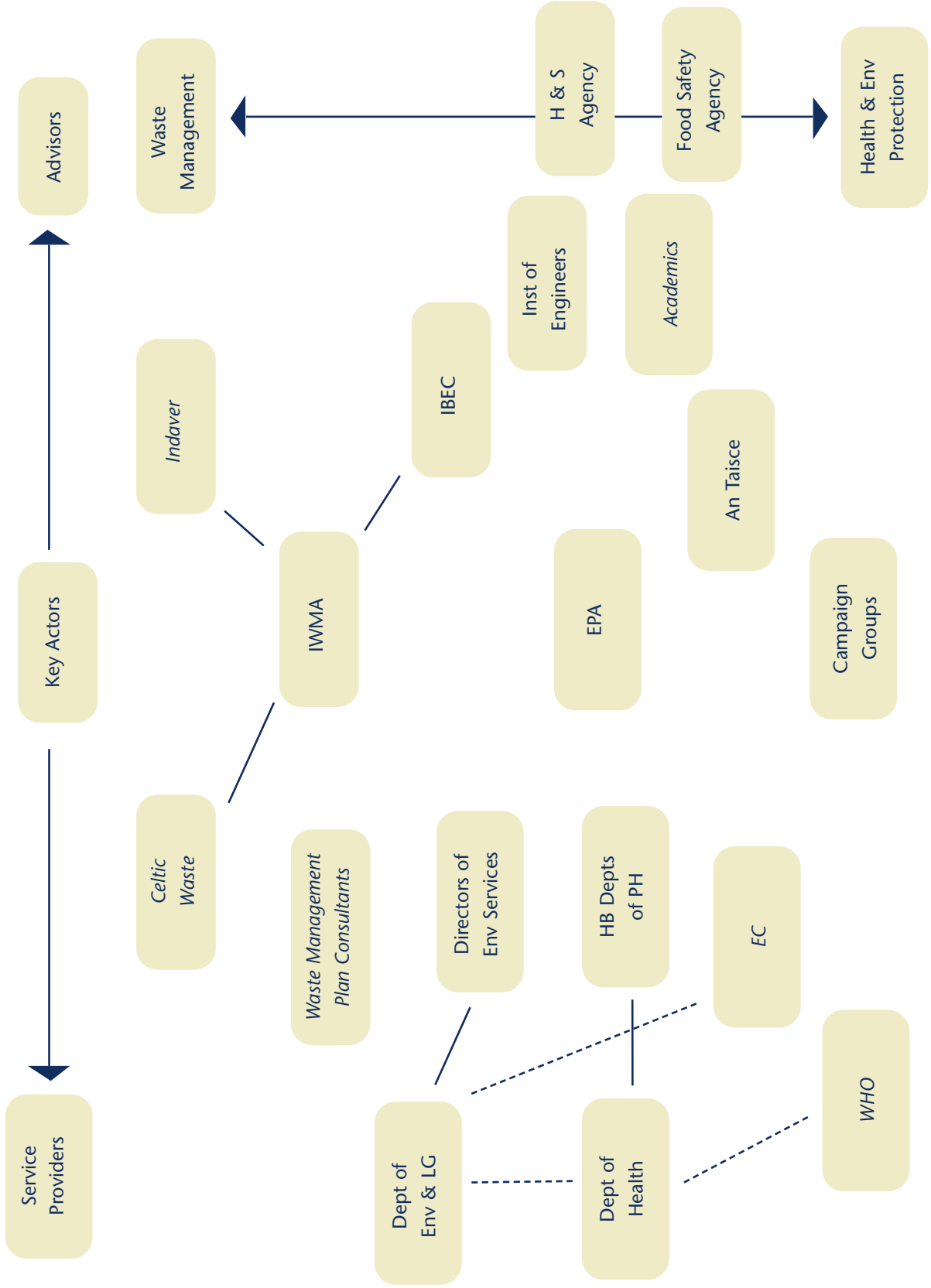


Figure 8.2 Policy Network Map



These informants were also concerned about the access and cost issues associated with the required infrastructure. Comments were made about increasing costs without a corresponding increase in service quality. 'At the moment organisations have higher costs and little or no access', with no increase in quality of service provided.

The fact that there was no capacity for recycling hazardous substances was noted as problematic. There was general concern that Ireland's ability to attract inward investment would suffer if waste infrastructure did not improve.

'We'll be seeing it on Sky News and once it reaches there then Ireland's image will be tarnished.'

'We have a very poor infrastructure for managing those types of waste (household and commercial).'

'I think the powers that be have neither recognised nor have grasped the nettle in terms of moving forward with the infrastructure.'

'In terms of setting aggressive timetables and moving it forward I still do not see any level of comfort.'

Some contributors questioned the development of regional plans and felt this duplication was a waste of resources. Another commentator was concerned that:

'Regional plans encompass the local authority plans but individual local authorities can have plans that haven't been necessarily built into the overall regional plan.'

Another contributor stated that the waste hierarchy was turned on its head in the regional waste plans and that, instead of prioritising and maximising recycling or prevention, that these facilities were attached to a landfill or incineration plan. This contributor felt that it was a challenge that the plans' starting points began with 'a need for a landfill in a certain place as a given' and that communities had not been listened to when they expressed the desire to 'go the route of zero waste'. Others felt that zero waste was an unrealistic aspiration and criticised the lack of integration at a national level.

'The challenges are that there is no coherent policy in relation to waste, that's the first major challenge, a very immediate challenge would be that there is a lack of enforcement.'

Parallel to the finite capacity problem were the issues of public opposition to alternatives and delays in planning and licence applications. The bureaucracy associated with operating in different counties and hence needing different licences and having different application procedures was also cited as a concern.

Industry was unhappy with the speed at which alternatives are being explored as they must deal with the fact that they can no longer use local authority sites. This grouping felt that lack of ownership at a macro level was dogging progress.

'There doesn't seem to be anything moving because the local authority are responsible, they've been made responsible for waste management, central government isn't.'

'You need something centralised for something to move quickly.'

'At the end of the day the government has a responsibility to ensure that waste is managed in the country so if it takes draconian legislation then this is what it has to be, because you cannot leave waste festering outside people's homes.'

The legacy of previous poor practice and statutory neglect was recognised by a number of contributors.

'Waste management has been neglected until the middle of the 90s in Ireland and now where we are today is reaping the benefits of that neglect.'

'Waste management was never given a priority in the Department of the Environment, in local authorities, in business or in consumers and suddenly we have to do something about it.'

'The solution was traditionally the least cost solution, find a hole near a local village and put it in there and that will do.'

'The government has walked away and ignored the reality, now there is a crisis.'

It was noted that prior to 1997 local authorities were not subject to licensing and tended to have very basic facilities, yet most (quoted at between 90% and 99%) of household waste was going into these landfills. 'So the gap is really infrastructure and the ability to manage the waste.'

Another contributor remarked on the amount of waste generated-'The huge amount of paper, plastic and food that is thrown out'-and the prevalent culture of not questioning how people dispose of their rubbish.

'The culture in the country has been that you didn't ever want to pay to dispose of your rubbish. It was either on the side of the road, or send it to a local dump, or put it in a river. So I think it's the culture of the way we respect our environment that is frightening.'

There was also a high degree of consensus about the need to convince the Irish population of the acceptability of alternative methods of waste management.

'One of our biggest challenges is to bring the public with us.'

'A bigger challenge than reaching targets is to change attitudes and practices...to make the individuals, the company, the organisation aware of the cost and basically improve their practices.'

'Behaviour change and attitudes, it's investing in providing information and sustaining and helping people through, between doing what they used to do and moving to what should be done.'

'There should be significant focus on waste prevention.'

'The inability to cope with organic food waste amazes me, I don't know why they can't take this up.'

'A need to move to separate collection systems, in other words, source segregation.'

The challenge of educating the public into the various aspects of waste management was seen as vital.

'People really need to know that their waste doesn't just go from their front door step into nowhere.'

Various groups, regardless of their positioning within the waste management debate mentioned the lack of energy recovery. Likewise, the lack of specific information in relation to alternatives to landfill was a cause for concern.

'In terms of the public, there probably isn't enough information out there for people in terms of recycle and reuse.'

Ireland's commitment and record regarding the environment was felt to be poor in relation to other European states despite our 'green' image. Another concern was the health and safety of workers operating both within waste disposal sites and of those further up stream in the production of waste. There was a plea for the Cabinet 'to see this issue as being one of the national priority issues'.

Peripherality was seen as a challenge.

'We're on the edge and it increases costs but is also puts constraints on what's actually feasible. There is little point in separating and segregating waste if you don't have an end market for it.'

Concerns and challenges relating to landfill

One contributor was concerned at the insufficient quantity of information regarding the health impact of landfills. Others were very concerned at the finite nature of landfill capacity.

The fact that landfill is at the bottom of the waste hierarchy was seen as a challenge. It was accepted that landfills were unpleasant and un-aesthetic if not properly managed and this mitigated against getting planning permission for new ones. The length of time taken for planning and objections to landfills was also seen as a concern. Correct management of landfills was seen as crucial as was the disposal of residual waste only into landfill. Many contributors ventured the view that if landfills were correctly managed that they did not have major concerns. The issue of diseconomies of scale was mentioned and the view put forward that there would always be landfill in Ireland.

Concerns and challenges relating to incineration

There is currently no municipal waste incineration in Ireland so there is no specifically Irish bank of experience and data to draw on. The regulators are mindful that there are emission limits set by EU Committees and incorporated into Directives that take into account the need to protect public health.

Two challenges were raised in relation to incineration: firstly that 'the appropriate and best technology is used' and secondly that 'in terms of ongoing operations and management and the monitoring', that reassurance and confidence raising is important alongside the provision of factual information. There was an acceptance that fears of dioxins and emissions were a concern that needed to be addressed in the public domain.

There was a strong view that the newer generation of incinerators, if properly managed, did not give rise to undue concerns and that incineration was an integral part of a comprehensive waste

management strategy. Some contributors said that they had no concerns and that households and smoking also generated dioxins. There was general acceptance that incineration technology had advanced greatly in the last ten years and that the associated problems related to heavy metals, dioxins and emissions had decreased. This acceptance of the protection afforded by new technology, and that dioxins are a common by-product of many human activities, implies a negation of a health impact of waste management strategies.

There was a sense that the relevant parties needed to educate the general public, to communicate the issues concerning incineration and to tackle the public's fear of the unknown.

'It is up to the government to capture the hearts and minds of people and to allay those fears.'

'The challenge is overcoming the general perception out there that it is extremely bad when it's not, as part of an integrated approach to waste management.'

'It is an unknown technology, it's never existed in the country. People are very suspicious especially if they are being told this is bad for you. It is a challenge for any company to overcome that.'

'Huge fears, fears of the unknown.'

'The perception is that if it goes down into the ground it won't affect you but if it goes up into the air it will.'

The lack of public ownership was mentioned in this context. Aligned to this lack of control was the need for national guidance with respect to incineration.

The location of incinerators should not fall to individual local authorities but should be dealt with on at a national level according to one informant. Allocating sufficient resources to ensure that best practice and the most appropriate technology were deployed was seen as an important challenge.

The point was made that there are already eleven licensed incinerators operating privately in Ireland, and that this information should be disseminated more effectively to the general public, to ease fears, instead of the scare-mongering that some felt passed for debate on incineration in the print media.

The issue of confidence, and whom the general public believes, surfaced, as did the need for someone whom people could have faith in.

'Who are they going to have confidence in, who the average person believes, if there's a complete absence of confidence in any authority, they're not going to believe industry.'

A national agency dealing with this issue was put forward as a preferable approach to having numerous agencies and individual local authorities trying to persuade the public of the benefits and advantages of incineration.

Waste management barriers

The lack of collective responsibility towards waste management came up frequently as a major barrier to progress. This issue manifested itself in many comments about the 'Not In My Back Yard' (NIMBY) and 'Not Over There Either' (NOTE) syndromes, which were generally viewed as an important barrier alongside the general public's lack of understanding or willingness to grapple with the concept that waste is everyone's problem.

'Cultural change is required on a major scale.'

'People want their waste taken away, literally 100 yards and they're not concerned what happens to it after that.'

Lack of public awareness and education were cited as barriers to a required shift in culture towards a collective response to waste as an issue. Industry cited misinformation and disinformation about incineration as a block to adopting alternative options to landfill.

Other barriers included the previous low cost of landfill, which averaged between £3 (€3.81) and £7 (€8.89) per tonne – the increase to £50 (€65.50) or £60 (€76.18) per tonne has acted as a disincentive to exploring other waste management options. The low rates of recovery and recycling in Ireland were also cited as a barrier.

Infrastructural difficulties and delays in both planning and licensing processes coupled with the open participative nature of public consultation were listed as barriers. 'An Bórd Pleanála takes a minimum of eight months to make a decision.' The previous underdeveloped framework, lack of regional plans and historic problem of badly managed landfills were also cited as barriers to progress. One commentator remarked that 'history is a problem' with regard to gaining future credibility for waste management options. A recommendation for more resources and a fast-track system for the planning and appeal process were made.

The possibility that local authorities can engage in 'solo runs' within the framework of regional waste management plans was felt to be problematic. The fact that each authority had equal status and power within the regional plans was felt by a local authority employee to have potential to create integration difficulties if different priorities emerged for different authorities. The absence of sanctioning, in the event of aspects of regional plans remaining unimplemented, was flagged as a barrier to progress, alongside the current lack of resources within authorities to implement their plans. The perceived lack of integration was viewed as a block to progress. In light of this perceived difficulty, different groups recommended the establishment of a national management agency to oversee waste strategy.

'There doesn't seem to be any national co-ordination of it. The Department of the Environment and Local Government doesn't really have much of a hold over the local authorities.'

Legislation itself was viewed as a barrier by one group, which felt that the Waste Management Amendment Act 2001 took decision-making away from people. This same group said that the lack of vision in local authority waste management plans also acted as a barrier.

'The regional waste management plans are boring. They're yesterday's thinking, they're pre-sustainable.'

Some statutory informants felt that vested interests, accountability and culture posed barriers. Lack of political will and leadership loomed large for this grouping, with variations of the view that 'there are no votes in waste' surfacing frequently. Likewise, business felt that local politicians still posed a problem, although the amendment did remove legislative power from councillors. Frustration was evident in this group, which criticised local politicians who did not openly support alternative waste options in their areas as it was seen to have a direct impact on their re-election prospects. It was felt that county managers had a difficult job to implement the plans, as they still had to contend with their political masters.

'No county manager is going to ride rough-shod over the local authority.'

'If the councillors are anti a particular project going ahead in a particular area they can stymie it in various ways and it's very, very difficult.'

The lack of incentives for the private sector to invest surfaced as a political leadership issue.

'The amount of money that it costs you to go through the planning and licensing process-you're talking about a phenomenal amount of money before they see a return for their money.'

Likewise, within the agricultural sphere, lack of leadership on the continued widespread use of fertiliser as the cheapest option was noted. It was felt that leadership should be shown with regard to creating financial incentives to move away from current fertiliser practice.

Impact of landfill on public health

Most contributors stated that, regardless of whether or not landfill or incineration was used, there would be impacts on both public health and the environment if traffic emissions, noise and health and safety were not stringently controlled.

There was a strong view that if properly managed and controlled landfill did not have significant impact on public health. Adequate implementation was seen as the key factor. A concern was raised with regard to illegal landfills and their prospective impact on public health, in particular if they contain toxic and biological waste.

'Very significant illegal landfills that are around the country and we don't know where they are, we don't know what's in them and when we find them we don't know what to do with them, there has to be a plan in place to systematically find them.'

Many interviewees stated that, if improperly managed, leachate, seepage, toxic matters and expired medication could present public health dangers. It was stated that vermin, odours, dust, traffic noise and emissions could also impact on public health. The psychological health of those living near sites might also be affected. In this case the risk of public health might be of a perceived nature but the outcome of this would be real, as in stress.

Emissions to air of dust and volatile organic compounds from landfill gases were mentioned, although this would not be an issue for newer sites that had flares to collect the gas. The potential risk of migration of gas was mentioned frequently. It was the view of one contributor that 'any landfill which produces gases is inherently dangerous'.

The potential for contamination of groundwater with older sites was the most frequently cited concern. It was accepted that newer sites were lined and did not pose this problem.

'The new landfills are so well engineered that it's actually not disposing of waste, it's storing waste.'

'There was far more groundwater health problems from local water schemes....and agriculture than there have been cases of landfill sites.'

There was concern that the fall-out from the illegal dumping in landfill had just begun and would continue for a long time, with subsequent issues for public health.

In the event of inappropriate items being put in landfill, there is the possibility of emissions such as hydrogen sulphide and gypsum sludge.

The danger of hazardous materials going into landfills and creating public health dangers was touched on.

'...the guy at the gate (of a landfill)-pay him a few bob and he will take anything. That is the culture of it.'

Vermin and scavengers were cited frequently and one contributor had concerns about sick seagulls alighting near schools and the risk of contamination for children.

Impact of incineration on public health

Many informants did not feel that the risk to public health from incineration was significant and that if incinerators were properly managed they were a good strategy for waste management.

It was generally accepted that previous inadequate management of incineration sites had led to cases of dioxin emissions but that this had changed now.

'In terms of emissions the standards imposed... are very stringent.'

'The gas cleaning waste, the fly ash and dust from the treatment system, it's a hazardous waste but there are facilities which can handle this and contain it without any impact on human health or the environment.'

'Overall I don't have major problems with incineration. I think the technology is there to operate in a satisfactory manner.'

'...potential risk from fly ash from the flue cleaning products if it isn't handled properly.'

'...more likely to be knocked down by a dustbin car than die of dioxin poisoning.'

'I wouldn't have any concerns certainly on the basis of emissions.'

'I don't feel at the moment that there is any evidence of any major public health issues.'

There was a sense that some of the negative data on incineration was out-of-date and that what was currently going into landfills could cause more harm. Disposing of the residue was considered to be a concern as was the control of air quality and emissions.

Impact of landfill on the environment

Groundwater contamination came up frequently and was felt to cause pollution affecting crops and the environment in general.

'If you get leakage of gas from the landfill site it could kill crops or plants.'

Seepage and leaching of poisons and expired medicines was a danger to the environment. Audit trails were seen as necessary for hospital waste.

Greenhouse gases were also mentioned frequently and the subsequent impact on climate change since this waste is biodegradable and generates methane. It was noted that although the newer landfill sites collect gases, there is still some leakage.

Energy recovery was an issue for some.

'Waste incineration plants generating electricity will only recover about 25% of the energy from the waste...and to maximise the benefit on climate from carbon dioxide emissions you would need to recover waste as well.'

'To maximise the recovery from a climate-change point of view, recovery of heat should take place.'

The consensus was that landfill was carried out 'in every modern nation...the only difference between Ireland and anywhere else is a lot of countries do it an awful lot better than we do'.

The issue of fly-tipping (illegal dumping) near the entrances to landfill sites was acknowledged as un-aesthetic and unfavourable to both the environment and public health.

It was felt that landfills should not be sited in peat bogs or places of outstanding beauty. Another view put forward was that landfills had a potential to 'impact very favourably on the environment' if they are transformed into public amenities after use. It was accepted that there were topographical changes at times with landfills, and that wildlife habitats were interfered with sometimes. It was also mentioned that at the time of this study there were 27 infringement proceedings against Ireland by the EU for breach of environmental directives and that this did not auger well for future controls.

It was felt that taking putrescants out of landfill would obviously minimise risk and control vermin.

Impact of incineration on the environment

It was felt by many of the contributors that if incineration was stringently controlled the impact on the environment would be minimal.

A positive impact on the environment could occur - 'If you're generating electricity using heat from incinerators, you are replacing fossil fuels and the balance between carbon dioxide emissions is favourable.' However it was noted that 'an incinerator needs a landfill or needs a way of recycling incinerator ash' and that needed to be borne in mind.

