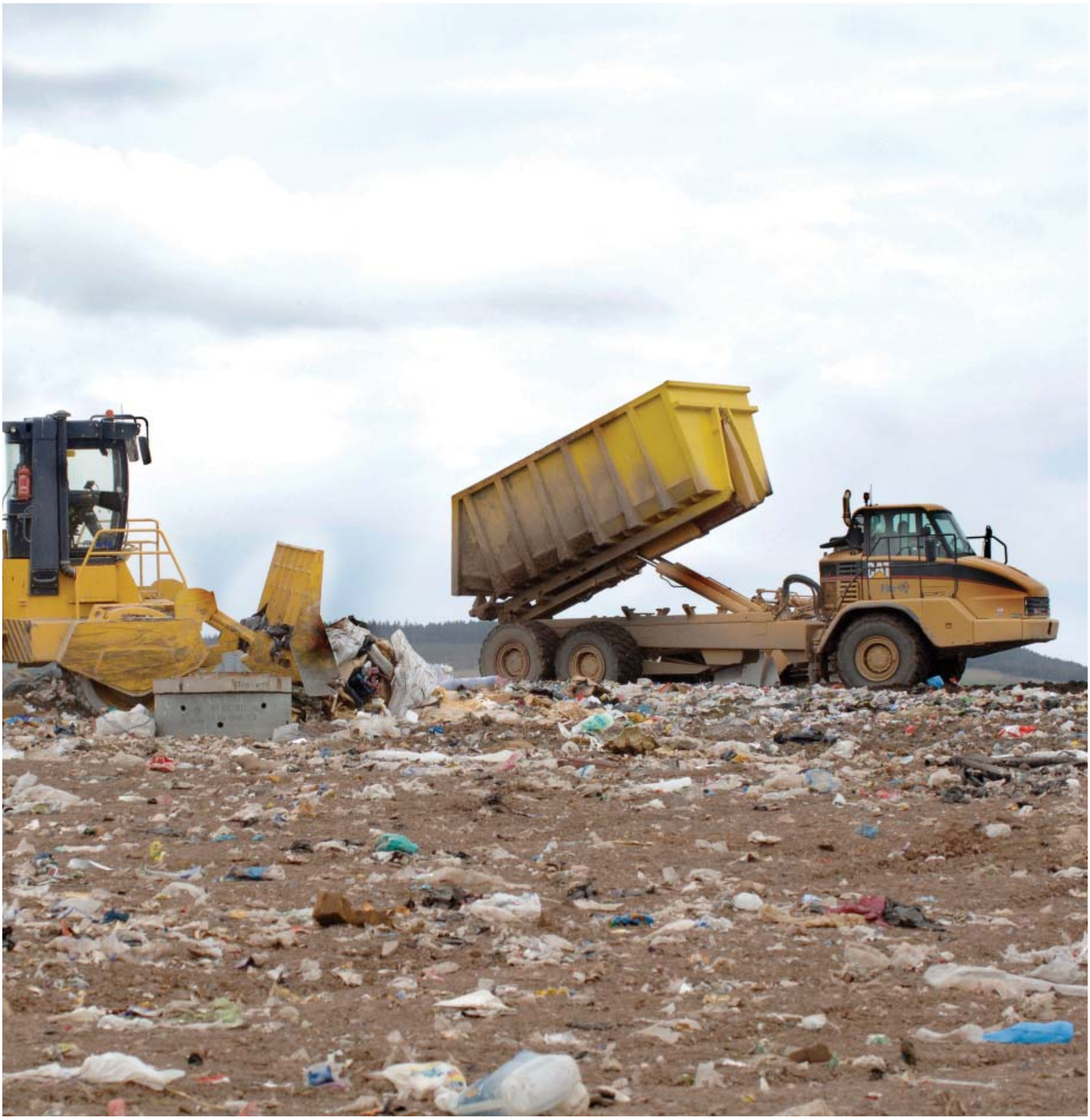
Health Protection Agency

Impact on Health of Emissions from Landfill Sites

Advice from the Health Protection Agency



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Contents

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This paper from the Health Protection Agency reflects understanding and evaluation of the current scientific evidence as presented and referenced in this document.

Summary

Most waste in the UK has traditionally been disposed of to landfill sites. These can generate considerable public concern about the health effects of emissions and there have been suggested links to a range of health effects including cancer and birth defects. The Health Protection Agency (HPA) recognises that the practice of disposing of waste materials to landfill can present a pollution risk and a potential health risk. However, modern landfills are subject to strict regulatory control which requires sites to be designed and operated such that there is no significant impact on the environment or human health. An assessment of the health risks posed by landfill sites and other forms of waste management was published by the Department for Environment, Food and Rural Affairs in 2004, incorporating a review of the assessment by the Royal Society. The HPA has now carried out a review of more recent research into the suggested links between emissions from landfill sites and effects on health. This review encompasses the results of a number of epidemiological studies, detailed monitoring results from a major project funded by the Environment Agency, and advice sought from the Committee on Toxicity of Chemicals in Food, Consumer Products and the Environment. The HPA concludes that there has been no new evidence to change the previous advice that living close to a well-managed landfill site does not pose a significant risk to human health.

It is important that research continues to inform the risk of exposure from UK landfill sites. This should include the development of more sensitive sampling and analytical methods for pollutants detected around landfill sites and, ideally, surveys of pollutant concentrations around more sites. It would also be valuable if more complete toxicological data were available for some of these pollutants. Detailed site-specific risk assessment should remain an important part of the permitting and management process.

The HPA is aware that concerns about the health effects of landfill sites often stem from historic sites. However, it is not possible to provide definitive advice regarding historic or closed landfill sites which pre-dated waste management regulation in the UK, due to the large variability in wastes which entered these sites, and the variability in their design and operation when open. Where landfills are the subject of local concern, site-specific monitoring and/or modelling is needed to aid any risk assessment and address any uncertainty about the nature of any emissions.

The role of the HPA is to provide expert advice on public health matters to government, stakeholders and the public.

1 Introduction

The Health Protection Agency (HPA) provides expert advice on the public health risks of chemicals, radiation and infectious diseases to government and a range of other stakeholders including members of the public. In England and Wales, the Environment Agency (EA) is the main regulator of emissions from active landfill sites and closed sites with permits*. Historic sites which no longer have a permit are the responsibility of the landowner or the local authority. The use of landfills for waste disposal in the UK is decreasing, with government policy encouraging the recycling, recovery and re-use of waste. In 2006, 69 million tonnes of waste went to landfill compared to 47 million tonnes in 2009 in England and Wales (EA, 2009). Modern landfills are subject to strict controls which require sites to be designed and operated such that there is no significant impact on the environment or human health. The Environmental Permitting Regulations 2010 are the main piece of legislation relating to the control of emissions from landfills in England and Wales and set strict criteria on emissions and the management of a site (GB Parliament, 2010). Historic landfills are managed under the Environmental Protection Act 1990, Part 2A (GB Parliament, 1990).

The European Landfill Directive was adopted in 1999 and introduced three classes of landfill (EC, 1999):

- **a** landfills for inert waste only,
- **b** landfills for non-hazardous waste,
- **c** landfills for hazardous waste.

There are now strict restrictions on the types of waste that each class of landfill can accept and the practice of co-disposal of different waste types is no longer permitted. Various materials are now banned from landfill including all liquid wastes, corrosive, explosive or flammable waste, hospital and clinical infectious waste, whole used tyres (since 2003) and shredded tyres (from 2006). Waste going to landfill is also required to be pre-treated (including sorting) to encourage recovery and recycling. In addition, there are now requirements to ensure that waste entering landfill meets the relevant waste acceptance criteria for the class of landfill. The aim of these criteria is to reduce the amount of waste going to landfill and to ensure that waste in landfill does not degrade or release contaminants into leachate which might be harmful to the environment. These restrictions serve to reduce the potential of modern landfills to contaminate the local environment.

The comparative impacts on health of different methods of waste management were considered in a report prepared for the Department for Environment, Food and Rural Affairs (Defra, 2004). This work was

* In Scotland, landfills are regulated by the Scottish Environment Protection Agency (SEPA) and in Northern Ireland by the Department of Environment (DOENI).

co-authored by the University of Birmingham and independent consultant Enviros and involved recognised experts in the field of air pollution and waste management. The report, which was reviewed by the Royal Society, concluded that there was no consistent evidence that people living close to landfill sites suffered worse health than people living further away from such sites. The report recommended that further work should be undertaken to show whether a causal connection between landfill sites and human health is plausible, especially in relation to adverse birth outcomes.

Since 2001, the EA has undertaken a considerable amount of research on potential routes of exposure around landfill sites (EA, 2001, 2003, 2010a–c). Between 2002 and 2009 the EA monitored concentrations of airborne chemicals, dusts and micro-organisms at the boundaries of four landfill sites selected to be typical of UK sites accepting municipal waste. The sites were selected on the basis of conformance criteria specified by the EA, which included the sites being operationally open, having a local population within close proximity, groundwater within 10 m, surface water within 50 m and landfill gas utilisation or flaring in place. The aim of the work was to provide information in relation to the potential risks to public health that may arise from landfill emissions.

The first set of data was collected at the boundaries of two municipal waste landfill sites between 2002 and 2005 (EA, 2010a,b). All potential exposure pathways were considered and over 60 chemicals or chemical groups were monitored. This study included a detailed survey of emissions to air and considered continuous monitoring of several compounds over a 22-month period and over 1200 site boundary measurements of potential contaminants of concern. Measurements were made at different times of the day and took into account the prevailing meteorological conditions. A second, subsequent study was undertaken in 2009 to improve on this dataset of substances (EA, 2010c). In this second study, fewer measurements were taken but with greater analytical sensitivity.