Incinerators were not felt to be aesthetically very pleasing 'not normally pretty to look at' although 'a box with a stack is not necessary'. There were views that technology had improved the appearance of incinerators and that they could look quite 'futuristic'.

Controlling the mix of waste going into incineration was seen as vital to reducing the levels of dioxins produced.

The risk of the release of heavy metals and dioxins into the environment was felt to be an important danger, with one contributor questioning the ability of the EPA to police this adequately.

'Infringement proceedings are being taken against Ireland at the moment because the EPA refuses to do its job and that, to our mind, is a major problem.'

Information sources

Figure 8.3 maps the network of information flows. The principal generators of information, those organisations who undertake or commission their own primary studies, are boxed. A number of informants commented on the growing impact of the World Wide Web, clearly a route to various and often unintended sources of information. Similarly the impact of the media was mentioned frequently but ambiguously by a large number of the informants. Within individual interviews a dichotomous view was often expressed-something of a love-hate relationship. Organisations expressed distrust of the media as a source of information (though this view was by no means universal), but also said how important it was to use the media as a source for disseminating their own information. Such ambiguity was not shown towards the World Wide Web.

A parallel ambiguity was seen in informants' views of Greenpeace. As a secondary source of scientific literature, Greenpeace was generally viewed very positively, implying considerable respect for the depth of expert knowledge it relied on. As a campaigning organisation, the use to which they put this expert knowledge was viewed with a certain suspicion, particularly, and not surprisingly, by the waste management industry.

With the exception of the ambiguity towards the media, a large measure of trust was demonstrated in the information being provided by other informants, not just those that constituted natural allies. Particular credibility was placed on information produced by the EPA and on peer-reviewed academic and medical literature. Some academics were felt by the waste management industry to have adopted a partisan position.

European organisational networks, often accompanied by European site visits, are clearly influential. Both governmental departments interviewed mentioned the European 'green network' of inter-departmental communication.

Compliance

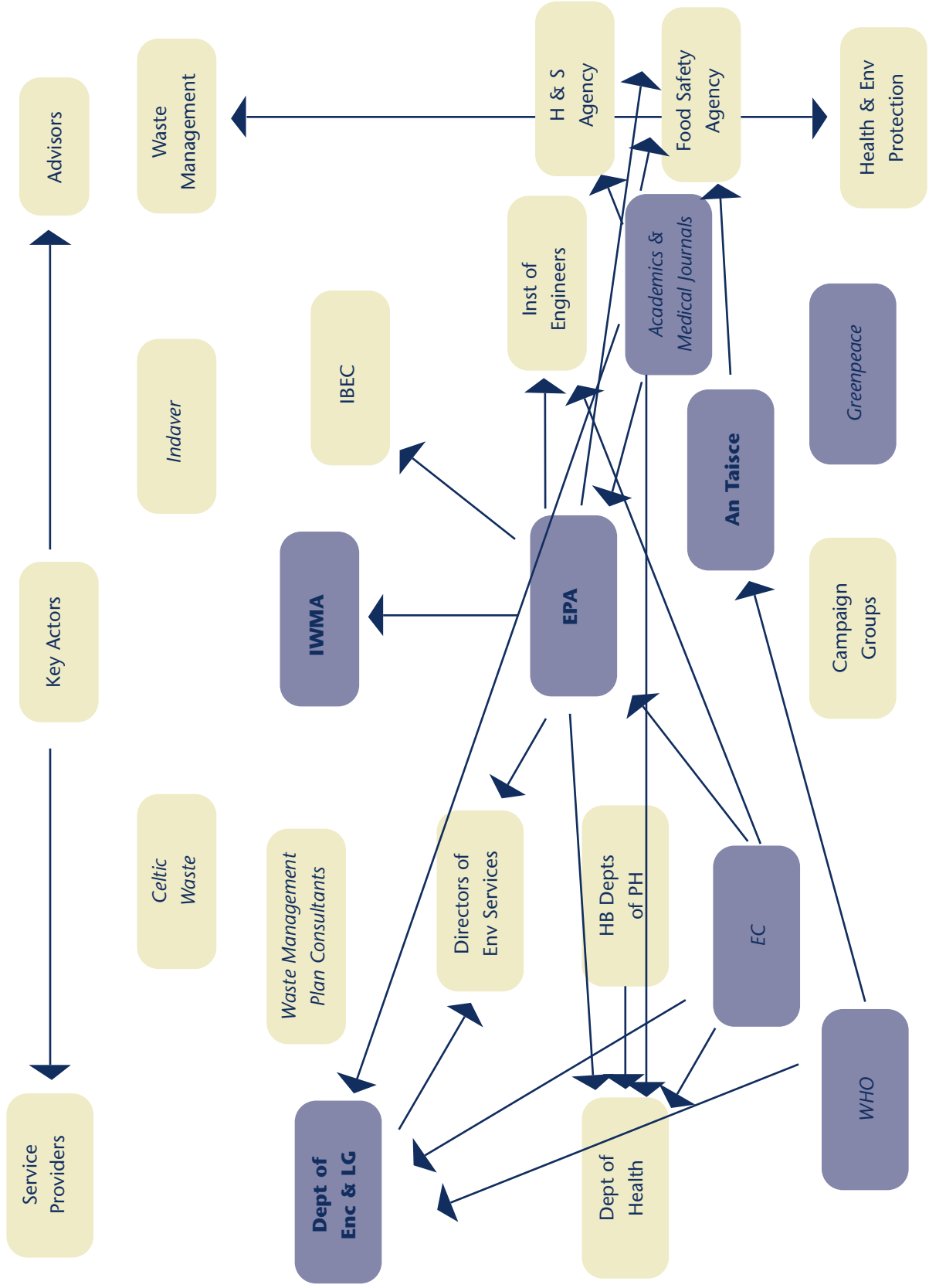
There were some general comments about the Irish non-conformist culture.

'I don't think we are a naturally compliant country.'

'(compliance is) poor but growing.'

'We have a very rigid legislative framework but no policing, no implementation or no enforcement.'

Figure 8.3 Information Flows



'Ireland Incorporated has been hauled over the coals by the EU in respect to non-compliance of environmental legislation.'

The example of the IFA campaigning in the 2002 election against nitrogen regulations, even though it is proven 'without doubt that the main polluter of our rivers and streams is pollution from farms and it has been enforced in every other EU country', was proffered to show how weak the culture of compliance is.

One industry contributor referred to the Drury survey conducted last year in which over 50% of people admitted to littering at one time or other and viewed the compliance level of citizens as 'appalling'. Most non-industry contributors felt the level of compliance with waste regulations was 'appallingly poor', 'weak' or 'improving', while the private sector contributors thought that business compliance was improving.

Enforcement was viewed as vital, with some contributors favouring a more developmental approach as opposed to inspection, while an industry representative thought that the regulations were immature.

'In the sense that getting people to do things that they otherwise would not do is a combination of carrot and stick and they don't know when to use the carrot and they don't know when to use the stick.'

Some contributors felt that the 'willingness (on the part of domestic waste producers) was there; the logistics and the structure is not'. One employee of a multi-national company noted that for years he had brought his domestic waste to work to recycle it and had only received a green bin at his home last week. The capacity of local authorities to supply adequate facilities for domestic users was questioned.

This group felt that compliance, at company level, with waste regulations was improving. 'I feel there's a high level of compliance.' However it was accepted that in the SME sector 'compliance is probably not as high, in some cases, as large factories...small businesses don't have the space...when the skip guy comes they take everything'.

A higher level of support was needed for smaller companies, 'that gap needs to be facilitated', to encourage compliance.

'We are aware through our hotline of waste being collected in certain areas by waste collectors and then being incinerated in the open air.'

The cost implications of complying with and surpassing minimum regulations was thought to be a genuine fear for companies.

That the Waste Management Act 1996 existed was felt to be positive.

'(The Act) pulled it all together. I think it was a very comprehensive piece of legislation, consolidation of the regulations...but in terms of implementation it's another matter.'

'...very modern and good framework legislation, it caters for everything, the enforcement is not particularly good, particularly with local authorities.'

'It (the legislation) covers the whole gamut...a weakness in it is that it doesn't have a central authority.'

The rigidity of the licensing process was seen as a strength by some of the statutory participants, while the private sector was more inclined to view the legislation as 'weak on persuasion', 'as having good aspirations', 'a plethora of regulations', or having some grey areas between then EPA and local authorities in terms of driving and enforcing the law.

The opportunity for industry to submit an amendment to both the EPA and Waste Management Acts was welcomed. However, weaknesses were also noted:

'We don't encourage the people who want to do the right things enough and we don't discourage the absolute scoundrel who undermines confidence in the system, we don't punish them enough.'

'At the end of the day there are clearly people who have behaved with absolute recklessness...are they going to be in jail?'

'Local authorities are going to have to take this a lot more seriously.'

'I question the position of importance it's given by the local authorities because it can vary from authority to authority, nationally and locally.'

'Even local authorities themselves are not compliant with the regulations they have been found to be dumping illegally.'

'They (local authorities) are aware of dumps but they've also hired a lot of those illegal contractors to dump their material illegally.'

'The local authorities are only now starting to clamp down on illegal dumping.'

'...lack of co-ordination between the government agencies and it's as if the EPA and the local authorities do not talk to each other.'

Unnecessary bureaucracy, lack of standardised procedures, duplication of form filling for waste collection permits for different counties, and delays were viewed as negative aspects of the compliance issue. It was felt that if there was a stepped approach to planning, collection and licensing deadlines this would prevent some of the bureaucratic problems.

The complex position of local authorities, from a competition perspective, in relation to being both providers of disposal facilities and responsible for collection of waste, was commented on.

'Basically it's a closed market, they're in a dominant position and it's statutory... and it's written into the Waste Management Act and I think that should really be reviewed.'

The fact that 'there's no authority responsible for the provision of (waste) infrastructure for business, industry and commerce' was viewed as a negative aspect of the legislation 'and there is no way around the legislation and the legislation can be quite onerous'.

The delay between the WMA being enacted and all regulations being finalised, towards the end of 2001, was viewed negatively.

'It's only since November 2001, which is two months ago, that you actually had the loophole in the Waste Management Act tied up...prior to that anyone could have gone in there with a truck and started collecting waste without a permit.'

The maximum district court fine of €1,900 was thought by a majority of participants to be insufficient to deter would-be dumpers.

'What's a grand and a half when you can make up to £80,000 (€101,579) a week?'

'The legislation is all there but the enforcement is very bad.'

The low number of indictments was seen to be disappointing, but there was an understanding that a higher level of proof was required to secure an indictment, which took time, money and diverted staff from other necessary functions.

One contributor felt that society had not paid enough attention to the issue: 'If society puts a low value on something then the courts do too, the courts are only composed of people out of society.'

In terms of its roles as both regulator and policy maker, the government was seen to be acting inconsistently. It was criticised for not using environmentally friendly products itself within its various departments. Unbleached paper was given as an example.

The gap between the DoELG and local authorities in relation to monitoring compliance was seen as a problem; having 'one large agency working to make sure this enforcement happens instead of the patchy regional (approach)' was proposed.

'A weakness in it is that it doesn't have a central authority. I think that's a huge weakness in the legislation because if nothing else it would give focus to it, it would give a priority to it. It should be an agency that would focus on that and nothing else.'

The EPA was not viewed as having a high profile, which was felt to have a negative effect on compliance. Both the agency's staff turnover and its high levels of bureaucracy were viewed by industry as having a negative effect on compliance.

'I don't see them as having and commanding the sort of respect and showing the sort of leadership. Where are they in this debate?'

'They're afraid to take the initiative to make decisions, they're always referring back to guidelines and rule books and waiting for somebody higher up.'

'We are aware that 94,000 tonnes of hazardous waste has gone missing recently. The EPA has not been effective in tracking it down even though through their documentation alone they are aware of when it goes missing. The documentation is designed to track this material and if the EPA was effective they could track this down.'

'Their (the EPA) performance is not good, according to the EU, that's the weakness of it; they are not living up to their role; if they don't have adequate resources they should say so publicly, it is their responsibility to say so publicly.'

'They (the EPA) should be investigating these things at the sources, they're not investigating the sources, they're investigating the receivers of the pollution.'

In the case of EPA licences, it was generally felt that compliance was higher. Measuring compliance with packaging regulations was thought to be difficult to monitor and measure. There was a sense that litter laws and waste charges were not being enforced.

Compliance with regulations was felt to be the base line for most companies as they had profit margins to focus on, although 'there's a huge sense of good practice'. 'Industry clearly wants to be part of the solution ultimately because it needs to.' Inward investment or multi-national companies were thought to be more likely to have a better compliance culture than indigenous businesses 'they bring it with them from a jurisdiction that's far more careful about these things than we are'.

From an agricultural perspective, the view was that regulations were poorly implemented and that local authorities were under-resourced to assist farmers to comply. It was felt that the implementation was an important element of conditioning farmers' attitudes. The nitrate directive, was seen to have been implemented seven years 'too late'. There was a view that farmers' compliance was linked strongly to better awareness and education – that they may not understand that manure-spreading at particular times was wrong. Insufficient slurry storage was felt to cause farmers to infringe regulations as they were often faced with the choice of spreading manure or letting it overflow into nearby water courses.

Long-term investment options – landfill or incineration

Incineration was viewed as the more expensive and more risky option to invest in, with some contributors suggesting that an integrated approach was preferable, where all options were investigated.

'I think there would be more risk with landfill than incineration believe it or not now, given the hierarchy, the level of importance that it is on the EU chain on the long term.'

'It's easier to develop a land site, well it's not easy but it's easier. An incinerator gives you a waste solution for 25 years, a landfill gives normally less than ten.'

'I would say landfill would be short-term, good return minimal investment...all you need is a bit of land.'

A comparison was made to Eastern Europe, and in particular to Poland and Czechoslovakia, where infrastructure is being developed. It was felt that these countries could prove more attractive for inward investors than Ireland, because efforts are being made to tackle waste management in an integrated manner.

Communication

There was unanimous agreement that the general public need to be informed as much as possible with regard to waste management options, risks, information and so on. There was also strong agreement that the public was not adequately informed on waste issues. An environmental survey was conducted by an urban local authority two years ago. Waste was ranked seventh or eighth below genetically modified food.

'The more you inform people the more likely that the solutions are going to come back. Everyone has a view and people might as well know what the issues are.'

The challenge was seen as 'building people's confidence, it's not building their data bank', and also finding the right person to get the message across.

'Because it doesn't matter what the facts are. If they inherently do not believe and have no confidence in the person who is telling them, then your message carries nothing whatsoever.'

Winning the hearts and minds of people was seen as critical.

'Open communication, credibility, starting on small projects showing that they have been properly planned, implemented and licensed, building a level of trust...showing the plans and clearly then deliver on that plan.'

'I think it's actually a leadership thing, when you talk about communicating with the general public you can talk about it in a derisory manner that they need to be educated to understand that I'm right, it can be very patronising.'

Communicating with the public was felt by one contributor to take 'an incredible amount of skill'. The example of the European Food Safety Agency was mentioned where they 'separated the sciences from the communication'. They are going to engage in risk assessment whereas 'the risk management will be in the hands of the EU Commission'.

'This is where you have the art and the science of public health and it is an art. Also honesty and empathy to see where people are.'

It was noted that public health specialists at health board level are no longer as involved as they once were.

'They are key people...they were much in the loop up to about ten years ago. There was a very strong relationship between the county manager and the directors of public health...and that seems to be lost.'

There was a strong recommendation that there should be closer working relationships between local authorities and public health staff in health boards. The case was given that, if a local authority issues a boiled water notice, the Director of Public Health 'gets no official notification'.

Cost was also felt to be an issue for certain cohorts of society, such as old age pensioners or social welfare recipients, for whom waste charges would make an inroad into their limited income.

'But they would say, "Well alright, I can take out the cardboard and I'll burn it out the back", so we have 100 million private incinerators but we can't have one general one.'

'I think there is a job to be done informing people that it's everybody's responsibility but also in providing choices for people.'

Contributors felt that educating children in schools was an important aspect of effective communication with the public.

The anti-incineration and anti-landfill lobby was viewed negatively by industry who felt that 'they're actually stalling the whole waste management process'.

Training programmes for farmers such as REPS were mentioned as a positive vehicle through which to communicate with the farming community. Knowledge and incentives were thought to be required to ensure that the topic was given adequate priority.

Individual organisations interviewed spelt out their current activities, their intentions and, in some cases, their aspirations, in respect to the communication of issues concerning waste disposal.

Monitoring and evaluation

Most of those interviewed did not have formal monitoring and evaluation systems to measure their communication effectiveness, although they thought this would be a good idea. Methods in use varied from informal review, to small-scale surveys, to quantifying responses and interaction resulting from initiatives.

Results for the environmental health officers

Description of informants

Details on Environmental Health Officers were obtained from the Environmental Health Officers Yearbook for 2001. This contains a list of 41 Principal Environmental Health Officers (PEHOs) in the Republic of Ireland. Thirty-eight PEHOs contained in this document were emailed and asked to take part in a semi-structured telephone interview on waste management. The email contained details of the topics to be covered. The order in which PEHOs were telephoned was alphabetical, by surname.

Of those PEHOs who were contactable, twelve were interviewed during the study period. This represented a response rate of 30%. The health authority location of the respondents was as follows:

Area Health Authority	N
Southern Health Board	1
Western Health Board	2
South Eastern Health Board	2
North Eastern Health Board	1
Mid Western Health Board	1
Eastern Regional Health Authority	5

Organisational mapping

All PEHOs reported peripheral involvement in waste management.

All PEHOs reported this involvement as relating complaints or referrals concerning poor waste management practice and general nuisance legislation issues. Fly tipping, pest control, noise pollution and odour problems were the most commonly received complaints.

Four PEHOs reported groundwater pollution incidents from local communities and requests from local authorities for advice on health concerns.

All but one PEHO reported some involvement in the planning process for waste disposal sites. All of these PEHOs perceived this involvement as having little direct influence on waste management practice.

All PEHOs expressed a view that, with suitable resources and enabling legislation, Environmental Health Officers should become more involved in waste management. All PEHOs saw this as beneficial to the practice of waste management.

All PEHOs saw a role in the following areas:

- Enforcing recommended standards and practices at waste disposal sites.
- Education and awareness programmes at local community levels.
- Waste minimisation and recycling initiatives at local community levels.
- Greater influence at the planning stage.

A majority of PEHOs saw an increasing role in formulating national and local waste management strategies as beneficial.

Half the PEHOs were of the opinion that health boards should become more involved through risk management initiatives such as Health Impact Assessments and Local or National Environmental Health Action plans.

Waste management in Ireland – general concerns and challenges

Four distinct areas of current waste management concern and challenge were reported by all Principal Environmental Health Officers (PEHOs):

- A scarcity of suitable sites.
- Well-organised opposition by local pressure and lobby groups.
- A reluctance to engage in waste minimisation/recycling other than on a small scale.
- Historical experience by local communities of poor waste management practice.

' Heretofore anything and everything went into landfill.'

'The NIMBY syndrome is out there.'

'The general public have had negative experiences in the past.'

'The only opinion out there is that they don't want dumps near them.'

Impact of landfill and incineration

All PEHOs were well informed as to current scientific theories. All PEHOs were of the opinion that landfill and incineration were acceptable and safe technologies. A small minority of PEHOs questioned the role of incineration as a necessary waste-management option.

'Can we trust in the management of these sites?'

Information sources

Three distinct areas emerged as credible sources of information:

- Educational background to a minimum degree level or equivalent.
- Scientific literature and professional journals.
- The Internet.

Other sources quoted by a minority of PEHOs included the media and first-hand experience of waste disposal sites.

Communication

All PEHOs thought local communities were not well informed as to the scientific issues involved in waste management.

The majority of PEHOs thought the general public was genuinely concerned about health risks from waste management.

A minority of PEHOs considered genuine health concerns were combined with or masked by financial concerns of waste management sites. Property price concerns were cited by this group as being a factor in local community opposition.

The majority of PEHOs cited local environmental pressure groups and the media as being the main information sources for the general public.

Almost all PEHOs reported that local communities did not trust the local authorities, the EPA, or central government information sources or officials on waste management issues.

These PEHOs cited the poor control of waste management in the past as being a main reason for this scepticism.

'The vast majority are not informed about what has happened or what is about to happen.'

'There are genuine concerns (among the community) about the health implications of waste disposal due to a lack of information.'

'Waste management has now turned into a trust issue. They (the local community) don't trust anymore.'

'There are very negative views of landfill due to poor past management.'

'There are a lot of misconceptions out there, like super dumps are full of rats and cause nuisance.'

'People are not well advised on how well landfill sites can be managed. I've received little complaint from well-run sites.'

Improvements

A number of key initiatives were cited by the majority of PEHOs in implementing improved waste management strategies.

- Convincing local communities that central and local government authorities could manage waste disposal sites without causing any nuisance or detriment.
- Providing more recycling facilities. Half the PEHOs considered the use of financial incentives to be necessary to begin recycling on an influential scale.
- Improving the level of information on the scientific issues and the planning process at local community level.
- Implementing local environmental initiatives aimed at waste minimisation and recycling.
- Implementing local awareness and education campaigns on the whole issue of waste management.
- Overcoming local elected representative and lobby group opposition to proposed waste management sites.
- Presenting transparent and inclusive waste management strategies at local and national levels.

Two PEHOs suggested that local community pressure groups should be taken to well managed landfill sites in Ireland.

Results for the general public

Description of informants

Four focus groups were held with members of the public living near existing or planned waste-management sites. Two were held in Dublin (Blanchardstown and Ballyogan), one was held in Drogheda and one was held in Cork. In total, 17 people attended. Blanchardstown/Mulhuddart was selected because of its proximity to a hazardous waste incinerator site. This site has been in operation for many years. Drogheda was selected because of its close proximity to waste sites and because it was felt that there was a history of awareness and concern about a number of environmental issues (such as Sellafield and incineration) in the area. The third focus group was conducted in the vicinity of an existing municipal landfill site in Ballyogan. The final focus group location was selected because of its proximity to a proposed mixed municipal and hazardous waste incinerator in Ringaskiddy, Co Cork.

The method of recruiting for the focus groups developed throughout the project. For the first group, hand-delivered letters were sent to a selection of residents in a housing estate next to an incinerator informing them of the study and asking them to participate and to phone a central number to receive details of the focus group meeting. When no one responded, one of the investigators visited each of these houses to actively recruit participants. However, on the evening of the focus group, only one individual attended. As the meeting was held in a public library, the researchers recruited four people who took part in the discussion. As this was not considered an effective and economic use of time and resources, a different method was applied to the other focus groups. Recruitment for the second group was carried out in an opportunistic manner, asking members of the general public to attend a meeting off-the-street in a town-centre hotel. Four participants attended this group. The third and fourth focus groups were organised with the assistance of local groups in recruiting people. There were five participants in the third and four participants in the fourth focus group. Some participants in the latter two groups were also members of special interest groups.

The difficulty in recruiting people to the first two groups can be explained. The first group was in the Blanchardstown/Mulhuddart area where an incinerator has existed for a number of years. The occupants of a housing estate close to the incinerator were targeted for the focus group but the response was exceptionally poor. Possible reasons for this are that the incinerator was located in an industrial area, it existed there for a long time and there were reportedly very good relations between the company and the local community. This could mean that the incinerator is no longer a cause of concern and that, over time, a degree of accommodation had been established. This hypothesis, though, would require more exhaustive investigation.

The second focus group was held in Drogheda. This location was largely selected for convenience. It does not have a waste disposal facility but it was thought that the public there would have an interest in the topic, given their location with regard to Sellafield. However, a priori, waste management did not appear to be an issue of importance to the residents. This might suggest a relative apathy of the general public who do not have an existing or planned facility in their immediate area. Though again this hypothesis would require more exhaustive investigation.

Waste Management in Ireland – general concerns and challenges

The people who attended the focus groups agreed that waste is a serious issue, it is a problematic one and it is one that is not going to go away. The main problems that were outlined during the focus groups were:

- Landfills are filling up and we are fast running out of places to dump rubbish.
- Incineration is a somewhat unpalatable option, as it is associated with risks to health and property values.
- Ireland has very limited recycling facilities and Irish people generally are not good at reducing or recycling their waste.
- People felt that Irish society has become a 'disposable' one and our current healthy economic situation has created a 'throwaway' society. It is cheaper and easier to throw out old things and replace them rather than keep and repair them. As a nation, we are not very tidy people, we dump everything.

'I think we could learn a lot from Australia. If the people of Australia can be so afraid to misbehave as far as their environment is concerned and protection of Australia, why we can't do the same thing ourselves? Its because we are a race that just dumps everything. We behave in the most outrageous manner in so many things. Waste is just another further extension.'

'I think the reason we behave like that is because we are allowed to. Its just like on the roads, we are allowed to do as we please on the road. You can drink and drive, you can break the lights, you can do as you please. You won't do that in countries where the law comes down on top of you.'

There was a feeling that Ireland is not geared towards efficient waste management or recycling. There was a belief that Irish people are very complacent about waste disposal and recycling, particularly when compared with other European countries, with America or with Australia. Informants maintained that the reason for this is the perceived lack of governmental interest in finding workable solutions to a problem that has been festering for years. This results in apathy and lack of concern at individual level. They believed that if the institutions at the top were seen to show an interest and make efforts to initiate changes, then individuals would respond and alter their habits and practices.

Informants felt that, on the ground, many people are aware of the problem, they are interested in it, they would like to be better informed about waste management, incineration, recycling, waste reduction, and they would like to have facilities that help them work towards a solution.

Contributors who had met with official planners, engineers, local authority or county council workers in connection with existing or proposed landfill sites or proposed incinerators reported negative reactions. Members of the public felt these representatives to be 'dismissive', 'rude', 'intimidating' and 'threatening'. They also felt that the officials used technical language or jargon and gave contradictory or misleading information to confuse the public. People felt that their complaints were not taken seriously.

People were aware that Ireland currently exports hazardous waste to other countries. Contributors felt that this cannot persist and that we will be forced to deal with our own waste problem.

Responsibility for waste management

Contributors knew that the local authorities or county councils are responsible for waste management. However, there was a strong body of opinion that more initiative should be taken at governmental level to make a serious attempt to reduce the amount of waste being generated and to raise people's awareness about the problem.

'I think it is a job for the local authority. I think the national governments have to lay down the parameters within which the local authorities have to operate. And the legislation within which they operate. There is always the danger with local authorities that they are not going to make the harder decisions, the selected politicians within the local authorities aren't going to make the hard decisions that are going to have to be made at some stage.'

There was an acceptance that waste is ultimately a matter of concern for all citizens and that responsibility lies with each individual.

'Ultimately, waste is our individual responsibility.'

However, there was a feeling that proper facilities should be provided and that attention should be drawn to the problem of waste management, including recycling, from the top down.

'I think it's a national responsibility. I would imagine that Fingal's hands are tied in some respects. I would imagine it should come from the government down. Waste has always been the responsibility of the local councils across the whole country and the same in all other countries; they look after their own local area. The government can't get involved at that level. All they can do is introduce initiatives and public awareness. But it can't be involved in working out where your waste is going to go.'

Household waste management

Those who attended the focus groups were conscious of how much rubbish they throw out. However, some found it impossible to avoid, given the amount of packaging on products. The lack of recycling facilities for newspaper and plastic contribute to this problem.

'When you go shopping, it amazes me. If you buy a package of biscuits, they may be in little separate cartons and it's inside another package and when you buy it in the shop they put it in a bag. So you are getting a few biscuits and a huge amount of rubbish. What you're bring in, in your shopping alone constitutes a huge amount of rubbish.'

'What amazes me is newspapers in this country, some people on Sundays buy four papers. That is a phenomenal amount of paper, and what do you do with them? There is very few places you can recycle them.'

'I think the worst invention of all time from the point of view of waste was the plastic bags, and plastic sheeting, everything plastic. I often wonder how did we manage before. There was a time when we had no such thing as plastic. I think plastic should be burnt whatever way they can burn it and melt it down and get rid of it. Plastic should be collected separately and destroyed.'

Those who have received new wheelie-bins welcome them, and find them more practical and more manageable than the traditional bin. Those who have new green bins for recyclable materials such as paper and packaging thought these are a good idea, although some people found a number of different bins difficult to store in their houses or gardens, particularly if living in a terraced house. One suggestion for improvement was to have one bin with different 'drawers'.

Those who attended the focus groups accepted paying for waste disposal. The general feeling was that people did not mind paying to have their rubbish removed. However, a reduction for pensioners was thought necessary. Having to pay for plastic bags was generally welcomed.

'I think the new directive on plastic bags will be very helpful. Any time you buy anything in the supermarket you can come out with a half dozen bags. Even if you go into a local newsagents to buy a paper you are given a bag, irrespective of whether you ask for it or not. If it's 15 cent each then people will think and bring their own bags.'

Waste management options

Contributors agreed that landfills do not provide the solution to the problem of waste. Informants were aware that landfill sites are filling up and that we are running out of places to dump rubbish.

They acknowledged that no one wants landfill sites located beside them. One person wondered why the practice of using waste to tackle erosion of the coastline was discontinued.

'In years gone past, there was a landfill idea, not so much a landfill in the centre of the country but at the shore, on the coastline, where the sea was ebbing away at the coastline. That was where the rubbish was dumped and it was extending the land. And I don't know why they stopped doing that. It wasn't taking up any space.'

Many people's instinctive reaction to incinerators was negative. However, some cited incinerators as the only solution. Many contributors accepted that, in theory, incinerators solve the problem of how to dispose of waste, particularly hazardous waste. The general feeling was that the lack of information was a difficulty, while one informant thought the difficulty was that the information available to date has been one-sided.

'Like every other thing in industry, technology has evolved, and the whole art of incineration has reached a certain stage now. And those that are being closed down are probably ones that are old and need to be closed down. ...I think it has to be said that everybody here today feels there is no alternative to incineration. It's because we have an existing hazardous waste problem, and the only known way of disposing of it at the moment is through incineration. If there were other solutions available we would like to hear about it.'

Those who advocate incineration as a method of getting rid of waste do so on the basis that it is the best solution we have so far, as landfill is no longer a viable option. However, they insist that incineration will have to be accompanied by huge improvements in the levels of waste reduction and recycling, as we should aim to burn only the minimum of materials.

'We cannot ignore incineration or thermal treatment. It is there and has to be used as part of the ultimate solution. That is it, we have to face reality. There is no point in saying we can have 60% recycling in the next five years, fine if we could, great, but I would doubt it. But what is going to happen to the other 40%? So it's fine to say that this area or country has been able to achieve great levels of recycling and so forth, but the other 40% is the one that you have to cater for. And it's totally wrong for people to say that incineration doesn't work, because it is happily working in quite a large number of European countries.'

Recycling was considered by all to be very important. However, it was felt that Irish people were very tolerant of non-recycling patterns. Two primary problems were identified:

- There is a lack of information and education about recycling. If people knew more about methods of recycling they probably would do it.
- There is a lack of recycling facilities. People have to go out of their way to bring bottles to bottle banks and recyclable materials to the small number of new 'Bring Centres' that have been set up. While informants welcomed these initiatives, they felt they are just the beginning and a lot of work has yet to be done. They believe that responsibility for this is at government level and that, when the proper facilities are put in place, individuals will react.

There were some inventive suggestions for further recycling at facilities; for example, a shop or warehouse at landfill sites where salvageable items could be resold, or a link with art colleges to collect broken tiles for mosaics. The government was called on to examine and implement the Eco-Waste programme being pursued in other European countries.

It was felt that waste management facilities should ideally be placed in industrial areas.

Effects of landfill and incinerators

Whether they are landfills or incinerators, most people do not want such waste disposals located near them. There is a strong 'Not In My Back Yard' attitude towards these structures. In many cases, this 'NIMBY' attitude is based on real experiences of hazardous health conditions, negative effects on lifestyles and houses being devalued.

Those living near existing landfill sites object to bad smells, heavy traffic in the area, dirt, flies, vermin, poor safety conditions, and particularly the risks it imposed on their health. The possible health effects mentioned by informants were: birth defects, asthma in children, sinus problems, headaches, pains and stiffness in joints, tiredness, regular illness in children and cancer risks. Other concerns mentioned were the stability of the sites, leachate, methane gas, broken monitoring wells and the lack of covers on shores and fire ponds. The lack of response received to emergency telephone calls has not facilitated the lessening of public concern.

However, most informants agreed that they do not know enough about the incineration process and they felt that there were health risks associated with burning waste.

'There is always fear of the unknown, to start, and then ignorance creates a lot of fear. Things you are not well up on, you worry about it.'

The need constantly to monitor and to inform the public about this process and its results was thought essential.

'People will have confidence in any sort of monitoring activity. The monitoring is really what is important.'

Contributors stressed that the public needed reassurance about the impact of waste management alternatives on their health and the environment. They also needed guarantees that facilities would be managed and maintained properly.

Information and education

The lack of reliable information available to the public was a concern. The confusion caused by inconsistent reports was also raised. Those who attended the focus groups were aware of waste as an issue in the media, although some admitted that they did not follow it very closely. Contributors felt that some information was available from the media, particularly local newspapers and local radio stations.

Contributors felt that impartial, comprehensive advice and information was needed.

'I think there is also the difficulty that people are not going to believe a lot of scientists anyway. Because too many of them are employed by major companies and they would come up with the answers to suit those companies rather than the people. Even if they were independent, you would also want to make sure their research isn't funded by these companies. I am sure if you look at scientists who are funded by the British Nuclear Research and scientists who are funded by Greenpeace, they will come up with different results from the same research. So I think that is part of the problem. So who can we believe?'

'It would be very nice that without saying for or against, if the EPA and the local authority dealt with all those relevant issues and fears and either knocked them off or explained them. That would be very good.'

'They don't want to be told by politicians that it's safe, they want to hear it from the scientists.'

'Anybody who is going to making a load of money is not going to be objective anyway.'

Informants acknowledged that children are learning about recycling in schools and they felt that this is the best time to make young people aware of the problem. However, children imitate adults and complacency soon sets in. If we want attitudes to change in the longer term, we have to set an example.

'Children litter because they see adults doing that... Adults give the bad example to children. Adults must behave properly and then pass that on to children. It won't work the other way. I have never seen any adult taking example from a child.'

The need for Local Area Charters was raised. It was suggested that these would include sections on respect, health and safety, emergency response procedures, the power structure of planning, independent reports and monitoring.

Submissions received

An invitation to submit comments regarding waste management in Ireland was published in *The Irish Independent* and *The Irish Times* (See Appendix D) on 24 January, 2002.

Description of informants

Eleven submissions were received: six from members of the general public (some of whom were also members of special interest groups), one from a senior environmental health officer in a regional health board, one from a German Professor of Food Chemistry and Environmental Toxicology, one from Indaver Ireland, one from Celtic Wastes and one from the group 'Irish Doctors for the Environment'. The originators of submissions from the general public were: a member of the Ballaghaderen Action group who is living near an existing landfill site; two people living near proposed incinerator sites; one 'concerned parent, citizen and consumer'; a member of the Togher Action Against Dumping Group living near an asbestos contaminated landfill site, and a member of the Louth People Against Incineration Action Group.

Landfills

The effects of landfills are a concern to the general public, with one submission explaining that the nearby landfill had 'ruined our lives completely'. The problems listed were toxins, fumes, smells, vermin, flies, polluted waterways and decreased land and property values. The recent 'tidying' of sites was appreciated but the call to close sites remains.

Another contributor included a number of letters of complaint sent to the European Commission regarding the 'toxic landfill and hazardous asbestos sites at Boycetown and Simontown', Co Louth.

The illegal dumping of hundreds of tonnes of waste and the lack of resultant prosecution was condemned. The submission called for the permanent decommissioning of both sites 'in view of a number of our community's recent illness which has created much fear locally'.

Incinerators

Four submissions particularly focused on the issue of incinerators. One contributor who visited two plants-Ivago in Ghent and Indaver in Beveren - compared them to the planned site at Carranstown, Duleek, Co Meath. The location and/or size of the plants were not similar to the site planned in Duleek and hence direct comparison was felt inappropriate. Of particular concern was the information received on one of these visits that there was 'no control of what type of rubbish was going into the incinerator'. The location of an incinerator within 100 metres of housing was considered unacceptable. The smell and the traffic were causes of concern. The submission contained a letter copied to Indaver Ireland, the company who have applied to build the incinerator, urging the company not to 'destroy our countryside with poisonous substances such as mercury, cadmium, heavy metals etc.' In addition, this letter sought 'a written guarantee that our health will not be affected should your incinerator be located in our area, prior to construction'.

Another contributor expressed concern about the siting of a proposed incinerator near the family home. A high proportion of 'damaged babies' in Co Wicklow was reported. The following was stated:

'There appear to be gaps as to who is empowered to be responsible for human health in connection with licensed industrial emissions. I would suggest that no further licences for incinerators or any other industrial emissions should be granted until this problem is resolved. I would also suggest that any reports of local clusters of sickness be taken seriously and fully investigated and not glossed over in any way....'

Another contributor provided detailed evidence of toxicology assessments, which show that the emissions of 'highly toxic pollutants' are extremely low from modern incinerators. A health risk from incinerators was denied, with the contributor stating that 'no scientifically sound epidemiological studies have shown any causal relationship between a modern municipal waste incinerator and health problems in the vicinity'.

However, other submissions provided evidence that disagreed with this. A detailed discussion of the issues relating to the health affects of incinerators and surveillance systems was included in one of the submissions.

'Only a limited number of studies have been carried out to determine whether individuals living near incinerators have been exposed to pollutants, and these have been limited to heavy metals and dioxins. Furthermore, as some of the emissions from incinerators are persistent and bioaccumulative, there may be a long latency period before any adverse health effects are found. We would have concerns that our present health surveillance systems are not sensitive or developed adequately to detect such events. Although it is stated that there will be low levels of dioxins in the emissions to air, this will reflect only what is inhaled. However, these compounds will also be absorbed from the skin, and from foods, often grown elsewhere, thus increasing overall exposure. With reference to dioxins again, current regulations only consider chlorinated dioxins. Mixed chloro and bromo varieties are also released from incinerators in appreciable quantities and appear to have equal toxicological significance.'

One submission included a letter from the EU Environment Commissioner, which stressed that 'incinerators are not the answer to waste management Incinerators only reduce the volume of waste but the environmental impact of incineration is significant.' This letter also points out that 'incineration plants which operate in the full respect of air and water emission requirements are extremely expensive'. The same contributor quoted the Head of EU Waste Management, who stated that incinerators need enormous input in order to be economic and that in many countries they are now considered similar to nuclear power stations and should be avoided:

'The Commission does not support incineration. We do not consider this technique is favourable to the environment or that it is necessary to ensure a stable supply of waste for promoting combustion over the long term. Such a strategy would only slow innovation. We should be promoting prevention and recycling above all. Those countries who are in the process of drafting their planning should not base it upon incineration.'

The following statement in a recent Greenpeace press release was also stressed:

'Incineration will never play a major role in truly sustainable waste management, the health effects which result from an incinerator's emissions are not yet fully known.'

One contributor listed objections to incinerators on a number of levels:

- The Proximity Principle – close to housing, the logistics of transport.
- The Equity Principle – each community should look after its own waste.
- The Precautionary Principle – the effect of emissions may be felt immediately or over generations.
- The Polluter Pays Principle – polluters would be the incinerator companies whereas the payers would be communities where these operate.

This submission from a member of the public also listed in detail the effects of incinerators on environment and health, as shown in a number of papers and studies.