The chemicals monitored were chosen on the basis of both known toxicity and because they are the principal ones expected to be emitted from landfill sites. Table 1 lists the chemicals and other substances which were measured. Measured concentrations were compared to specific health criteria values (HCV)* derived for the project. In the first study, for a few chemicals, the concentrations detected were close to the detection limits used, raising questions about the reliability of these results. The second study employed lower detection limits. Unless otherwise stated, exposure data cited in this report have been taken from these monitoring studies.

Despite such an intensive monitoring programme, it is important to appreciate that the design and composition of waste material within landfills will vary considerably from site to site. This variability makes it extremely difficult to predict what chemicals and other substances may be emitted into the local environment from any specific site. Where landfills are subject to local concern, site-specific monitoring and/or modelling is needed to aid any risk assessment and address any uncertainty in the nature of any emissions.

* Health Criteria Value (HCV) is a generic term used to describe a benchmark level of exposure to a chemical derived from available toxicity data for the purposes of safeguarding human health (eg a tolerable daily intake).

TABLE 1 Chemicals and other substances measured in the Environment Agency landfill exposure study (EA, 2010a,b)

1,1-dichloroethane	Chromium	Moulds
1,1,1-trichloroethane	Chrysene	Naphthalene
1,2-dichloroethane	Cobalt	Nickel
1,2-dichloroethene	Copper	Nitrogen dioxide
1,3-butadiene	Dibenzo(ah)anthracene	Nitromethane
2-butanone	Dichlorobenzene	Particulate matter, PM_{10}
2-ethyl-1-hexanol	Dichlorodifluoromethane	Penicillia
2-methylfuran	Dichlorofluoromethane	Phenanthrene
Acenaphthene	Dichloromethane	Polychlorinated biphenyls (PCBs)
Acenaphthylene	Dimethyl disulphide	Polychlorinated dibenzo-p-dioxins, polychlorinated dibenzofurans (PCDDs and PCDFs)
Anthracene	Dimethyl sulphide	Pyrene
Antimony	Endotoxins	Stibine
Arsenic	Entrobacteriaceae	Styrene
Arsine	Ethylbenzene	Sulphur dioxide
Aspergillus fumigatus	Ethyl mercaptan	alpha-terpinene
Benzene	Fluoranthene	Tetrachloroethene
Benzo(a)anthracene	Fluorene	Thallium
Benzo(a)pyrene	Fibres	Thermophilic bacteria
Benzo(b/k)fluoranthene	Formaldehyde	Thermophilic fungi
Benzo(ghi)perylene	Fungi and yeasts	Tin
Cadmium	Gram-negative bacteria	Toluene
Carbon disulphide	Hydrogen sulphide	Trichloroethene
Chlorobenzene	Indeno(123-cd)pyrene	Trimethylbenzene
Chlorodifluoromethane	Lead	Vanadium
Chloroethane	Manganese	Yeasts
Chloroethene	Mercury	m- and p-Xylene
Chloroform	Mesophilic aerobes	o-Xylene
Chloromethane	Methyl mercaptan	

The advice in this report has considered published research from the EA on the level of exposure to emissions from landfill sites, published peer-reviewed epidemiological studies and statements from the government's independent advisory committee, the Committee on Toxicity of Chemicals in Food, Consumer Products and the Environment (COT) (COT, 2001, 2010). The HPA notes that data on the composition of closed or historic landfill sites, which pre-dated modern waste management regulations in the UK, are extremely limited due to the large variability in wastes which entered these sites and differences in their design and operation when open. This inherent variability is recognised within this advice.

2 Landfill Emissions

The main sources of emissions from landfill sites are as follows:

- **a** the waste materials as they are brought onto site, normally in heavy goods vehicles,
- **b** emissions from this transport and any heavy plant used on site,
- **c** waste blown by the wind as it is tipped or deposited at the landfill site,
- **d** dust generated from the surface of the landfill and when waste is tipped or unloaded,
- **e** the waste materials which have previously been deposited in the landfill site,
- **f** any gas generated as the waste breaks down, which is not collected and treated,
- **g** any plant used to burn landfill gas, including gas flares or engines,
- **h** any leachate produced as the waste breaks down,
- **i** the discharges from any processes used to treat the leachate.

Modern landfills are lined and capped, which restricts emissions and makes it less likely that chemicals, gases, dusts, etc, will come into contact with the local population. Under the European Landfill Directive and the Environment Permitting Regulations the site operators are required to control all emissions from landfill sites. This involves risk assessments to look at both typical and atypical operations to ensure that emissions to air and the wider environment from landfill sites are controlled to be within required limits and so minimise the impact on human health and the environment. Where necessary, controls will be put in place to ensure the environment and health are adequately protected.

Landfill gas is the principal component of emissions to air from landfill sites. It is an end-product of the anaerobic process of degradation of biodegradable wastes once the waste has been deposited to landfill. The composition of the gas varies according to the type of waste and the phase of degradation of the waste, but typically it contains a large proportion of methane (around 65% by volume) and carbon dioxide (around 35% by volume). Small amounts (around 1% in total) of a range of trace components such as organic gases or vapours are also present (EA, 2002).