One contributor wrote to inform the investigators that their organisation would not be sending a submission. Among the reasons provided were the following statements:

'Terms of reference of the report are too narrow...and do not include exploring safe alternatives of waste reduction, reuse and repair.'

It was also stated that the study 'conveys the impression that there are only two options, incineration and landfill. The zero-waste option should be explored if the study is to have any credibility. Use of this option would avoid the dangerous effects associated with incineration.'

'The terms of reference convey the false impression that incineration dispenses with the need for landfill.'

'The group are fearful that the health study is a mere cosmetic exercise to justify the introduction of incineration, as a tool of waste management.'

It was also noted that 'although requested by the European Environmental Bureau, there is no requirement for health related surveillance of incinerators'.

One submission, although welcoming the research into waste management at a national level, stated that the time-scale for conducting the research was too short.

Waste management options

Two submissions explicitly discussed options for waste management. One stated that the ultimate goal of any local authority should be waste avoidance, recognised by the Community Strategy for Waste Management (COM 96(399) and by the European Parliament Resolution (A4-0364/96). This strategy is based on a 'hierarchy' of waste management principles-prevention, minimisation, reuse, recycling, incineration and landfill.

Another contributor called for the adoption of a 'Zero Waste' principle, effective in a number of countries. The US/Canadian 'Citizen's Agenda for Zero Waste' was suggested for extrapolation to Ireland. The success in Renmore, Co Galway, where 56% of household waste has already been diverted from landfill, was noted.

One submission highlighted the value of a 'clean, green image' and referred to the findings of a study conducted in New Zealand, which concluded 'environmental image is a substantial driver of the value New Zealand can derive for goods and services in the international market place'.

The lack of recycling centres in some towns was condemned and the government was accused of 'jumping straight to the least favoured options' of waste management. The 'illogicality of present and proposed Irish waste-management' was discussed in one submission which noted that 'materials that are perfectly good to be reused or recycled when they are retrieved selectively at the point of generation, are pulped into an inseparable mish-mash of 'waste' that then needs to be disposed of with all the inherent risks, costs and consequences'.

Responsibility

One contributor felt the health boards should have a statutory role in the regulatory monitoring of waste sites. The boards have the technical resources to provide this service.

'Legal provision should require local authorities to take on health board environmental assertions regarding proposals for landfill and incineration of waste.'

It was also expressed that 'better co-ordination of the regulatory authorities in terms of environmental control' was needed in order 'to provide an effective, seamless service and to utilise our resources efficiently'.

Summary and conclusions

Focus groups and semi-structured interviews were conducted with representatives of service providers, industry, environmental health officers and the general public. Submissions were also invited through an advertisement in the national press.

Either as representatives of their constituent group, or in an individual capacity, all informants were agreed that waste management in Ireland is currently facing a crisis. The precise nature of this crisis varied depending on the perceptions of the informant.

There was virtual unanimity that landfill no longer offered a medium- to long-term solution; but there was disagreement as to the acceptability of incineration as a replacement means of waste management. Members of the public favoured greater use of recycling and the introduction of measures to reduce the amounts of waste generated, but it was the 'professional view' that such measures would have only a marginal impact in the medium term, requiring maintenance of substantial waste disposal capacity for the time being. They tended to favour incineration as the option for this, and saw the major challenge as increasing its acceptability to the general public.

At the root of this divergence lies a significant difference in view in respect of the environmental and health hazards of the respective options for waste disposal, the capability of existing structures and institutions to 'police' compliance with the regulation of waste disposal and the likelihood of achieving significant change in public attitudes towards waste generation and waste disposal.

Informants' perceptions of health and environmental impacts were very general in nature, and it was difficult to draw out any distinction by informants of impacts that were 'health-related' and impacts that were 'environmental' in nature. In respect of landfill, venting and potential leakage of gases, pests and water contamination were identified as health hazards. In respect of incineration, emissions of dioxins and disposal of waste ash were similarly mentioned. In general, informants showed little detailed knowledge of epidemiological relationships. Specific health impacts were either unknown or un-stated, except in one detailed submission. Informants frequently commented critically on the absence of local studies. There was a tendency from the representatives of the waste management industry to equate this absence of local knowledge with an absence of impact.

The perception of the general public was that incineration was 'unpalatable'. In contrast, informants from the industrial and commercial sector tended to demonstrate a strong belief in the current state of incineration technology as a safeguard against health impact. This view was generally dependent on a rider concerning the quality of management. It was the view of service providers that the poor public perception of landfill and the consequent suspicion of incineration had their origins in the historically poor management of waste disposal sites.

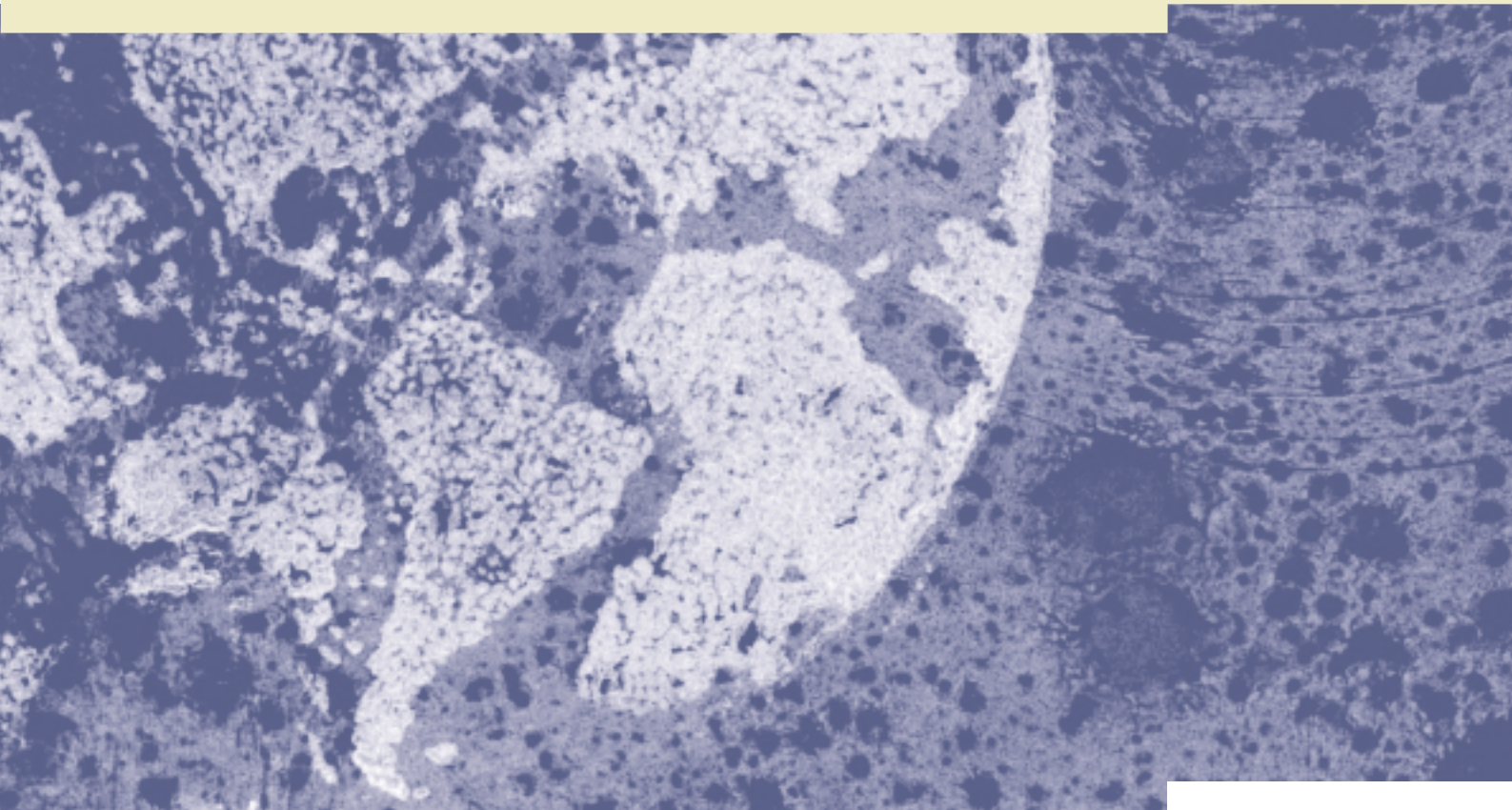
Representatives of the service providers and of industry were generally optimistic that greater compliance with regulation could be achieved in the future. While it was frequently noted that Ireland exhibited a 'non-compliant' culture, it was felt that, in relation to waste management, this had to change because of pressure from the European Union. There was, though, little overall satisfaction with existing agencies and structures. The EPA, although seen as a reliable source of information, was not generally regarded highly in respect of achieving compliance with regulation. There was a more general ambiguity as to whether the primary locus of ensuring compliance should rest at the centre or at the periphery. Local authorities were felt to be 'compromised', or to behave erratically, because of the ambiguities of their responsibility vis-à-vis waste management and public representation. Regional plans were perceived as being duplicative or inconsistent with local plans. Health boards were seen as having a potentially greater role to play, with reference being made to the new Health Strategy, its call for the wider use of health impact assessment and for health proofing of the plans of other sectors, and to the National Environmental Health Action Plan. However, some ambiguity was also perceived in the role of health boards, given their parallel responsibility as managers of the large quantities of hazardous hospital waste.

From their respective positions and perspectives, informants converged in the view that the key to the resolution of existing disagreement on the future for waste management lay in the production of trustworthy and trusted information. Not unnaturally, the various parties were generally convinced

that this would persuade other parties over to their own particular view. Apart from doubts as to the trustworthiness of the press as a source of information, most informants were generally confident that the information which did reach the public domain was credible. For example, representatives of organisations who might have been considered to be, a priori, antagonistic to bodies such as Greenpeace were often complimentary in their view of them as a source of reliable information.

Whereas the dissemination of better information was never perceived as being a solution to local fears concerning the proximate location of waste disposal facilities, it was felt that it would assist in shifting the general tenor of the debate to one over which the general public could exhibit greater ownership.

Appendix A: Study Protocol



Appendix A: Study Protocol

A PROPOSAL TO STUDY THE EFFECTS OF LANDFILL AND THERMAL TREATMENT OF WASTE ON PUBLIC HEALTH AND THE ENVIRONMENT IN IRELAND

Summary

Waste generated from commercial, industrial and domestic sources has been steadily increasing world-wide. Although accepted as one of the least desirable options for waste management, most Irish household and commercial waste is consigned to landfill, with a minor proportion being recycled. Current concerns about waste generation extend beyond those relating to disposal capacity. Landfill and thermal treatment have both been implicated as sources of environmental contamination. In relation to human health, recent epidemiological studies have reported adverse outcomes associated with living near landfill sites and incinerators. Attempts to tackle the problems arising both from the increasing volume of waste production and from the many potentially toxic substances in waste have resulted in developments in the areas of prevention, such as minimisation, recycling, energy recovery and safe disposal.

This study aims to evaluate the effects of landfill and thermal treatment of waste on public health and the environment, in Ireland. Specific objectives include: (a) a literature review of the effects of landfill and thermal treatment of waste; (b) a study of the knowledge and attitudes of service providers and members of the public to waste management options; (c) a comprehensive description of current policy and practice of waste management in Ireland and in selected other countries; (d) a review of national and international literature on environmental risk assessment; (e) an examination of the risks posed to the environment and public health by similar hazards from other sources and comparison of the risks posed by each.

The proposed research will allow a collation of existing and new information with which to plan future waste management policies and further research in this field.

DESCRIPTION OF THE PROPOSED STUDY

Introduction and background information

The scale of the problem

Waste generated from commercial, industrial and domestic sources has been steadily increasing (1). It is currently estimated that 0.52 tonnes of waste are generated per capita per year in Ireland (2). As the population and, more importantly, the economy has grown, so too has the volume of waste generated. Although accepted as one of the least desirable options for waste management, most Irish household and commercial waste is consigned to landfill, with a minor proportion being recycled (3). This is in contrast to many other mainland European countries, which are less reliant on landfill and utilise other options in waste management, such as incineration and composting, in addition to landfill and recycling (4).

Current concerns

Current concerns about waste generation extend beyond those relating to disposal capacity. Landfill and thermal treatment have both been implicated as sources of environmental contamination (5). Of the many hazardous emissions from thermal treatment of waste, those of most concern are dioxins, furans, other persistent organic compounds and heavy metals. These substances are all known to have adverse effects on the environment and on human health. The use of ash from thermal treatment of waste for road construction has also caused concern about the possibility of environmental contamination. In addition to atmospheric pollution from gaseous emissions such as methane, landfills have been identified as sources of contamination of surface water groundwater and soil, caused by air pollution and leachate (6).

In relation to human health, recent epidemiological studies have reported adverse outcomes associated with living near landfill sites and incinerators (7, 8, 9, 10). Although epidemiological studies provide a very powerful tool with which to identify and measure adverse health effects in populations (11), such methods are poorly equipped to measure exposure. Research is needed to determine exposure more accurately (12). In addition, the health outcomes that are recorded may not readily allow analysis of small populations over short periods of time (13).

Waste prevention programmes

Attempts to tackle the problems which arise both from the increasing volume of waste production and from the many potentially toxic substances in waste are best approached by an integrated waste management system (5). Ireland and many other countries have adopted a source-oriented approach to effective waste management. This includes prevention of waste generation, prevention of impact on the environment, recovery of material or energy, and safe and efficient final disposal (3, 14).

Growing concerns about hazardous substances in waste have resulted in new research and developments in analysing pathways of hazardous substances through the waste- management process (15). Waste characterisation and, more specifically, waste-stream analysis, facilitate the identification of existing and newly formed hazards within waste and have aided the development of indicators (3). These indicators, in addition to those relating to environmental monitoring, are vital tools for planning waste policies and for aiding the risk assessment process (16).

Risk assessment

Risk assessment, as a conceptual framework, provides the mechanism for a structured review of information on health and the environment. Through a process of hazard identification, dose-response assessment, exposure assessment and risk characterisation, information for prevention and remediation of public health and adverse environmental effects can be obtained (17). As evidenced by other studies of the effects of pollution on environmental and human health, hazards may originate from many different sources (18, 19). Calculation of the magnitude of the adverse effect attributable to each source can provide information with which to plan pollution-control strategies, relating both to waste management and to other sectors such as transport, industry and agriculture.

Risk perception

Concerns about environmental exposures are often associated with strong feelings. Public perceptions of health risks associated with the environment are not always in agreement with the

perceptions of environmental professionals (20). Communication is a two-way process and communication of risks about environmental exposure requires an understanding of the knowledge and attitudes of the general public and special-interest groups involved (21).

Aims and objectives

Aims

- To evaluate the effects of landfill and thermal treatment of waste on public health and the environment in Ireland.

Objectives

- To review national and international literature relating to the effects of landfill and thermal treatment of waste on (a) human health and (b) the environment.
- A distinction will be made between waste categories and characteristics of environmental contaminants.
- To describe the knowledge and attitudes of service providers, special-interest groups and the general public to waste management options and to undertake an analysis of the source and basis of knowledge and attitudes.
- To describe (a) the current policy and practice of waste management in Ireland in terms of the hierarchy of principles in waste management, including methods of monitoring of waste and surveillance of emissions and (b) practices in waste management in other countries, in order to identify best practice in terms of efficiency and safety. This will include technical descriptions of different waste- management options and new technologies.
- To review national and international literature on environmental risk assessment and to identify and describe formal risk assessments that have been carried out on landfill and thermal treatment facilities to date. This will also identify those emissions that have been categorised as hazardous to human health and the environment.
- To compare risks posed to public health and the environment by emissions from landfill and from modern thermal treatment plants with those posed by similar emissions from other sectors.

Proposed study methods

1. Literature review

Review of Medline and environmental scientific databases for reports on control or monitoring of adverse effects of waste facilities. Gaps in research to date will be identified.

Review of grey literature from:

- (a) National bodies in Ireland such as the Environmental Protection Agency and from other such bodies in Europe, the US and Canada, Department of the Environment and Local Government and Department of Health and Children.

- (b) International organisations such as OECD, WHO, European Environmental Agency, International Association for Research against Cancer, International Programme on Chemical Safety, Agency for Toxic Substances and Disease Registry. An additional advantage of this information search will be to provide an information resource, which will be published in the final report.

2. Qualitative study of service providers, special-interest groups and the general public

- (a) Semi-structured interviews and focus groups with service providers

The following service providers, in addition to any others identified during the course of the review, will be interviewed:

- Local Authorities
- Waste site managers
- Environmental Protection Agency
- Health and Safety Authority
- Food Safety Authority

The following topics will be included in the interviews:

1. Current activities in the areas of:
 - Environmental monitoring and surveillance
 - Biological monitoring, both human and ecosystem
 - Research in aspects of risk assessment
2. Knowledge of risks to the environment and to public health
3. Understanding of the knowledge and attitudes of the general public on aspects of waste management, such as the following:
 - What are the main worries of the general public?
 - Are these concerns legitimate?
 - How should the public be informed about waste management, etc.?

- (b) Qualitative study of the general public and of special-interest groups

Focus Groups with members of the public living near current and planned sites.

Focus Groups with groups who have lobbied the Department of the Environment and Local Government.

The purpose of this aspect of the study is to collect information on perceived risk, actual experience, source of information and attitudes to various aspects of waste management.

(c) An Assessment of Perceived Health Impacts

Mapping interests of stakeholders to provide a greater awareness of the origins and implications of perceptions of health impact (22, 23). This will provide a deeper understanding for exploration of reactions to solutions and alternatives to proposed or actual facilities. A framework will be developed which will inform further research on public attitudes and knowledge of waste management practices.

Number of focus groups

Four focus groups will be conducted in locations close to existing or proposed sites by public advertisement in area.

Two with lobby groups by invitation. In addition, the submissions that have already been received by the Department of the Environment will be examined.

Proposed topic guide

The Topic Guide will be informed by the above submissions and will include the following topics:

For those living near existing sites:

- Were you concerned about any risks/problems prior to the introduction of this site?
- Why were you worried about this/these?
- What problems have you actually experienced/In what way has the landfill negatively affected your life?

For those living near proposed incinerators:

- Do you oppose the incinerator?
- What are the risks you perceive?
- Where did you obtain the information about these risks?
- Do you know of and have you attended any information meetings about the incinerators?

For those representing special interest groups:

- What are your concerns?
- Do you agree or disagree with the location and operation of the proposed/existing site?
- What are the risks posed by this site?
- Where did you obtain your information about these risks?

- What is the best solution to this problem?

3. Review of current practices in waste management in Ireland and internationally

A review of different systems of waste management will be examined. This review will be conducted using the hierarchy of prevention of waste, (a) for waste in general and (b) for specific waste streams. In addition, the review will include descriptions of new and old sites, current and new technologies, location and scale of existing and planned sites and issues relating to transport of waste.

The Irish Waste Management Association, affiliated to IBEC, is the umbrella body for the industry in Ireland. We will obtain a complete list of waste management operators in Ireland from them. The following information will be sought from waste management operators and from the National Waste Database held by the Environmental Protection Agency (3):

- Waste sampling and analyses
- Projected fate of contaminants and ultimate fate/disposal of residuals and effluents
- Engineering design specifications and descriptions of systems in operation that affect emissions
- Emission monitoring
- Permits or approvals to operate
- Operation and maintenance plan
- Quality assurance and quality control plans
- Worker health and safety

In addition, a comparative study of waste management practices will be carried out in selected countries. Documentation such as annual reports, waste statistics and emission surveillance and monitoring programme reports will be identified and summarised in this report.

4. Review of risk assessment

The risk assessment review will be divided into the following categories:

(a) Health hazard identification

A literature review of environmental monitoring of landfill and thermal treatment plants will be undertaken. This will include the following: characterisation of chemical hazards, their mechanism of transport in the environment, risk factors for their release, mechanisms of toxicity and reported effects on human health and on the environment.