Table 2 summarises the main potential pathways for exposure of local people to emissions from landfill sites. Where exposure does occur, it is most likely to occur by inhalation of airborne emissions or dusts. Exposure through drinking water contaminated with leachate from landfill sites is considered less likely due to operational controls and the strict regulation and monitoring of drinking water supplies. Airborne pollutants can also be released from the combustion of landfill gas by gas engines or flares. If a landfill gas collection and control system is in place and operating efficiently, exposures to fugitive (uncontrolled) emissions away from a landfill site should be kept to a minimum. Proper regulation and post-closure monitoring should ensure that emissions are minimised and any exposure is low.

TABLE 2 Summary of potentially significant pathways for exposure of local people (adapted from EA, 2010a)

Hazard	Source	Medium of exposure
Acid gases	Flare/engine emissions	Inhalation exposure
Toxic organic micropollutants	Flare/engine emissions	Inhalation or ingestion exposure
Organics (including volatile organic compounds and other gases)	Flare/engine emissions	Inhalation exposure
Organics (including volatile organic compounds and other gases)	Leachate/surface water runoff	Inhalation or ingestion exposure
Bulk gases (ie methane), volatile organic compounds and other gases	Landfill gas	Inhalation exposure
Particulates, metals and toxic organic micropollutants	Tipping	Inhalation or ingestion exposure
Particulates, metals and toxic organic micropollutants	Waste in vehicles	Ingestion exposure
Bioaerosols	Tipping	Inhalation exposure
Bioaerosols	Waste in vehicles	Inhalation exposure

It has been suggested that landfills account for between 10 and 25% of all odour complaints to local authorities (Defra, 2004). Potential odour sources at landfill sites include leachate, landfill gas and odour from newly deposited materials. In some cases landfill odours have been detected over 1 km away and over half of the complaints made about landfills relate to odour (Defra, 2004).

2.1 Acid gases

Acid gases may be emitted from landfill gas flares and engines as a result of the landfill gas combustion process. Examples of acid gases which can be emitted are nitrogen dioxide, sulphur dioxide and halides, such as hydrogen chloride and hydrogen fluoride. Emissions from landfill sites can contribute to existing background levels of these pollutants in the local area. This is especially important for nitrogen dioxide and sulphur dioxide which can be produced in significant quantities from many other industrial and transport sources and therefore any additional contribution from landfill sites could have an impact on local air quality.

At high concentrations, nitrogen dioxide (NO_2) acts as an irritant of the airways and exposure can produce inflammation and bronchoconstriction (narrowing of the lungs) and can affect the immune cells in the lungs, increasing susceptibility to respiratory infections. Asthmatics are most susceptible, although high levels of NO_2 may also produce effects on the lung function of non-asthmatics.

Measurements from the boundaries of landfill sites indicate that emissions of NO_2, from flares or engines, even when combined with background levels, were below relevant health-based ambient air quality standards (EA, 2010a). As a result, emissions of NO_2 from active well-managed landfill sites should not significantly impact local air quality and consequently the health of those living close to a landfill site. Proper control of emissions and strict regulation of landfill sites should ensure that emissions do not result in an exceedance of ambient Air Quality Objectives as set out in the UK Air Quality Strategy (Defra, 2007).

Sulphur dioxide (SO_2) can also have an irritant effect on the airways and can cause bronchoconstriction. Asthmatics, children and the elderly are particularly sensitive and the concentration required to produce an effect in asthmatic individuals would typically be far less than that required for non-asthmatic individuals. High concentrations of SO_2 may trigger asthma attacks. However, asthmatic individuals will vary considerably in their response to SO_2. Regulation of landfill sites and pollution control measures should limit SO_2 emissions. Monitoring data from the boundary of landfill sites suggest that SO_2 concentrations were comparable to those found at many other urban and rural locations in the UK and typically below health-based standards (EA, 2010a). Therefore, providing the site is properly managed and regulated, it is unlikely that emissions from landfill sites will significantly affect local air quality.

Landfill gas combustion may produce small amounts of halides, but these are not routinely monitored. Therefore data on halides such as hydrogen chloride and hydrogen fluoride are very limited. High concentrations of hydrogen chloride and hydrogen fluoride are an irritant to the mucous membranes and can cause irritation to the eye, nose and throat and airways due to dissolution in body fluids to form acidic solutions. Halides such as hydrogen chloride have a high solubility and are readily deposited in the nose and upper respiratory tract where the main effects tend to be observed (EPAQS, 2009). It is also thought that halides may stimulate the irritant receptors associated with nerve endings in the airways, which can cause cough, chest tightness, breathlessness and bronchoconstriction. The HPA is not aware of any reports that halides from landfill gas combustion have caused health problems.