(b) Dose-Response assessment

For the identified hazards, to describe inter- and intra-species variability of effects, derivation of levels of effect and no effect levels, non-neoplastic effects, neoplastic effects.

(c) Exposure assessment

Review of quantification of exposure through personal monitoring, biomonitoring and biomarkers. To describe methods to assess uncertainty, and to identify risk categories in terms of susceptible populations and in terms of waste management characteristics.

(d) Risk characterisation and risk management

Review of population risks, review of the use of risk comparisons including their use in risk communication, public perception of risks associated with waste, and risk communication.

(e) Impact assessment

Using the information collated, estimates of the likely impact of present and proposed waste-disposal practices on the health of the Irish population will be derived.

5. Study of other sources of environmental emissions and a comparison of risks

Using the information obtained from the literature review and from descriptions of current practice, hazards will be identified. Other sources of these hazards will be examined through the following information sources:

- Review of Integrated Pollution Control Licences (EPA)
- Pollution emission register (EPA)
- Air-quality monitoring (EPA)
- Drinking water and bathing water monitoring (EPA)
- Dangerous occurrences database (Health and Safety Authority)

Specific research projects such as:

- Dioxins in the environment
- Heavy metals in the environment
- Persistent organic pollutants

A critical analysis of the available data sources will be undertaken to determine their usefulness in characterising and quantifying the identified hazards from sources other than waste sites.

Time-scale and project management

The time-scale for this project is very short. Deadline for completion is the end of February 2002. Assuming a start date of 1 November 2001, the project will be carried out over the following four-month period. This time-scale is attainable with a multi-disciplinary approach, and will require three key researchers to study the following aspects of the proposed research:

- Literature review of health effects of different waste-management options and review of risk assessment.

- Literature review of environmental effects of different waste-management options.
- Review of current practice in waste management in Ireland and internationally, and identification of recent advances in waste-treatment technology and waste-management systems.
- Qualitative study of knowledge and attitudes of service providers, special-interest groups and members of the public.

(W = week)

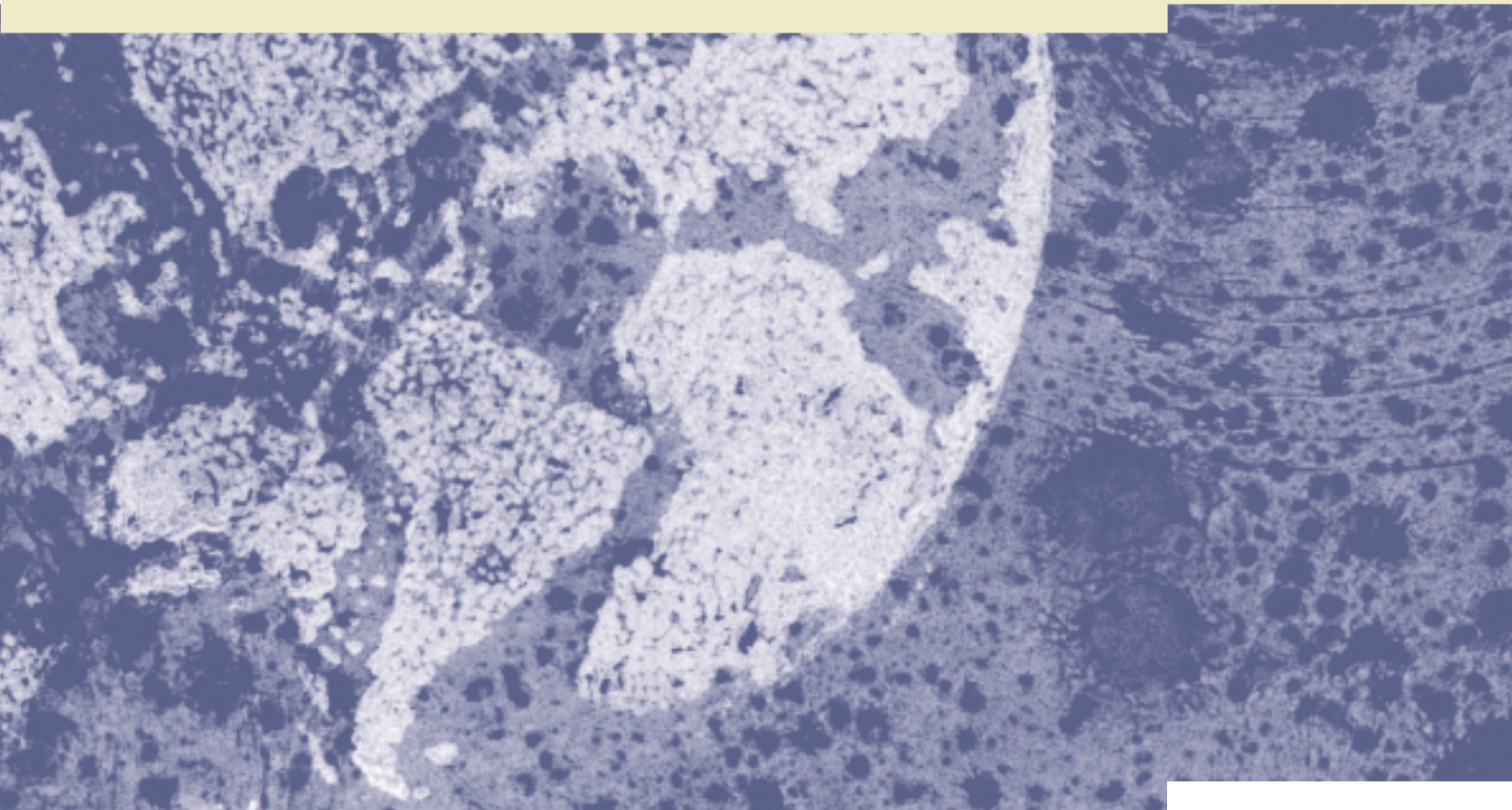
W1-W2	Commencement of literature search and literature reviews. Identification of agencies and service providers to be interviewed. Commencement of review of written submissions to Department of the Environment and Local Government.
W3-W4	Development of sampling strategy and content of focus groups and semi-structured interviews. Commencement of visits to waste-treatment facilities.
W5-W6	Commencement of semi-structured interviews and focus groups.
W7-W8	
W9-W10	Completion of draft review of risk-assessment research.
W11-W12	Completion of draft review of literature on health effects of waste-treatment facilities. Completion of focus groups and semi-structured interviews.
W13-W14	Analysis of focus groups and semi-structured interviews.
W15-W16	Completion of report on current waste-treatment facilities.
W17-W18	Report writing.

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Appendix B: Glossary



Appendix B: Glossary

A

abatement: Reducing the degree or intensity of, or eliminating, pollution.

acceptable daily intake (ADI): Estimate of the largest amount of chemical to which a person can be exposed on a daily basis that is not anticipated to result in adverse effects (usually expressed in mg/kg/day). Same as RfD.

acid deposition: A complex chemical and atmospheric phenomenon that occurs when emissions of sulphur and nitrogen compounds and other substances are transformed by chemical processes in the atmosphere, often far from the original sources, and then deposited on earth in either wet or dry form. The wet forms, popularly called 'acid rain,' can fall as rain, snow, or fog. The dry forms are acidic gases or particulates.

acid rain: Precipitation that has been rendered (made) acidic by airborne pollutants.

acidic: The condition of water or soil that contains a sufficient amount of acid substances to lower the pH below 7.0.

active ingredient: In any pesticide product, the component that kills, or otherwise controls, target pests. Pesticides are regulated primarily on the basis of active ingredients.

advective transport: When material is carried with the flow.

agricultural waste: Poultry and livestock manure or residual materials in liquid or solid form generated in the production and marketing of poultry, livestock, fur-bearing animals and their products, rice straw, rice husks and other plant wastes.

air pollutant: Any substance in air that could, in high enough concentration, harm man, other animals, vegetation, or material. Pollutants may include almost any natural or artificial composition of airborne matter capable of being airborne. They may be in the form of solid particles, liquid droplets, gases, or in combination thereof. Generally, they fall into two main groups: (1) those emitted directly from identifiable sources and (2) those produced in the air by interaction between two or more primary pollutants, or by reaction with normal atmospheric constituents, with or without photoactivation. Exclusive of pollen, fog, and dust, which are of natural origin, about 100 contaminants have been identified and fall into the following categories: solids, sulphur compounds, volatile organic chemicals, nitrogen compounds, oxygen compounds, halogen compounds, radioactive compounds, and odours.

asbestos: A mineral fibre that can pollute air or water and cause cancer or asbestosis when inhaled. EPA has banned or severely restricted its use in manufacturing and construction

B

bacteria: (singular 'bacterium') Microscopic living organisms that can aid in pollution control by metabolising organic matter in sewage, oil spills or other pollutants. However, pathogenic bacteria in soil, water or air can also cause human, animal and plant health problems.

baghouse: air pollution abatement device that traps particulates (dust) by forcing gas streams through large permeable bags usually made of glass fibres.

base catalysed decomposition (BCD): fly ash is mixed with paraffin oil, sodium hydroxides and a carbonaceous catalyst and heated to between 300 °C and 350 °C for several hours to neutralise the furans and dioxins.

bioaccumulants: Substances that increase in concentration in living organisms as the organisms take in contaminated air, water, or food because the substances are very slowly metabolised or excreted.

bioassay: A method used to determine the toxicity of specific chemical contaminants. A number of individuals of a sensitive species are placed in water containing specific concentrations of the contaminant for a specified period of time.

bloom (algal): A proliferation of algae and/or higher aquatic plants in a body of water; often related to pollution, especially when pollutants accelerate growth.

bottom ash: The non-airborne combustion residue from burning solid fuel (e.g., pulverised coal, municipal solid waste) in a combustion chamber; the material which falls to the bottom of the chamber and is removed mechanically; a concentration of the non-combustible materials, which may include toxics.

C

cancer: A disease characterised by the rapid and uncontrolled growth of aberrant cells into malignant tumours.

cap: A fairly impermeable layer of clay soil or a combination of clay soil and synthetic liner, which is placed over a landfill during closure to act as a seal against entry of precipitation into the landfill. The cap serves to minimise leachate volume during biodegradation of the waste by keeping precipitation from percolating through the landfill. The cap also helps minimise the release of odours, and helps prevent animal scavengers from gathering.

carbon dioxide (CO₂): A colourless, odourless, gas produced by the oxidation of carbonaceous compounds. It is one of the main by-products of combustion and is one of the green-house gases that are considered to contribute to global warming.

carbon monoxide (CO): A colourless, odourless, poisonous gas produced by incomplete fossil fuel combustion.

carcinogen: Any substance that can cause or aggravate cancer.

catalyst: A substance that changes the speed or yield of a chemical reaction without being consumed or chemically changed by the chemical reaction.

catalytic converter: An air pollution abatement device that removes pollutants from motor vehicle exhaust, either by oxidising them into carbon dioxide and water or by reducing them to nitrogen and oxygen.

catalytic incinerator: A control device that oxidises volatile organic compounds (VOCs) by using a catalyst to promote the combustion process. Catalytic incinerators require lower temperatures than conventional thermal incinerators, thus saving fuel and other costs.

chelation: A chemical complexing (forming or joining together) of metallic cations (such as copper) with certain organic compounds, such as EDTA (ethylene diamine tetracetic acid). Chelation is used to prevent the precipitation of metals (e.g., copper).

chlorosis: Discoloration of normally green plant parts caused by disease, lack of nutrients, or various air pollutants.

climate change: This term is commonly used interchangeably with 'global warming' and 'the greenhouse effect,' but is a more descriptive term. Climate change refers to the build-up of man-made gases in the atmosphere that trap the sun's heat, causing changes in weather patterns on a global scale. The effects include changes in rainfall patterns, sea level rise, potential droughts, habitat loss, and heat stress. The greenhouse gases of most concern are carbon dioxide, methane, and nitrous oxides. If these gases in our atmosphere double, the earth could warm up by 1.5 °C to 4.5 °C by the year 2050, with changes in global precipitation having the greatest consequences.

closure: The procedure a landfill operator must follow when a landfill reaches its legal capacity for solid waste; ceasing acceptance of solid waste and placing a cap on the landfill site. The cap is then planted with grasses and other ground covers. Post-closure care includes monitoring ground water, landfill gases, and leachate collection systems, sometimes for as long as 30 years.

co-incineration plant: A plant whose main purpose is the generation of energy or the production of material products.

combustion: 1. Burning, or rapid oxidation, accompanied by release of energy in the form of heat and light. A basic cause of air pollution. 2. Refers to controlled burning of waste, in which heat chemically alters organic compounds, converting them into stable inorganics such as carbon dioxide and water.

commercial waste: All solid waste from businesses. This category includes, but is not limited to, solid waste originating in stores, markets, office buildings, restaurants, shopping centres, and theatres.

comminution: Mechanical shredding or pulverising of waste. Used in both solid waste management and wastewater treatment.

compost: Stabilised organic material that is produced when bacteria decompose organic matter (e.g., garbage and biodegradable trash), usually under controlled conditions. Making compost requires turning and mixing and exposing the 'raw' materials to air, and usually adding nutrients. Gardeners and farmers use compost for soil enrichment. The relatively stable humus material that is

produced from controlled composting is a relatively odour-free and pathogen-free material suitable for use as an organic fertiliser.

confidence interval: A range of values within which the true measure of some estimated feature (e.g., risk) is likely to lie. All scientific measurements contain some level of uncertainty due to randomness, and the confidence interval is one way of expressing the level of certainty. In risk assessments, this is usually quoted as the 95% confidence interval, a range within which scientists are 95% sure that the risk being estimated lies. Confidence interval is sometimes called a credibility interval. Note that a 90% confidence interval will be narrower than the corresponding 95% confidence interval. An example will be helpful. Say an imaginary study identified a relative risk of 1.5 for oesophageal cancer amongst men with occupational exposure to landfills. The 95% confidence intervals might be from 0.79 to 2.3, while the 90% confidence intervals could be 1.04 to 1.97, and the corresponding 99% confidence intervals might be from 0.63 to 2.78.

confounding: This is the problem of the alternative explanation. It might be observed that there was an excess of lung cancer amongst people living near an industrial estate, compared with national figures. Besides residential exposure to fumes from industry, these people might be rather different from the general population in other ways. For example, they might be more likely to work in the factories, they might be poorer, they might smoke more, or they might simply live in an urban area. All of these factors are associated with an increased risk of lung cancer. If any of them are also associated with living near an industrial site, the observed excess risk might be partly due to poverty, smoking, or the generally raised urban risk of lung cancer, rather than residential exposure to industrial emissions. These factors would be said to confound the true effect under study.

construction and demolition waste: Waste building materials, dredging materials, tree stumps, and rubble resulting from construction, remodelling, repair, and demolition of homes, commercial buildings and other structures and pavements. May contain lead, asbestos, or other hazardous substances.

contaminant: Any physical, chemical, biological, or radiological substance or matter that has an adverse affect on air, water, or soil.

continuous discharge: A permitted release of pollutants into the environment that occurs without interruption, except for infrequent shutdowns for maintenance, process changes, etc.

CO_x: A chemical formula that is used to refer to both carbon dioxide (CO₂) and carbon monoxide (CO).

D

decomposition: The conversion of chemically unstable materials to more stable forms by chemical or biological action. If organic matter decays in water when there is no oxygen present (anaerobic conditions or putrefaction), undesirable tastes and odours are produced in the water. Anaerobic decay in the absence of water releases undesirable odours. Decay of organic matter when oxygen is present (aerobic conditions) tends to produce much less objectionable odours.

decontamination: Removal of harmful substances such as noxious chemicals, harmful bacteria or other organisms, or radioactive material from exposed individuals, rooms and furnishings in buildings, or the exterior environment.

degradation: Chemical or biological breakdown of a complex compound into simpler compounds.

diffusion flux: When material is effectively spread out in any or all directions due to the random movement of its molecules (often used loosely for dispersive flux where the spreading out is due to turbulence in flow).

dioxin: A generic term which is used to describe chlorinated di-benzo p-dioxins (PCDDs), chlorinated di-benzo furans (PCDFs) and, recently, co-planar chlorinated bi-phenyls (PCBs). They have similar chemical properties and are considered to be highly toxic and carcinogenic. 2,3,7,8 Tetra-Chloro Dibenzo p-Dioxin (TCDD) is considered to be the most toxic of all the dioxins.

disposal: Final placement of toxic, radioactive, or other wastes that cannot be degraded to stable (i.e., harmless) end products due to technical or economic limitations. Materials for which disposal is appropriate include surplus or banned pesticides or other bio-resistant chemicals; polluted soils; and drums containing hazardous materials from remediation actions or accidental releases. Disposal may be accomplished through use of approved secure landfills or in natural formations within the earth where the likelihood of material release is believed to be acceptably small.

dry scrubber: An air pollution control device used to remove an acid gas pollutant from a gas stream. The pollutant is collected on or in a solid or liquid material, which is injected into the gas stream. A dry scrubber produces a dry product that must be collected downstream from this control device.

E

ecological impact: The effect that a man-made or natural activity has on living organisms and their non-living (abiotic) environment.

ecological indicator: A characteristic of the environment that, when measured, quantifies magnitude of stress, habitat characteristics, degree of exposure to a stressor, or ecological response to exposure. The term is a collective term for response, exposure, habitat, and stressor indicators.

ecological risk assessment: The application of a formal framework, analytical process, or model to estimate the effects of human actions(s) on a natural resource and to interpret the significance of those effects in light of the uncertainties identified in each component of the assessment process. Such analysis includes initial hazard identification, exposure and dose-response assessments, and risk characterisation.

ecology: The study of the relationships between all living organisms and the environment, especially the totality or pattern of interactions; a view that includes all plant and animal species and their unique contributions to a particular habitat.

ecosystem: The interacting synergism of all living organisms in a particular environment; every plant, insect, aquatic animal, bird, or land species that forms a complex web of interdependency. An action taken at any level in the food chain, use of a pesticide for example, has a potential domino effect on every other occupant of that system.

electrostatic precipitator (EP): An air pollution control device that removes particulate matter from an air stream by imparting an electrical charge to the particles for mechanical collection at an electrode.

emission: Release of contaminants into the environment. The releases may be into the atmosphere from smokestacks, other vents, and surface areas of commercial or industrial facilities; from residential chimneys; and from motor vehicle, locomotive, or aircraft exhausts. Likewise, the releases may occur to soil or water from effluent pipes or by the movement of precipitation (and subsequent runoff) over or through a site containing contaminants.

environment: The sum of all external conditions affecting the life, development and survival of an organism.

environmental equity: Equal protection from environmental hazards for individuals, groups, or communities regardless of race, ethnicity, or economic status.

environmental exposure: Human exposure to pollutants originating from facility emissions. Threshold levels are not necessarily surpassed, but low level chronic pollutant exposure is one of the most common forms of environmental exposure.

environmental impact assessment (EIA): A systematic environmental analysis prepared to determine whether a proposed action would significantly affect the environment (including human beings, flora, fauna, soils and geology, air, water, climate, the landscape, interactions among these components, and material assets).

environmental impact statement (EIS): A document prepared in respect of EU Directive 85/337/EEC that articulates an environmental impact assessment, including potential impacts of a proposed development, alternatives and actions to be taken in the recommended development that will minimise environmental impact. As a tool for decision-making, the EIS describes positive and negative effects and lists alternatives for an undertaking.

environmental technology: An all-inclusive term used to describe pollution control devices and systems, production / managerial practices, waste treatment processes and storage facilities, and site remediation technologies and their components that may be utilised to remove pollutants or contaminants from, or to prevent them from entering, the environment. Examples include wet scrubbers (air), soil washing (soil), granulated activated carbon unit (water), and filtration (air, water). Usually, this term applies to hardware-based systems; however, it can also apply to methods or techniques used for pollution prevention, pollutant reduction, or containment of contamination to prevent further movement of the contaminants, such as capping of landfills, solidification or vitrification, and biological treatment.

epidemiology: The study of the occurrence and causes of health effects in human populations. An epidemiological study often compares two groups of people who are alike except for one factor, such as exposure to a chemical or the presence of a health effect. The investigators try to determine if any factor is associated with the health effect.

excess risk or risk difference: The difference between the two risks being compared.

exposure: Radiation or pollutants that come into contact with the body and present a potential health threat. The most common routes of exposure are through the skin, mouth, or by inhalation.

exposure assessment: The determination or estimation (qualitative or quantitative) of the magnitude, frequency, duration, route, and extent (number of people) of exposure to a chemical.

exposure level (chemical): The amount (concentration) of a chemical at the absorptive surfaces of an organism.

F

flue gas: The combustion gases discharged to the atmosphere through a flue or chimney. Flue gases can include nitrogen oxides, carbon oxides, water vapour, sulphur oxides, oxygen, particulate matter and other chemical pollutants; however, nitrogen is the primary constituent..

fly ash: The airborne combustion residue from burning coal or other solid fuels. Consists mainly of various oxides and silicates. Major sources are pulverised coal-burning boilers.

fume: Tiny particles trapped in vapour in a gas stream.

G

Gamma ray irradiation: Experimental hazardous waste chemical treatment method that disinfects waste by using gamma radiation to destroy disease-causing organisms.

Gamma rays: Electromagnetic rays similar to X-rays, emitted in an unstable atom's nucleus, which travel in straight paths at the speed of light, penetrate matter readily, but do not make the material radioactive. They penetrate a greater area than alpha or beta rays, but do less damage because they are weaker forms of radiation.

gasification: Gasification of waste is the reaction of oxygen in the form of air, steam or oxygen at high temperature with the available carbon in the waste to produce a gas product, ash and a tar.

greenhouse effect: Energy from the sun drives the earth's weather and climate, and heats the earth's surface; in turn, the earth radiates energy back into space. Atmospheric greenhouse gases (CO₂, H₂O etc.) trap some of the outgoing energy and retain some of this heat in a manner similar to the glass panels of a greenhouse. The designated green-house gases are:

Carbon dioxide: released to the atmosphere when solid waste, fossil fuels (oil, natural gas, and coal), and wood and wood products are burned and is also a by-product of biological activity.

Methane: emitted during the production and transport of coal, natural gas, and oil. Methane emissions also result from the decomposition of organic wastes in municipal solid waste landfills, and the raising of livestock.

Nitrous oxide: emitted during agricultural and industrial activities, as well as during combustion of solid waste and fossil fuels.

Very powerful greenhouse gases that are not naturally occurring include hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF₆), which are generated in a variety of industrial processes.

groundwater: Water below the land surface that is in the zone of saturation where all void spaces between soil particles are filled with water. Saturated zones that can yield usable quantities of

groundwater are called aquifers, and may be unconfined or confined, depending on the absence or presence, respectively, of impermeable geologic material above the aquifer. The interface between unsaturated soil and the top of the zone of saturation in an unconfined aquifer is called the watertable.

H

half-life: 1. The time required for one-half of a material to be converted, e.g. the time required for a pollutant to lose half its effect on the environment, or the time required for a radioactive isotope to lose half its radioactivity. Half-life is a measure of persistence; the biochemical half-life of DDT in the environment is 15 years, of Radium 1,580 years. 2. The time required for half of the atoms of a radioactive element to undergo self-transmutation or decay. 3. The time required for the elimination of one half a total dose from the body.

hazard evaluation: A component of risk assessment that involves gathering and evaluating data on the types of health injury or disease (e.g., cancer) that may be produced by a chemical and on the conditions of exposure under which injury or disease is produced.

hazardous air pollutants: Air pollutants that may reasonably be expected to cause or contribute to irreversible illness or death. Such pollutants include asbestos, beryllium, mercury, benzene, coke oven emissions, radionuclides, and vinyl chloride.

hazardous substance: 1. Any material that poses a threat to human health and- /or the environment. Typical hazardous substances are carcinogenic, infectious, irritant or harmful to human health, toxic, corrosive, ignitable, explosive, or chemically reactive.

hazardous Waste: Defined in the *Directive on Hazardous Waste (91/689/EEC)*

hazardous waste list: A subset of the European Waste Catalogue representing a list of wastes considered to be hazardous as defined in the Council *Directive on Hazardous Waste (91/689/EEC)* and drawn up under Commission Decision of 22 January 2001, amending Decision, 2000/532/EC replacing Decision 94/3/EC establishing a list of wastes pursuant to Article 1(a) of Council Directive 75/442/EEC on waste and Council Decision 94/904/EC, establishing a list of hazardous waste pursuant to Article 1(4) of Council Directive 91/689/EEC on hazardous waste.

HCl: Chemical formula for hydrogen chloride, an acid gas resulting from the combustion of chlorinated compounds.

heavy metal: Metallic elements with high atomic weights, e.g., mercury, chromium, cadmium, arsenic, and lead; can damage living things at low concentrations and tend to accumulate in the food chain.

HF: Chemical formula for hydrogen fluoride, and acid gas resulting from the combustion of fluorinated compounds.

high-density polyethylene (HDPE): A material used to make plastic bottles and other products that produce toxic fumes when burned.

high-level radioactive waste (HLW): Waste generated in core fuel of a nuclear reactor; found at nuclear reactors or by nuclear fuel reprocessing; is a serious threat to anyone who comes near the waste without shielding.

household waste (domestic waste): Solid waste, composed of garbage (i.e., food wastes) and rubbish (paper, glass, metal, etc.), which normally originated in a private home or apartment house. Domestic waste may contain a significant amount of toxic or hazardous waste.

humus: Organic portion of the soil remaining after prolonged microbial decomposition.

hydrocarbon: Chemicals that consist entirely of hydrogen and carbon. Hydrocarbons contribute to air pollution problems such as smog.

I

incineration: The high temperature thermal oxidation of waste materials.

industrial waste: Unwanted materials produced in or eliminated from an industrial operation and categorised under a variety of headings, such as liquid wastes, sludge, solid wastes, and hazardous wastes. Industrial wastes arise from the inefficiencies inherent in any production process.

infectious waste: Hazardous waste with infectious characteristics, including: contaminated animal waste; human blood and blood products; isolation waste, pathological waste; and discarded sharps (needles, scalpels or broken medical instruments.)

inhalation: Type of exposure through the lungs.

I-TEF (International Toxicity Equivalency Factor): The toxicity equivalency factor was first introduced in 1988 by the NATO/CCMS Working Group on Dioxins and Related Compounds and subsequently re-evaluated by a WHO/IPCS working group. The term TEF was defined to be an order of magnitude estimate of the toxicity of a compound relative to the toxicity of 2, 3, 7, 8 TCDD that is derived using careful scientific judgement after considering all available data. TEF values for individual congeners in combination with their chemical concentration can be used to calculate the total TCDD toxic equivalents concentration (TEQs or I-TEQs) contributed by all dioxin-like congeners in the mixture using the following equation, which assumes dose additivity:

$$\text{TEQ} = \sum (\text{PCDD}_i \times \text{TEF}_i) + \sum (\text{PCDF}_i \times \text{TEF}_i) + \sum (\text{PCB}_i \times \text{TEF}_i)$$

I-TEQ (International Toxic Equivalents): see I-TEF.

L

landfill: A site designed and operated to facilitate solid waste 'disposal' either below the existing ground surface or on the land surface. In modern landfills, refuse is spread and compacted and a cover of soil applied daily so that effects on the environment (including public health and safety) are minimised. Under current regulations, landfills are required to have liners and leachate treatment systems to prevent contamination of ground water and surface waters. An industrial landfill receives

non-hazardous industrial wastes. A municipal landfill receives domestic waste including garbage, paper, etc., which may include toxins that are used in the home, such as insect sprays and powders, engine oil, paints, solvents, and weed killers. The forerunners of landfills were, colloquially, 'dumps' and 'tips', neither of which were designed or operated with very high regard for environmental safety or human health.

leachate: The liquid, which usually originated as rainwater, that percolates through a landfill and which frequently is contaminated by materials dissolved from the waste in the landfill.

latency period: The period of time between exposure to a toxic chemical and the onset of health effects. Cancer caused by chemical exposure may have a latency period of 5 to 40 years.

level of concern (LOC): The concentration in air of an extremely hazardous substance, above which there may be serious immediate health effects to anyone exposed to it for short periods.

lifetime exposure: Total amount of exposure to a substance that a human would receive in a lifetime (usually assumed to be 70 years).

low-level radioactive waste (LLRW): Wastes less hazardous than most of those associated with nuclear reactors; LLRW are generated by hospitals, research laboratories, and certain industries.

M

manifest system: Tracking of hazardous waste from 'cradle to grave' (generation through ultimate disposal) with accompanying documents known as manifests.

margin of safety (MOS): Maximum amount of exposure producing no measurable effect in animals (or studied humans) divided by the actual amount of human exposure in a population.

methane (CH₄): A colourless, non-poisonous, flammable gas created by anaerobic decomposition of organic compounds. Methane is also considered to be a very potent greenhouse gas.

minimisation: Measures or techniques that reduce the amount of wastes generated during industrial production processes; this term also is applied to recycling and other efforts to reduce the volume of waste going to landfills. This term is interchangeable with waste reduction and waste minimisation.

N

nitric oxide (NO): A gas formed by combustion under high temperature and high pressure in an internal combustion engine; NO changes into nitrogen dioxide (N₂O) in the ambient air and contributes to photochemical smog.

nitrogen dioxide (N₂O): The result of nitric oxide combining with oxygen in the atmosphere; major component of photochemical smog.

non-point source: Diffuse pollution sources (i.e., those without a single point of origin or easily identified specific outlet). Non-point pollution sources are typically associated with the landscape and may contribute pollutants to both the atmosphere and water. Water pollutants are generally carried

off the landscape surface over land flow (runoff) or to groundwater by rainfall that infiltrates into and percolates through the soil. Common non-point sources are agriculture, forestry, urban construction, mining, construction, dams, channels, land application of organic wastes, saltwater intrusion, and wash-off from city streets. Many of these same sources can contribute pollutants (e.g., greenhouse gases) to the atmosphere.

NO_x: Pronounced 'nox' and is a general term for nitrogen oxides, NO and N₂O.

O

on-site facility: Any waste treatment, storage or disposal facility that is located on the site where wastes are generated.

oxidant: A substance containing oxygen that reacts chemically in air to produce a new substance; the primary ingredient of photochemical smog.

ozone: Found in two layers of the atmosphere, the stratosphere and the troposphere. In the stratosphere (the atmospheric layer 11 to 16 km or more above the Earth's surface) ozone is a natural form of oxygen that provides a protective layer shielding the earth from ultraviolet radiation. In the troposphere (the layer extending up 11 to 16 km from the Earth's surface), ozone is a chemical oxidant and major component of photochemical smog. Ozone in the troposphere is produced through complex chemical reactions of nitrogen oxides, which are among the primary pollutants emitted by combustion sources; hydrocarbons, released into the atmosphere through the combustion, handling and processing of petroleum products; and sunlight.

ozone depletion: Destruction of the stratospheric ozone layer that shields the Earth from ultraviolet radiation harmful to life. This destruction of ozone is caused by the breakdown of certain chlorine- and/or bromine-containing compounds (chlorofluorocarbons or halons), which break down when they reach the stratosphere and then catalytically destroy ozone molecules.

ozone hole: Thinning break in the stratospheric ozone layer. Designation of amount of such depletion as a 'ozone hole' is made when detected amount of depletion exceeds 50%. Seasonal ozone holes have been observed over both the Antarctic region and the Arctic region and part of Canada and the extreme north-eastern United States.

ozone layer: The protective layer in the atmosphere, about 24 km above the ground, that absorbs some of the sun's ultraviolet rays, thereby reducing the amount of potentially harmful radiation reaching the Earth's surface.

P

packed bed scrubber: An air pollution control device in which emissions pass through alkaline water to neutralise hydrogen chloride gas.

PAH: Poly-aromatic hydro-carbons or polynuclear aromatic hydro-carbons occur in petroleum fractions and also as by-products of combustion reactions. Benzo(a)pyrene is a typical PAH.

PCDD (Poly Chlorinated Di-Benzo p-Dioxin): See Dioxin.

PCDF (Poly Chlorinated Di-Benzo Furan): See Dioxin.

photochemical oxidants: Air pollutants formed by the action of sunlight on oxides of nitrogen and hydrocarbons.

plume: 1. A visible or measurable discharge of a contaminant from a given point of origin. A plume can be visible or thermal in water as it extends downstream from the pollution source, or visible in air as, for example, a plume of smoke. 2. The area of radiation leaking from a damaged reactor. 3. Area downwind within which a release could be dangerous for those exposed to leaking fumes.

PM: Particulate matter, sometimes designated along with a number which specifies the mean size of the particles in question, e.g. PM¹⁰-particulate matter smaller than ten microns in size.

pollutant: Generally, any substance introduced into the environment that adversely affects the natural character (physical, chemical or biological) or usefulness of a resource; often used interchangeably with 'contaminant'.

pollution: Any substances in water, soil, or air that degrade the natural quality of the environment, offend the senses of sight, taste, or smell, or cause a health hazard. The usefulness of the natural resource is usually impaired by the presence of pollutants and contaminants.

polychlorinated biphenyls (PCBs): A group of hazardous compounds used for a number of industrial purposes. PCBs are toxic to some marine life at concentrations of a few parts per billion and are known to cause skin diseases and even death in humans at higher concentrations. PCBs are persistent in the environment, do not decompose easily and tend to bio-accumulate.

polychlorinated phenols (PCPhs): Ring compounds based on phenol with substitute chlorine atoms.

polychlorinated benzenes (PCBzs): Ring compounds based on benzene with substituted chlorine atoms.

ppm (parts per million): a concentration term commonly used to express the amount of a substance in a medium such as air or water. For example, mg/kg as a measure could be expressed as ppm.

ppb: parts per billion.

precipitation: 1. The process by which atmospheric moisture falls onto a land or water surface as rain, snow, hail, or other forms of moisture. 2. The chemical transformation of a substance in solution into an insoluble form (precipitate).

prevalence study: An epidemiological study that examines the relationships between diseases and exposures as they exist in a defined population at a particular point in time.

primary waste treatment: First processes in wastewater treatment in which screens and sedimentation tanks are used to remove most materials that float or will settle. Primary treatment removes about 30 per cent of carbonaceous biochemical oxygen demand from domestic sewage.

putrefaction: Biological decomposition of organic matter, with the production of ill-smelling and tasting products, associated with anaerobic (no oxygen present) conditions.

pyrolysis: Pyrolysis is the thermal degradation of organic waste in the absence of oxygen to produce three products—a carbonaceous char, oil and combustible gases - all of which may be recycled or used for process energy. The process conditions are selected to produce the desired char, gas or oil end-product.

Q

quality control (QC): The overall system of technical activities that measures the attributes and performance of a process, item, or service against defined standards to verify that they meet the stated requirements established by the customer; operational techniques and activities that are used to fulfil requirements for quality. The system of activities and checks used to ensure that measurement systems are maintained within prescribed limits, providing protection against 'out of control' conditions and ensuring the results are of acceptable quality.

quench: The rapid cooling of flue gases by direct contact with cold water or air.

R

radiation: Transmission of energy through space or any medium. Also known as radiant energy.

radioactive decay: Spontaneous change in an atom by emission of charged particles and/or gamma rays; also known as radioactive disintegration and radioactivity.

radioactive waste: Any waste that emits energy as rays, waves, or streams of energetic particles. Radioactive materials are often mixed with hazardous waste, usually from nuclear reactors, research institutions, or hospitals.

recycling: Reusing materials and objects in original or changed forms rather than discarding them as wastes.

refuse derived fuel (RDF): This is the term applied to fuel pellets produced from municipal waste by shredding and separating out the non-combustible element.

relative risk: The ratio between the risk in the study group and some comparison group. In the types of studies considered here, the study group is typically people living close to a landfill site or a waste incinerator, and the comparison group is either the whole population, or people living further away from the site.

release: Any spilling, leaking, pumping, pouring, emitting, emptying, discharging, injecting, escaping, leaching, dumping, or disposing into the environment of a hazardous or toxic chemical or extremely hazardous substance.

remediation: 1. Cleanup or other methods used to remove or contain a toxic spill or hazardous materials from a contaminated site; abatement methods including evaluation, repair, enclosure, encapsulation, or removal.

residual: Amount of a substance remaining after a natural or technological process has taken place to modify it, e.g., the sludge remaining after initial wastewater treatment, ash remaining after combustion, or particulates remaining in air after it passes through a scrubbing or other process.

resistance: For plants and animals, the ability to withstand poor environmental conditions or attacks by chemicals or disease. May be inborn or acquired.

resource recovery: The extraction of useful materials or energy from solid waste. Such materials can include paper, glass, and metals that can be reprocessed for re-use. Resource recovery also is employed in pollution prevention.

reuse: Using a product or component of municipal solid waste in its original form more than once, e.g., refilling a glass bottle that has been returned or using a coffee can to hold nuts and bolts.

risk: A measure of the probability that damage to life, health, property, and/or the environment will occur as a result of a given hazard.

risk assessment: A qualitative or quantitative evaluation of the environmental and/or health risk resulting from exposure to a chemical or physical agent (pollutant); combines exposure assessment results with toxicity assessment results to estimate risk.

risk factor: A characteristic (e.g., race, sex, age, obesity) or variable (e.g., smoking, exposure) associated with increased chance of toxic effects. Some standard risk factors used in general risk assessment calculations include average breathing rates, average weight, and average human lifespan.

risk management: Actions taken in response to identified hazards, including 'do nothing' actions. In environmental terms, risk management includes such things as groundwater protection strategies in which certain land use activities are discouraged in areas susceptible to groundwater pollution. In a health context, risk management includes decisions about whether an assessed risk is sufficiently high to present a public health concern and about the appropriate means for control of a risk judged to be significant. Risk management also includes the process of evaluating and selecting alternative regulatory and non-regulatory responses to risk. The selection process necessarily requires the consideration of legal, economic, technological and behavioural factors.

route of exposure: The avenue by which a contaminant comes into contact with an organism (e.g., inhalation, ingestion, dermal contact, and injection).

run-off (surface overland flow and interflow): That part of precipitation, snow melt, or irrigation water that runs off the landscape by overland pathways or through the very upper layer of the soil profile, and thence into streams or other surface water. It can carry pollutants adsorbed by precipitation from the air and those removed from the landscape and deposit them into the receiving waters.

S

safe: Condition of exposure under which there is a 'practical certainty' that no harm will result in exposed individuals.

safe water: Water that does not contain harmful bacteria, or toxic materials or chemicals. Water may have taste and odour problems, or colour and certain mineral problems, and still be considered safe for human consumption.

scrap: Materials discarded from manufacturing operations that may be suitable for reprocessing.

scrubber: An air pollution device that uses a spray of water or reactant or a dry process to trap pollutants in emissions.