2.2 Toxic organic micropollutants

The term ‘toxic organic micropollutants’ (TOMPs) includes polychlorinated dibenzo-para-dioxins and polychlorinated dibenzofurans (PCDDs and PCDFs) (collectively termed ‘dioxins’) and polycyclic aromatic hydrocarbons (PAHs). These compounds are all ubiquitous in the environment and are therefore not just associated with landfill sites.

2.2.1 Dioxins (PCDDs and PCDFs)

The presence of chlorine-containing substances in landfill gas may give rise to the formation of dioxins through the combustion process. The COT has recommended a tolerable daily intake (TDI) for dioxins, which is the amount that can be ingested daily over a lifetime without appreciable health risk (COT, 2001). This TDI is based on a detailed consideration of the extensive toxicity data on the best-studied dioxin, 2,3,7,8-tetrachlorodibenzo-para-dioxin (TCDD), but may be used to assess the toxicity of mixtures of dioxins and dioxin-like polychlorinated biphenyls (PCBs) by use of Toxic Equivalency Factors (TEFs), which allow concentrations of the less toxic compounds to be expressed as an overall equivalent concentration of TCDD. These toxicity-weighted concentrations are then summed to give a single concentration expressed as a Toxic Equivalent (TEQ). The system of TEFs used in the UK and a number of other countries is that recommended by the World Health Organization (WHO), and the resulting overall concentrations are referred to as WHO-TEQs (van den Berg et al, 2006).

The TDI for dioxins of 2 picograms (pg) WHO-TEQ per kilogram (kg) bodyweight per day is based on the most sensitive effect of TCDD on laboratory animals, namely, adverse effects on the developing foetus resulting from exposure *in utero*. As a result, this TDI will protect against the risks of other adverse effects including cancer. The advice of the sister committees to the COT, the Committee on Carcinogenicity of Chemicals in Food, Consumer Products and the Environment (COC) and the Committee on Mutagenicity of Chemicals in Food, Consumer Products and the Environment (COM), informed the conclusion that dioxins do not directly damage genetic material and that evidence on biological mechanisms suggests that a threshold-based risk assessment is appropriate.

Data for two landfill sites show median concentrations of dioxins in air at the boundaries of the sites to be 19 femtograms (fg) WHO-TEQ m^{-3} and 15 fg WHO-TEQ m^{-3}, respectively (EA, 2010a). To place these results into context, a typical UK rural background concentration was estimated to be 10 fg WHO-TEQ m^{-3}, and a typical urban background level was estimated to be 40 fg WHO-TEQ m^{-3} (Defra, 2004). Monitoring by the EA did result in a report of a single high level concentration of 1839 fg WHO-TEQ m^{-3} at one site, but no evidence was found of any unusual activity at the site which could have given rise to the high reading. Furthermore, dioxins in soils nearby were found to be low and within the normal UK range, suggesting that this single high value was not representative of emissions from the site.

The EA 'Dioxin Risk and Exposure Assessment Model' (DREAM) was used to estimate the total exposure to dioxins around these landfill sites including dietary exposure. The results indicated that the estimated intake from eating locally grown produce was comparable to background levels and well below the TDI of 2 pg WHO-TEQ per kg bodyweight per day (Food Standards Agency, FSA, 2003; COT, 2010).

2.2.2 Polycyclic aromatic hydrocarbons (PAHs)

Polycyclic aromatic hydrocarbons (PAHs) are a large group of structurally similar chemicals which are ubiquitous in the environment as both gases and associated particulates. They are emitted from landfills as a product of the combustion of landfill gas. Studies in humans and experimental animals have found an association between exposures to mixtures of certain PAHs and tumours of the lung, skin and possibly other sites in the body. Certain PAH compounds are considered to have potential genotoxic carcinogenic properties* and these are the main compounds of concern in relation to landfill emissions. The only PAH which has been tested in detail in health studies is benzo(a)pyrene (BaP).

* Genotoxic carcinogens induce cancer by a mechanism that involves the compound itself, or a metabolite, reacting directly with the genetic material of cells (DNA), producing a mutation. This process is called mutagenicity. It is theoretically possible that one 'hit' on DNA may produce a mutation that can eventually develop into a tumour. The assumption is thus made for genotoxic carcinogens that they do not have a threshold and that any exposure is associated with an increase in risk, albeit this may be very small.

Polycyclic aromatic hydrocarbons are not routinely measured from landfill gas combustion systems. The EA has monitored six carcinogenic PAHs commonly found as air pollutants at the boundaries of two landfill sites and found that the 50th percentile concentrations were either below or only slightly above the Air Quality Standard of 0.25 ng m^{-3} BaP recommended by the Expert Panel on Air Quality Standards as an annual average for PAH compounds (EPAQS, 1999). It was concluded that the concentrations measured were not a major cause for concern (COT, 2010).

2.3 Other gases

Landfills also emit other gases, including:

a methane (CH_4) and carbon dioxide (CO_2), as a result of surface and lateral landfill gas emissions and as a result of combustion of landfill gas engines and flares,

b volatile organic compounds (VOCs), which are a trace component of landfill gases and are also emitted from landfill gas engines and flares.

2.3.1 Methane (CH_4) and carbon dioxide (CO_2)

The health effects of exposure to methane and carbon dioxide are well known. Both are colourless, odourless gases which act as asphyxiants. Carbon dioxide is non-flammable and, at low concentrations or low levels of exposure, it increases the depth and rate of respiration, blood pressure and pulse (HPA, 2010). At increasing concentrations, a depressive phase develops which can culminate in cardiorespiratory failure. Concentrations above 6% by volume can give rise to headache, dizziness, mental confusion, palpitations, increased blood pressure, difficulty breathing and central nervous system depression. Humans cannot breathe air containing more than 10% carbon dioxide without losing consciousness.

In contrast to carbon dioxide, methane is a flammable gas which is explosive in air at concentrations between 5 and 15% by volume. Inhalation can cause nausea, vomiting, headache and loss of coordination. At very high concentrations it may cause coma and death due to respiratory arrest (HPA, 2009a).

Emissions of both methane and carbon dioxide from landfill sites should be controlled through a landfill gas management system based around capping and gas flares and/or engines. Therefore concentrations should not be high enough to cause significant health effects unless the gases are allowed to build up in confined spaces such as sewers and basements.

2.3.2 Volatile organic compounds (VOCs) and other gaseous compounds

Landfill gases include trace gases such as VOCs and gaseous compounds such as arsine and stibine, which typically make up approximately 1% of raw landfill gas. The composition of trace gases is dependent on the type of waste in landfill but includes groups such as halogenated hydrocarbons and aromatic hydrocarbons. The percentage of fugitive (uncontrolled) gas escaping will depend primarily on the overall collection efficiency on-site, which is dependent on the collection system, the site dimensions, the engineering design of the site (lining and capping) and the volume of gas generated. If a landfill gas collection and control system is in place and operating efficiently, exposures to fugitive emissions away from a landfill site should be minimal. VOCs may also be generated by landfill gas engines (eg crankcase emissions) and landfill flares. A study reported that landfill gas engines were effective at destroying VOCs with a typical efficiency of 96 to 99.9% (Gillett et al, 2002).

The EA monitored a large number of VOCs and other gases at the boundary of typical landfill sites (EA, 2010a,c). The VOCs were selected on the basis of their toxicity and odour potential. The overwhelming majority of the VOCs and other gases measured were well below (<1%) the relevant HCV. A number of VOCs and other gases were present in higher concentrations, including compounds such as chloroethene, 1,2-dichloroethane, dimethyl sulphide, dimethyl disulphide, formaldehyde, methyl mercaptan, styrene, toluene and stibine. However, the health risks associated with stibine are difficult to quantify owing to the lack of data on the amount of stibine emitted from landfill sites. Current analytical methods of monitoring stibine are not especially sensitive.

Arsine was also detected in the first EA study at levels in excess of the HCV. However, the levels detected were close to the detection limit and it is not clear how reliable they were. No arsine was detected in the second study, which used lower detection limits but, as the detection limit was lower than the HCV at only one site, it is not possible to say whether the levels were above or below the HCV at the other site (EA, 2010c). Arsine is a colourless gas with a mild, garlic odour which is expected to be converted in humans to arsenic (although the extent of conversion is unclear). While arsine is acutely toxic, measured concentrations are unlikely to present a risk to health. However, given the risks associated with chronic exposure to arsenic (inorganic arsenic is a known human carcinogen which acts through a genotoxic mechanism), research on arsine metabolism in a suitable species and further monitoring data are needed.

The COT noted that, although there were limited toxicity data on some of the chemicals from which to formulate health advice, the levels of the VOCs and other gases found at the boundaries of the sites were unlikely to give rise to significant adverse health effects (both acute and chronic) (COT, 2010). The HPA agrees with this view and therefore, provided the landfill is well regulated and managed, emissions of VOCs at landfill sites are unlikely to pose a significant risk to health.

2.3.3 Hydrogen sulphide (H_2S)

Hydrogen sulphide (H_2S) is a colourless, flammable gas with a characteristic odour of rotten eggs. It is produced in landfill sites when high sulphate bearing materials (such as gypsum and plasterboard) are mixed with biodegradable waste. The composition of the waste material and the design and management of the site will determine the amount of H_2S produced and concentrations in landfill gas can vary considerably. The landfilling of biodegradable waste materials with high sulphur content has been prohibited in England and Wales since July 2005 (EA, 2008). At low concentrations, H_2S may result in irritation to the mucous membranes of the eye and respiratory tract. Exposure to high concentrations results in depression of the central nervous system, loss of consciousness and respiratory paralysis (HPA, 2009b). Other health effects have been reported, although data on the effects in humans following repeated exposure are limited and difficult to interpret because of co-exposure to other chemicals. Odour complaints may also be associated with H_2S.