Selective catalytic reduction (SCR): A flue gas treatment process that is used for the reduction of nitrogen oxides from both incineration and coal combustion applications. Ammonia or urea is injected into the flue gases, typically after the energy recovery stage, at temperatures of 3-400 °C. The flue gas is passed over a solid catalyst, based on titanium oxide, zeolite, iron oxide or activated carbon containing the catalytic material, typically vanadium and the nitrogen oxides are selectively reduced to nitrogen (N₂).

selective non-catalytic reduction (SNCR): The selective reduction of oxides of nitrogen to nitrogen by the direct injection of a reducing agent (typically ammonia or urea) into the combustion zone of a furnace. This process takes place at temperatures in the range 800-1100 °C.

semi-natural habitat: An ecosystem that has been significantly modified by human activity: i.e. essentially all Irish ecosystems.

smog: Dust, smoke, or chemical fumes that pollute the air and make hazy, unhealthy conditions (literally, the word is a blend of smoke and fog). Automobile, truck, bus, and other vehicle exhausts and particulates are usually trapped close to the ground, obscuring visibility and contributing to a number of respiratory problems.

solid waste: Any solid, semi-solid, liquid, or contained gaseous materials discarded from domestic, industrial, commercial, mining, or agricultural operations and activities. Solid waste includes household waste, construction debris, commercial refuse, sludge from water supply or wastewater treatment plants, or air pollution control facilities, and other discarded materials.

solid waste management facility: Any disposal or resource recovery system; any system, programme, or facility for resource conservation; any facility for the treatment of solid wastes.

SO_x: A chemical formula used to designate oxides of sulphur, primarily sulphur dioxide (SO₂) and sulphur trioxide (SO₃).

source reduction: The design, manufacture, purchase, or use of materials (such as products and packaging) to reduce the amount or toxicity of garbage generated. Source reduction can help reduce waste disposal and handling charges because the costs of recycling, municipal composting, landfilling, and combustion are minimised. Source reduction conserves resources and reduces pollution.

stable air: A motionless mass of air that holds, instead of dispersing, pollutants.

stationary source: A fixed-site producer of pollution, mainly power plants and other facilities using industrial combustion processes.

sulphur dioxide (SO₂): A pungent, colourless, gaseous pollutant formed primarily from the combustion of fossil fuels containing sulphur and contributes to the formation of 'acid rain'.

surface water: All water naturally open to the atmosphere (rivers, lakes, reservoirs, ponds, streams, impoundments, seas, estuaries, etc.) and all springs, wells, or other collectors directly influenced by surface water.

T

thermal stratification: The formation of layers of different temperatures in a lake or reservoir.

threshold: The lowest dose of a chemical at which a specified measurable effect is observed and below which it is not observed.

threshold level: Time-weighted average pollutant concentration values, exposure beyond which is likely to adversely affect human health (see 'environmental exposure').

time-weighted average (TWA): In sampling, the average concentration of contaminants during a given period.

toxic chemical: Substances that can cause severe illness, poisoning, birth defects, disease, or death when ingested, inhaled, or absorbed by living organisms.

toxic cloud: Airborne plume of gases, vapours, fumes, or aerosols containing toxic materials.

toxic pollutants: Materials contaminating the environment that cause death, disease or birth defects in organisms that ingest or absorb them. The quantities and duration of exposure necessary to cause these effects can vary widely.

U

unsaturated: The characteristic of a carbon atom in a hydrocarbon molecule that shares a double bond with another carbon atom.

urban runoff: Storm water runoff from city streets and adjacent domestic or commercial properties that carries pollutants of various kinds into the sewer systems and receiving waters.

V

vapour: The gas given off by substances that are solids or liquids at ordinary atmospheric pressure and temperatures.

vapour dispersion: The movement of vapour clouds or plumes in the air due to wind, gravity, spreading, and mixing.

vegetative controls: Non-point source pollution control practices that involve the use of plants (vegetative cover) to minimise the loss of pollutants, provide a screen for visual amenity protection, or to assist in odour dispersion.

vitrification: A process of combining a material/waste with molten glass. When cooled, the materials form a solid non-crystalline structure.

volatile organic compound (VOC): Any organic compound that evaporates readily to the atmosphere. VOCs contribute significantly to photochemical smog production and certain health problems.

W

waste: any of a number of solid or liquid materials regarded as useless or superfluous, including unwanted by-products of industrial processes, human and animal excrement, materials banned by law, etc. In the context of the EU *Waste Framework Directive* (91/156/EEC), waste is 'any substance or object which the holder discards or intends to discard'. Some wastes (e.g., animal manures containing useful plant nutrients) may also be considered 'resources out of place'.

waste exchange: Arrangement in which companies exchange their wastes for the benefit of both parties.

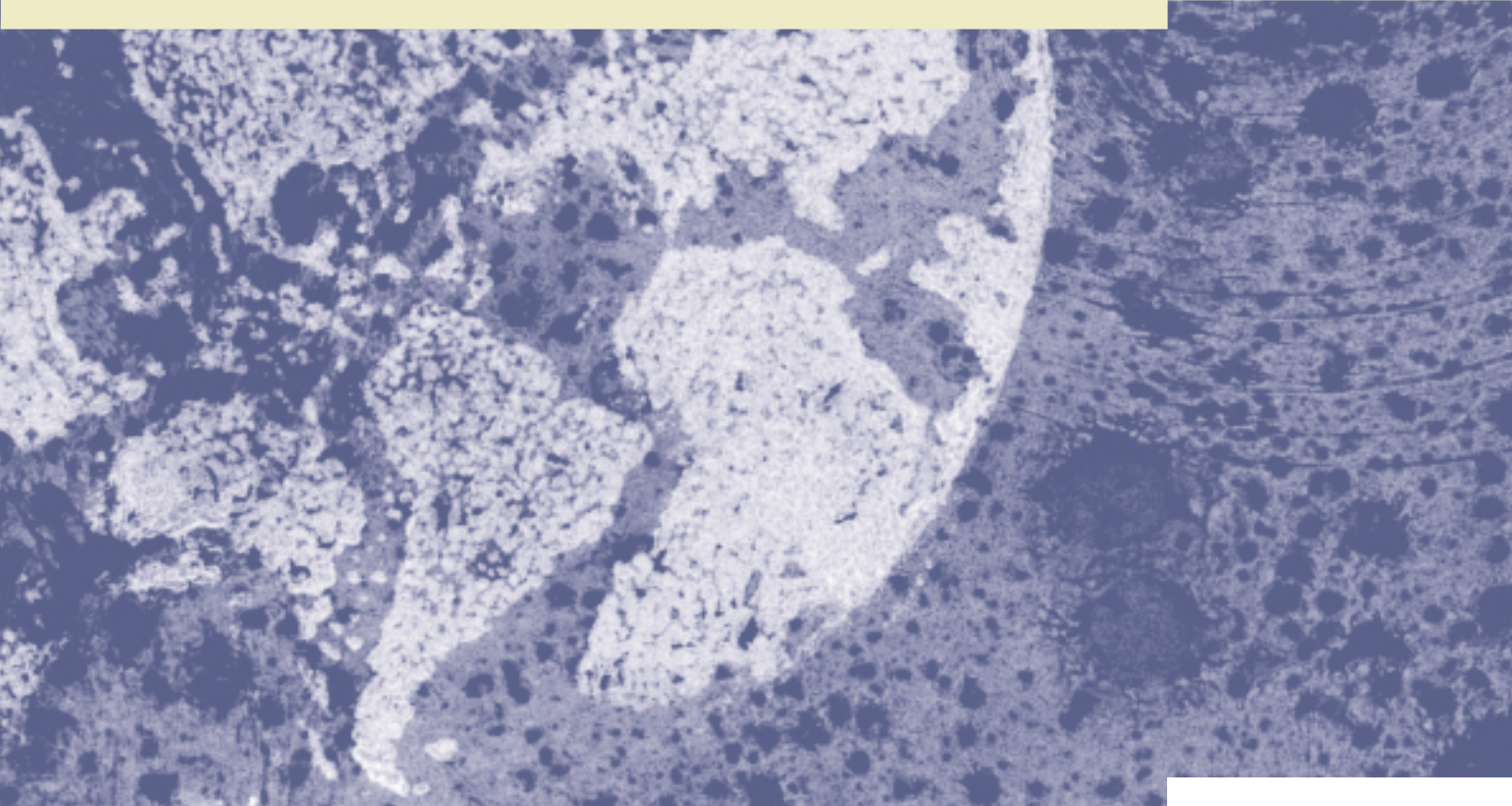
waste reduction: Using source reduction, recycling, or composting to prevent or reduce waste generation.

waste stream: The total flow of solid waste from homes, businesses, institutions, and manufacturing plants that are recycled, burned, or disposed of in landfills, or segments thereof such as the 'residential waste stream' or the 'recyclable waste stream'.

wastewater: Water carrying wastes from homes, businesses and industries that is a mixture of water and dissolved or suspended solids.

wet scrubber: A vessel used for removing pollutants from a gas stream by means of a liquid spray, liquid jet, or liquid layer.

Appendix C:
Compounds Found in
Fresh Kills (US) Landfill Gas



Appendix C:

Table C1 Compounds Found in Fresh Kills (US) Landfill Gas

Compound	Concentration	Unit
Ethane	311.41	ppmV
Propane	17.17	ppmV
Dichlorodifluoromethane	2.23	ppmV
Isobutane	15.05	ppmV
Acetaldehyde		ppmV
Vinyl Chloride	0.17	ppmV
Isobutene + 1-Butene	0.52	ppmV
1,3-Butadiene		ppmV
n-Butane	8.25	ppmV
Methanol (+)		ppmV
Bromomethane		ppmV
t-2-Butene		ppmV
Neopentane		ppmV
c-2-Butene		ppmV
Chloroethane	0.21	ppmV
Vinyl Bromide		ppmV
3-Methyl-1-Butene		ppmV
Isopentane	4.14	ppmV
Acetone (+)	25.46	ppmV
Trichlorofluoromethane	0.87	ppmV
1-Pentene	0.14	ppmV
2-Methyl-1-Butene	0.45	ppmV
Acrylonitrile		ppmV
n-Pentane	0.93	ppmV
Isoprene	0.18	ppmV
t-2-Pentene	0.81	ppmV
1,1-Dichloroethylene		ppmV
c-2-Pentene		ppmV
Methylene Chloride	0.88	ppmV
2-Methyl-2-Butene		ppmV
Neohexane	0.14	ppmV
Cyclopentene		ppmV
t-1,2-Dichloroethylene		ppmV
4-Methyl-1-Pentene		ppmV
1,1-Dichloroethane	1.18	ppmV
Cyclopentane	0.63	ppmV

Table C1 (continued)

Compound	Concentration	Unit
1-Propanol		ppmV
2,3-Dimethylbutane		ppmV
Methyl t-Butylether		ppmV
c-4-Methyl-2-Pentene		ppmV
Isohexane	0.41	ppmV
Butyraldehyde		ppmV
t-4-Methyl-2-Pentene		ppmV
2-Butanone		ppmV
3-Methylpentane		ppmV
1-Hexene	0.2	ppmV
2-Methyl-1-Pentene		ppmV
c-1,2-Dichloroethylene	0.63	ppmV
2-Ethyl-1-Butene		ppmV
n-Hexane		ppmV
Chloroform		ppmV
c-3-Hexene		ppmV
t-2-Hexene		ppmV
2-Methyl-2-Pentene		ppmV
c-2-Hexene		ppmV
c-3-Methyl-2-Pentene		ppmV
Methylcyclopentane	0.46	ppmV
1,2-Dichloroethane		ppmV
2,4-Dimethylpentane		ppmV
1,1,1-Trichloroethane	0.25	ppmV
Methylcyclopentene		ppmV
Benzene	0.38	ppmV
Carbon Tetrachloride		ppmV
1-Butanol		ppmV
Cyclohexane	0.65	ppmV
Isoheptane + 2,3-Dimethylpentane	0.76	ppmV
Cyclohexene		ppmV
3-Methylhexane	1.05	ppmV
1,2-Dichloropropane		ppmV
1,4-Dioxane		ppmV
Trichloroethylene		ppmV
1-Heptene		ppmV
2,2,4-Trimethylpentane	0.57	ppmV
n-Heptane	1.08	ppmV
t-3-Heptene		ppmV

Table C1 (continued)

Compound	Concentration	Unit
t-2-Heptene		ppmV
2,4,4-Trimethyl-1-Pentene		ppmV
c-1,3-Dichloropropene		ppmV
Methylcyclohexane	1.15	ppmV
Methylisobutylketone		ppmV
2,4,4-Trimethyl-2-Pentene		ppmV
2,5-Dimethylhexane	0.14	ppmV
2,2,3-Trimethylpentane		ppmV
t-1,3-Dichloropropene		ppmV
1,1,2-Trichloroethane		ppmV
2,3,4-Trimethylpentane	0.14	ppmV
Toluene	20.96	ppmV
1-Methylcyclohexene	0.36	ppmV
3,5,5-Trimethylhexene		ppmV
Dibromochloromethane		ppmV
3-Methylheptane	0.33	ppmV
Hexanal	0.55	ppmV
1,2-Dibromoethane		ppmV
2,2,5-Trimethylhexane		ppmV
1-Octene	0.33	ppmV
n-Octane	1.66	ppmV
Tetrachloroethylene	1.1	ppmV
c-2-Octene		ppmV
Chlorobenzene	1.48	ppmV
Ethylbenzene	3.99	ppmV
p-Xylene + m-Xylene	6.55	ppmV
Bromoform		ppmV
Styrene	3.04	ppmV
Heptanal		ppmV
1,1,2,2-Tetrachloroethane		ppmV
o-Xylene	1.97	ppmV
1-Nonene		ppmV
n-Nonane	4.07	ppmV
4-Nonene		ppmV
Cumene	0.36	ppmV
a-Pinene	6.84	ppmV
Benzaldehyde		ppmV
o-Chlorotoluene		ppmV
m-Chlorotoluene		ppmV

Table C1 (continued)

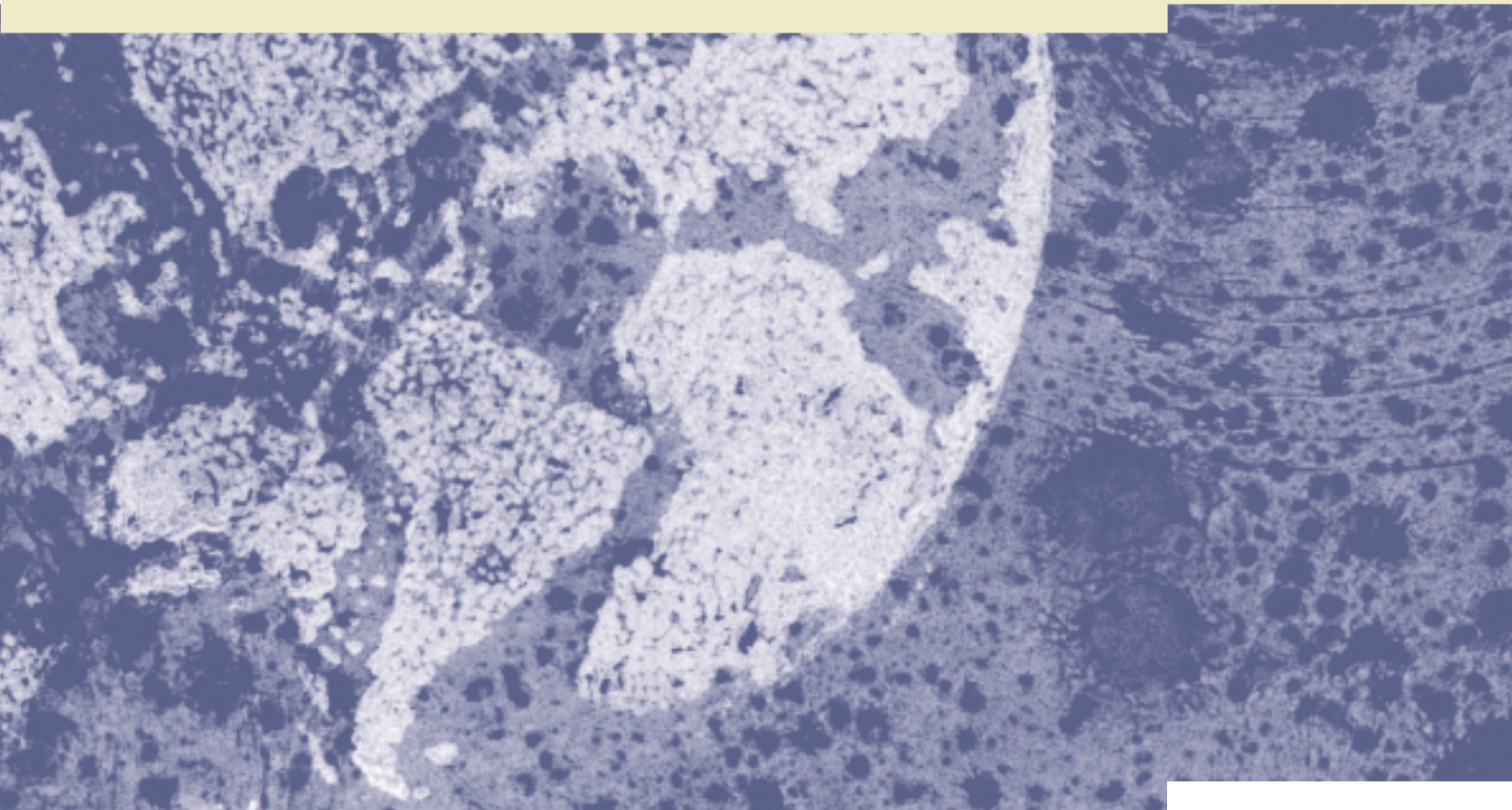
Compound	Concentration	Unit
n-Propylbenzene	1.68	ppmV
p-Chlorotoluene		ppmV
m-Ethyltoluene	1.83	ppmV
p-Ethyltoluene	1.2	ppmV
1,3,5-Trimethylbenzene	1.99	ppmV
o-Ethyltoluene	2.25	ppmV
b-Pinene	0.75	ppmV
1-Decene		ppmV
Isobutylbenzene	0.5	ppmV
1,2,3-Trimethylbenzene	0.65	ppmV
p-Isopropyltoluene		ppmV
o-Dichlorobenzene	0.8	ppmV
Limonene	25.23	ppmV
Indan		ppmV
Indene		ppmV
m-Diethylbenzene	0.72	ppmV
n-Butylbenzene	0.62	ppmV
p-Diethylbenzene	0.89	ppmV
1-Undecene	0.58	ppmV
n-Undecane	2	ppmV
Dichlorotoluene	0.26	ppmV
Naphthalene	0.09	ppmV
Total Unidentified VOCs	114.61	ppmV
Chloroprene		ppmV
Ethylene		ppmV
Chlorodifluoromethane		ppmV
Freon 113	0.13	ppmV
Vinyl Acetate		ppmV
Hexachloro-1,3-Butadiene	0.45	ppmV
Bromochloromethane		ppmV
Freon 23		ppmV
1,2,4-Trichlorobenzene	0.22	ppmV
Bromodichloromethane		ppmV
Benzyl Chloride & m-Dichlorobenzene	1.22	ppmV
n-Decane & p-Dichlorobenzene	8.66	ppmV
Ethanol & Acetonitrile		ppmV
1,2,4-Trimethylbenzene & t-Butylbenzene	2.73	ppmV
Diethyl Ether & 2-Propanol		ppmV

Table C1 (continued)

Compound	Concentration	Unit
2-Methylheptane	0.18	ppmV
Trichloroethene	0.49	ppmV
Carbon Dioxide	26.75	%
Chloromethane/Halocarbon 114	0.15	ppmV
Methane	39.21	%
Nitrogen	24.61	%
Oxygen	6.7	%
Carbon Monoxide		%
TNMHC	421	ppmV

(Source: EPA (US) 1999. See references in Chapter Three.)

Appendix D: Topic Guides, List of Participants and Advertisement for Submissions



Appendix D: Topic Guides, List of Participants and Advertisement for Submissions

D.1 Topic guide for service providers/industry/PEHO survey

(semi-structured interviews or focus groups)

General topics

What do you see as the main concerns and challenges in the way that waste is currently managed in Ireland?

What do you see as the main concerns and challenges in relation to landfilling of waste in Ireland?

What do you see as the main concerns and challenges in relation to incineration of waste in Ireland?

Who and what are the main drivers in the current situation?

What barriers do you see impeding progress to effective waste management?