The levels of H_2S associated with landfill sites have been assessed (EA, 2010a). The World Health Organization recommends an air quality guideline for H_2S of 150 $\mu g\ m^{-3}$ over a 24-hour averaging period (WHO, 2000). Owing to the odorous properties of H_2S, the WHO also recommends a value of 7 $\mu g\ m^{-3}$, with a 30-minute averaging period to avoid substantial complaints about sensory annoyance. Monitoring data from the EA indicated that H_2S concentrations, measured over a 15-minute monitoring period, occasionally exceeded the WHO sensory-based recommended level but were below levels associated with toxic effects. This indicates that there is the potential for odours to affect nearby residents and enforces the need for odour control at landfill sites.

2.4 Particulates

Landfilling activities have the potential to produce both fine and coarse particulates, the make-up of which will depend on the activities undertaken on-site and the types of waste being handled.

Landfilling activities with the potential to generate particulates include:

a movement of waste on- and off-site,

b handling storage and processing of waste,

c plant traffic both on- and off-site,

d plant used to burn landfill gas, including gas flares or engines,

e dust generated from the surface of the landfill.

Exposure to particles that can enter the respiratory system is known to be associated with a range of adverse effects on health. Particles of greater than 10 μm in diameter (particulate matter, PM_{10}) are unlikely to penetrate beyond the nose and larynx but, as the diameter of particles falls, the likelihood of their entering the lungs and being deposited in the airways increases. Particles of less than about 2.5 μm diameter ($PM_{2.5}$) are referred to as 'fine' particles and are deposited relatively efficiently in the deeper parts of the lung – for example, in the alveolar spaces. Particles between 2.5 and 10 μm in diameter are referred as comprising the 'coarse' fraction of PM_{10}. These particles may also have effects on health. Dust emitted from landfill sites will include particles which fall into both the PM_{10} and $PM_{2.5}$ categories. People with pre-existing lung and heart disease, the elderly and children are particularly sensitive to particulate air pollution.

Dusts from landfill sites can become airborne and move off site by a number of mechanisms. The amount of dust lifted from the surface of the landfill is dependent upon the speed of the wind, the condition of the surface and the size of the dust particles. Emissions of dust as a result of wind-blow can be significantly reduced if the surface is wet. Where dust generation has been assessed as an issue the operator should employ dust suppression measures such as surface wetting to combat the effects of wind-blow.

The distance travelled by dust emissions will depend on the particle size and on the wind speed and turbulence. Smaller dust particles will stay airborne for longer and disperse over a wider area. Strong and turbulent winds will also keep larger particles airborne for longer. Data reported from quarries indicated that the coarser dust particles (>30 μm) are mainly deposited within 100 m of the source, intermediate particles (10–30 μm) between 250 and 500 m, while fine particles (<10 μm) can travel up to 1 km (DoE, 1995a,b). Ultrafine particles (<2.5 μm) would be expected to travel considerably further.

Environmental permits for landfill sites require that dusts must be adequately controlled using, for example, dust suppression measures, so as not to have an adverse impact on public health. Furthermore, monitoring for particulates would be required by the environmental permit where justified by a risk assessment. For nuisance dust issues then the regulator will set a nuisance criterion level along with action and trigger levels to ensure that there is minimal impact on the local population (EA, 2004).

Levels of PM_{10} measured at the boundary of landfill sites are comparable to those encountered in many parts of the UK (EA, 2010a) and should not impact local air quality significantly. Even when added to the existing background PM_{10}, exceedances of the UK Air Quality Objective are not anticipated.

2.5 Metal compounds

Particulates emitted from landfills may also contain metals such as arsenic, cadmium, chromium, cobalt, copper, lead and manganese. Monitoring of metal compounds at the boundary of landfill sites indicated that the 50th percentile concentrations of metals were well below the relevant health guideline level (EA, 2010a,c). However, the COT noted that the maximum concentration of total chromium exceeded the appropriate HCV of 2.5 ng m^{-3}, although the 50th percentile concentrations were well below this value and were lower than the typical urban background concentration of chromium (COT, 2010). The HCV used reflects the risk from hexavalent chromium (Cr(VI)) and the EA study was not able to provide information on the speciation of chromium. It would be expected that the highly reducing environment within a landfill site would favour the formation of the less toxic trivalent form (Cr(III)). As a result, it is difficult to judge whether concentrations of total chromium at the boundary of these landfill sites present a significant risk to health. The HPA recommends that better techniques need be developed to measure Cr(VI) in air around landfill sites for use in future assessments.

2.6 Odours

Odours are frequently a key issue for landfill sites, especially those receiving biodegradable waste. Odours are typically associated with activities such as the handling of odorous wastes and the covering of biodegradable wastes or with the presence of trace components in landfill gas or leachates.