Public Health and Environment

What is the impact on public health of landfill?

What is the impact on public health of incineration?

What is the impact on the environment of landfill?

What is the impact on the environment of incineration?

What sources do you base your information on?

In general, from where does your organisation source its information, data and knowledge on waste management?

Why have you chosen this source above others?

Which sources of information are the most credible in your opinion?

Organisational

Where in the waste management hierarchy does your organisation / body / department operate? What functions do you fulfil?

How do you view this positioning? Do you feel you / your organisation is effective in carrying out its functions in relation to waste management? What would you change about it if you could?

Compliance

What are your views (and, if different, your organisation's views) regarding current compliance with the regulatory framework?

What are the strengths and weaknesses of the regulatory mechanisms/framework? What needs to change?

(For Industry only)

To what extent is the firm's objective (a) to contribute to solving the waste problem or (b) to satisfy (just) the regulatory requirements?

Do you consider the area of waste management as being a suitable one for long-term investment and are there differences between landfill and incineration which affect your investment decisions or your access to venture capital?

Communication

What is your view on communicating waste management issues to the general public?

To what level do you think the general public is informed about issues in waste management?

How do you believe the public is currently informed about waste management issues?

To what level do you think the general public should be informed, and how?

Does your agency/organisation have specific initiatives, strategies and mechanisms to inform the general public on waste management issues? What are these? Could they be improved? If so, how?

What monitoring and evaluation methods do you use to measure the effectiveness and efficiency of your organisation's communication initiatives?

D.2 Topic guide for focus groups with the general public

Current waste management practices

What constitutes your household rubbish? What do you throw out regularly?

Where does your household waste go?

How do you know where it goes? Who informs you? How are you informed?

Whose responsibility is waste management (i.e., waste collection, disposal, recycling) in your area?

Whose responsibility do you think waste management should be (local authority, individuals, local business)?

Do you think there are problems with the current systems of waste management in your locality?

Do you think there are problems with the current systems of waste management in Ireland generally?

What objections do you have? Why? What have you done about them?

What are your concerns in terms of personal/family health and environmental effects, emissions, smells, impact on property prices, traffic? What other objections do you have?

Recycling

Do you recycle? Do you compost? What items do you recycle? How do you recycle?

Do you know about recycling facilities in your area? Do you use them? How often?

What is your overall attitude to recycling? (Discuss attitudes vs. behaviour.)

Would you be willing to pay for recycling facilities?

Compare Ireland's waste disposal and recycling practices with Scandinavian countries. Should Ireland recycle more?

Exporting waste

What do you know about Ireland exporting its waste?

What is your attitude to this?

Information

Do you receive information about waste management? From whom? How are you informed?

Who do you think should provide information? What methods should they use?

Do you believe what you are told about waste management practices? Do you trust the informants? If not, why not? (Discuss local authorities, political representatives, EPA, media, community action groups, local informal networks, rumour.)

Values

Is waste management an issue for you? How concerned are you about household, industrial, agricultural waste disposal and recycling?

What do you perceive to be the level of risk to you/your family? Local environment? Ireland? Future generations? The world generally?

How much of this do you think is related to modern lifestyles? Technocratic, consumer society vs environmental concerns?

What do you think are the long-term, short-term interests of decision-makers regarding waste management?

Changes

Have you any suggestions for change in terms of waste management in your area (i.e., bin collections, waste disposal, recycling)?

How likely do you think these changes are to come about?

How embedded do you think Irish people's beliefs and practices are regarding waste disposal, recycling?

What are your attitudes to different methods of waste management, i.e., landfill, incinerators, recycling?

Specific issues for people living near existing landfill/ incinerator sites:

Can you recall if you were concerned about any risks/problems prior to the introduction of this site?

What concerns, worries did you have? Why? What information were you given?

What problems have you actually experienced?

What benefits have you experienced?

Specific issues for people living near proposed landfill/incinerator sites:

What is your attitude to the proposed landfill/incinerator?

What have you been told about the proposed landfill/incinerator?

What risks do you perceive?

What benefits do you perceive, what is being put back into the community?

Where did you hear about plans for the proposed landfill/incinerator? Sources of information?

What is your attitude towards the information you have received? Towards the sources of information?

Do you know of any information meetings or opportunities for members of the local community to meet with planners/those responsible for the proposed landfill/incinerator? Did you attend? Why / Why not? What was the outcome?

Do you feel you were adequately consulted? Do local people have a strong voice about these issues?

D.3 Survey of service providers and industry

List of participants

Health and Safety Authority

Dept. of Environment & Local Government: Senior advisor on waste.

Dept. of Health & Children: Environmental unit and Senior EHO.

IWMA co-ordinator.

IWMA members (6).

Enterprise Ireland: Environment Department.

Institute of Engineers in Ireland.

Local Authorities Directors of Environmental Services: Dublin Corporation, Fingal and Dun Laoghaire Rathdown.

An Taisce: Chairman of Waste Management Group.

Food Safety Authority.

IBEC: Social, Environmental & Social Policy Co-ordinator.

IBEC members.

EPA: Programme Manager, Environment Management & Planning.

Monaghan County Council: County Manager (*phone*).

Monaghan County Council: Senior Engineer Environment Section (*phone*).

Teagasc: Head of Environmental Services (*phone*).

Southern Health Board: Director of Public Health (*phone*).

D.4 Advertisement in *The Irish Times* and *The Irish Independent* for submissions from the general public and interested parties

Waste management in Ireland

Will you share your views?

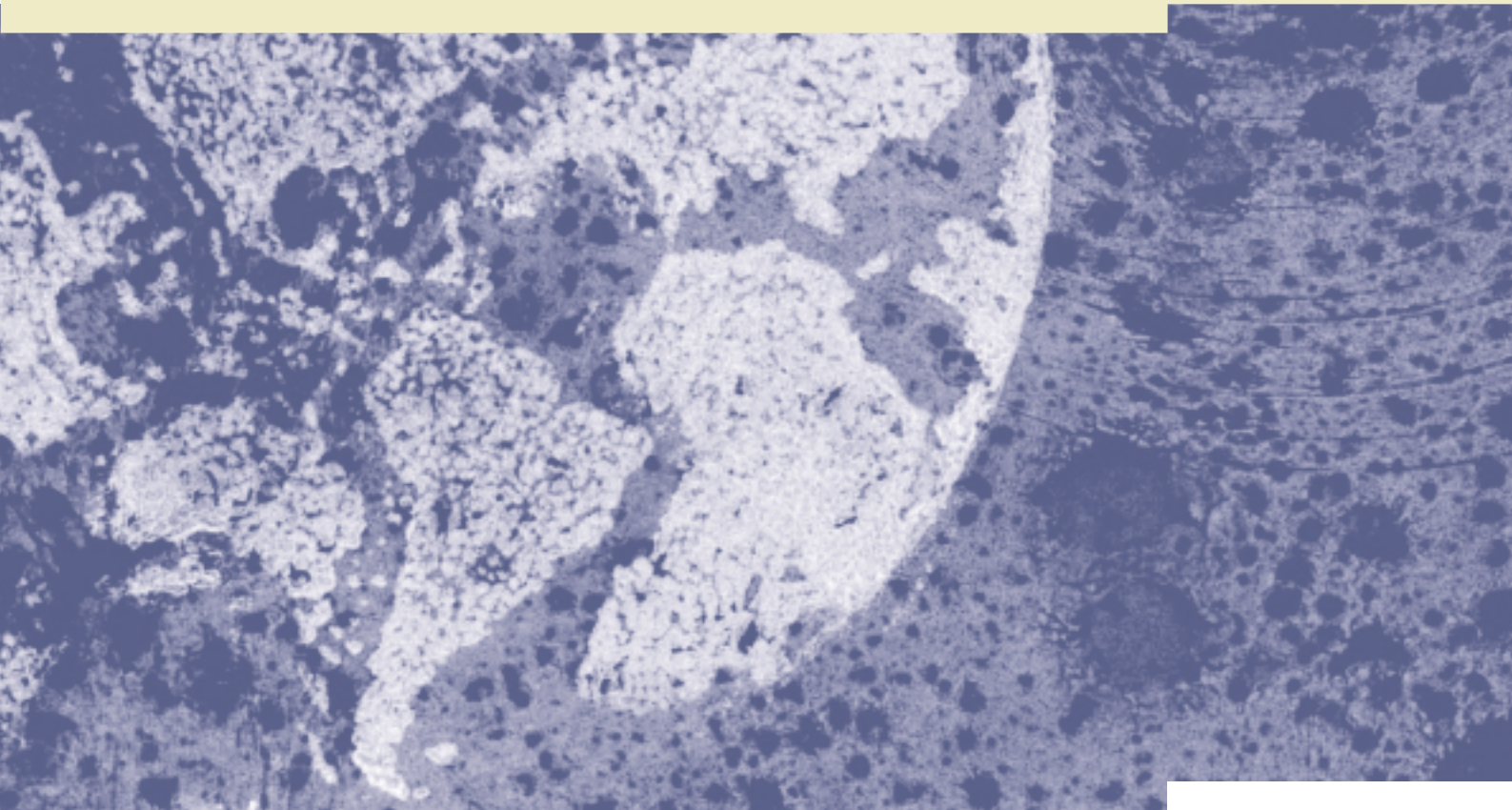
On behalf of the Department of the Environment and Local Government, the Health Research Board has commissioned a study of the public health and environmental effects of landfill and incineration of waste in Ireland.

Submissions are invited from members of the general public and interested groups.

Submissions should be titled 'Waste Management Study' and sent to The Department of Public Health Medicine and Epidemiology, University College Dublin, Earlsfort Terrace, Dublin 2.

The deadline for receipt of submissions is Feb 15, 2002.

Appendix E: Relevant EU Legislation



Appendix E: Relevant EU Legislation

Waste framework

Framework Directive on Waste (Council Directive 75/442/EEC as amended by Council Directive 91/156/EEC).

Hazardous Waste Directive (Council Directive 91/689/EEC as amended by Council Directive 94/31/EC).

Specific wastes

Disposal of waste oil (Council Directive 75/439/EEC).

Directives on waste from the titanium dioxide industry (Council Directives 78/176/EEC, 82/883/EEC and 92/112/EEC).

Batteries and accumulators containing certain dangerous substances (Council Directive 91/157/EEC).

Packaging and packaging waste (Council Directive 94/62/EC).

The disposal of polychlorinated biphenyls and polychlorinated terphenyls (PCB/ PCT) (Council Directive 96/59/EC).

Protection of the environment, and in particular of the soil, when sewage sludge is used in agriculture (Council Directive 86/27/EEC).

Processes and facilities

Reduction of air pollution from existing municipal waste-incineration plants (Council Directive 89/429/EEC).

Reduction of air pollution from new municipal waste-incineration plants (Council Directive 89/369/EEC).

Incineration of hazardous waste (Council Directive 94/67/EC).

Directive on the Landfill of waste (Council Directive 99/31/EC).

Transport, import and export

The supervision and control of shipments of waste within, into and out of the European Community (Council Regulation EEC No 259/93).

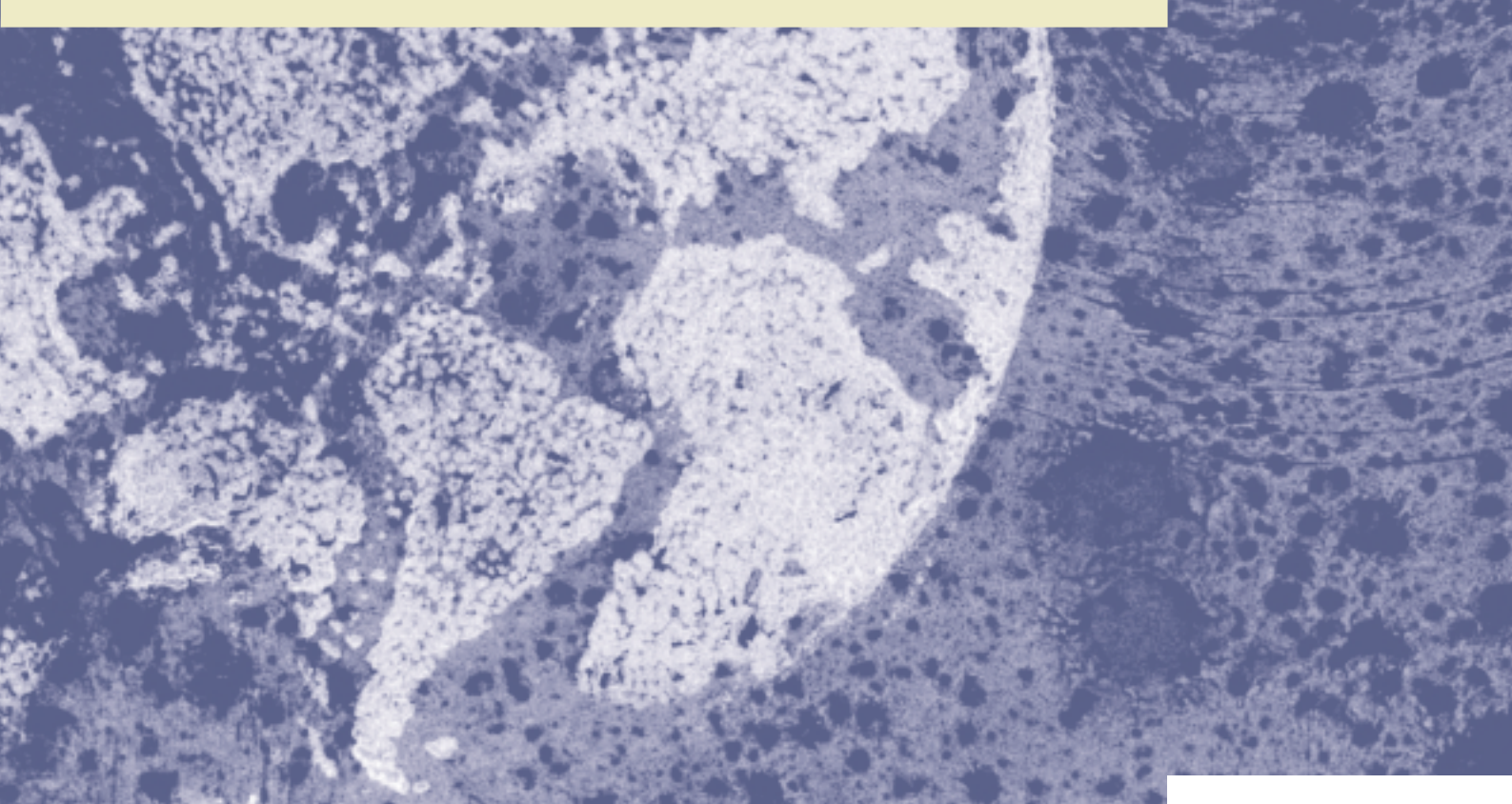
Table E1 Summary of inter-relationships between legislation in the waste management sector and other relevant EU legislation

Related sector legislation	Relevance
Horizontal sector	
Environmental Impact Assessment Directive (85/337/EEC)	Requires an EIA for new projects that are judged to have a significant impact on the environment. The results are to be made public, and the views of the public taken into consideration in the consent procedure. Projects affected include waste disposal facilities.
Access to Environmental Information Directive (90/313/EEC)	Requires environmental information held by public bodies to be made available to the general public on request. Some of the waste directives require member state to collect information. Any such information. This directive would cover any such information held by public bodies.
Reporting Directive (91/692/EEC)	Sets out provision on the transmission of information and reports concerning certain EU directives from member states to the European Commission. Waste directives have reporting requirements (see Section 6).
Air quality sector	
Air Quality Framework Directive (96/62/EC)	Sets out framework for a common strategy to address air pollution covering objectives for ambient air quality, assessment of air quality, publication of information, and maintaining air quality. This objective could affect waste management options (e.g. incineration).
Water quality sector	
Proposed Water Quality Framework (COM(97)49)	Aims to establish a framework for protection the quality of quantity of surface and groundwater resources. The development of waste management strategies and plans should take account of potential impacts of different option on water resources.
Urban Waste Water Directive (91/271/EEC)	Sets out measures to reduce pollution by nitrates of receiving waters. This affects the volume and character of sludge produced and future waste management strategies.
Nitrates Directive (91/67/EEC)	Sets out measures to reduce pollution by nitrates of receiving waters from agricultural practices. This potentially affects the disposal of sewage sludge to land.

Table E1 (continued)

Related sector legislation	Relevance
Water quality sector	
Dangerous Substance Directive (76/46/EEC) and related Directive	Controls emission of dangerous substance to receiving waters through permitting. This potentially affects the design; location and permitting of waste treatment and disposal facilities for example on wastewater discharges and site drainage.
List 1. Substances Directive (86/280/EEC)	Specific emission standards for prescribed substances for discharge to receiving waters. This potentially affects the design; location and permitting of waste treatment and disposal facilities for example wastewater discharges and site drainage.
Industrial pollution control and risk management sector	
IPPC Directive (96/61/EC)	Implements integrated measures for the prevention and control of pollution. Requires permits for prescribed activities (including waste treatment and disposal), which set conditions including emission limits. Requires application of BATNEEC. This affects waste treatment and disposal facilities.
Large Combustion Plants Directive (88/609/EEC)	Sets emission standards for new and existing energy generating plants with a thermal input of 50 MW or more. This affects waste disposal by incineration, and disposal of fly ash. Slag and other by-products from gas cleaning.
Seveso II Directive (96/82/EC)	Aims to prevent major accidents involving dangerous substances and limiting impacts on people and the environment. Wastes can be dangerous substances, and accidents can potentially occur during the collection, treatment, transport and disposal of wastes.
Chemical and genetically modified organisms	
Classification, packaging and labelling of dangerous substances Directive (67/548/EEC)	Sets rules on classification, packaging and labelling of prescribed chemicals. Requires notification of the placement of these substances on the market in member states. This potentially affects the transport of materials recovered or recycled from waste.
Risks of existing substances Regulations (EEC/793/93) and related Regulations Import and export of Dangerous Chemicals Regulations (EEC/245/92)	Requires reporting on chemicals and risks assessment for certain chemicals. This potentially affects material recovered or recycled from wastes. Establishes a common system of notification and reporting on the transport of dangerous chemicals. Some wastes can be considered dangerous chemicals.

Appendix F: The Powers and Functions of the Environmental Protection Agency



Appendix F: The Powers and Functions of the Environmental Protection Agency

The Agency protects and significantly strengthens the management and regulation of our environment through the following functions.

Control

- Licensing major developments and enforcing compliance.
- Licensing and regulation of waste disposal and recovery activities including landfills.
- Authorising certain public sector activities.
- Imposing conditions on marine developments.

Monitoring

- Monitoring general environmental quality.
- Monitoring the quantity and quality of water resources.
- Monitoring specific problems.

Promotion

- Issuing guidelines on environmental issues.
- Issuing codes of practice.
- Encouraging environmental audits.
- Encouraging environmentally friendly products and services.
- Co-ordination of environmental research programmes.
- Encouraging local authorities in environmental protection.
- Providing training in environmental protection.

Advice

- On policy matters.
- On the need for legislative changes.
- On environmental quality standards.

- On emission standards.
- On environmental impact statements.

Supervision

- Supervising environmental monitoring by other authorities.
- Overseeing the environmental activities of local authorities.

Consultation

- Providing consultation for developers seeking licences.
- Consulting with public authorities about their environmental functions.

Information services

- Publication of monitoring results.
- Provision of public access to environmental databases
- Preparation and updating of a national hazardous waste plan.
- Publication of ' State of the Environment' reports.
- Holding of seminars and conferences.

(available at <http://www.epa.ie/about/default.htm>)

(For the purposes of this section we distinguish between risk – the generic term for all aspects of the adverse consequences of waste disposal – and hazard – an estimate of the likely adverse effects of waste disposal as measured by the number of extra deaths, extra cases of cancer, or other adverse health outcomes.)