Odorous emissions are often accompanied by reports of ill-health from communities (Steinheider, 1999). Individuals may report a wide range of non-specific health symptoms, attributing these to odour exposure, including nausea, headaches, drowsiness, fatigue and respiratory problems. Health symptoms reported in association with odorous emissions can arise at olfactory detectable concentrations well below the levels associated with toxic effects or thresholds for mucous membrane irritation. Individual responses to odours are highly variable and are influenced by many factors including sensitivity, age and prior exposure to the odour. Psychological and social factors, in addition to an individual's level of concern about the potential harm to their health, will also play an important role in an individual's response. There are published studies that show strong correlation between perceived odour annoyance and subjective symptoms (Dalton et al, 1997; Dalton, 2003).

The EA measured a number of chemicals capable of causing odour problems at the boundaries of landfill sites. Methyl mercaptan, dimethyl sulphide and dimethyl disulphide are foul-smelling chemicals with low odour thresholds*. Air monitoring data indicated that concentrations of these chemicals at the boundary of these study sites did occasionally exceed the relevant odour threshold, although they were well below levels associated with toxic effects. However, the presence of detectable odours may cause annoyance among the local population, possibly leading to stress and anxiety. Some people may experience symptoms such as nausea or dizziness as a reaction to the odours even when the concentrations of these chemicals are insufficient to be directly harmful to health. Members of the public should consult their family doctor if they are concerned about any effects on their health from exposure to odours.

Since odours can have a detrimental impact on health, any potential odorous activities should be well regulated through the environmental permit. All landfill sites should have robust on-site plans to manage and reduce odours and any emissions should be the subject of a comprehensive risk assessment process. This should include evaluation of the key substances emitted in order to assess their toxicological and odour potential and, if necessary, off-site modelling and/or monitoring to predict the impact of these emissions on local communities. The HPA expects that landfill sites should be managed in such a way to ensure that odours do not materially affect local residents and if problems do occur, or are likely to occur, that appropriate actions are taken to prevent or minimise odours. The HPA will continue to work with the Environment Agency and other key partners, such as primary care trusts and local health boards, to minimise the potential health impact of odours.

2.7 Leachate

The nature of landfill leachate is a function of waste types, solubility, the state of decomposition and degradation. Rainfall input can serve to dilute and flush contaminants in addition to assisting in the degradation process by wetting the wastes. A wide range of substances may potentially be present in leachate, some of which are potentially harmful to human health. There is a considerable body of evidence on the constituents of landfill leachate, and the EA has undertaken a significant amount of research and identified those substances found in more than 5% of samples of landfill leachate (EA, 2001, 2003, 2010a). These substances are listed in Table 3.

Modern landfills are subject to risk assessments under the Environmental Permitting Regulations which require sites to be designed and operated such that there is no significant impact on groundwater. The majority of leachate in a modern landfill is discharged following treatment in an on-site process, and/or at

* Published odour detection threshold values for individual chemicals are based on the concentration at which half of a test group can just detect the odour.

TABLE 3 Priority substances in landfill leachate (taken from EA, 2010a)

Aniline	Fluoride	Organotin compounds
Arsenic	Mecoprop	Pentachlorophenol
Biphenyl	Methyl chlorophenoxy acetic acid	Phenols
Cyanide	Methyl tertiary butyl ether	Phosphorus
Di(2-ethyl hexyl) phthalate	Naphthalene	Polycyclic aromatic hydrocarbons
Dichloromethane	Nitrogen	Toluene
Ethylbenzene	Nonylphenol	Xylenes

an off-site sewage works. Modern landfill liners should also be very effective in containing leachate and very little leachate will be released via the landfill lining system to land or groundwater. Leachate stored or treated at a landfill site can become low in oxygen, resulting in the generation of odorous compounds such as sulphides. This can result in odour from tanks used to store leachate. This is likely to contribute to odour complaints associated with landfill sites.

As part of the monitoring of landfill sites by the EA, the possible effects of leachate on human health, via groundwater, were examined (EA, 2010a). The concentrations of substances released from landfill were based on either measured concentrations or estimated concentrations from a leachate quality database, together with calculated dilution rates. Analysis of leachate quality was undertaken for the priority substances in landfill leachate identified by earlier research (EA, 2003). The estimated exposure concentrations were assessed against widely used benchmarks for groundwater and drinking water quality to establish the significance of the estimated exposure concentrations. It was concluded that releases to groundwater are unlikely to pose a significant risk of adverse effects on health. Any risk is further reduced since most people receive their water from a public water supply usually some distance from a landfill site and unlikely to be at risk of leachate contamination. Furthermore, public water supplies are subject to strict regulation and monitoring which further reduces the likelihood of exposure.

Historic landfills are not regulated by current permit conditions, either because they ceased operations before controls were introduced, or the permit has been surrendered or otherwise disowned by the operator. These landfill sites often have no leachate treatment systems or engineered lining within the landfill to contain the leachate within the boundary of the site. The local authority has responsibilities for potentially contaminated land under Part 2A of the Environmental Protection Act 1990. Many of these historic landfills were sited and operated on the principle that the leachate generated slowly migrates into the underlying geology and, in doing so, any compounds within the leachate are attenuated through chemical, physical, biological and microbiological processes. These are known as 'dilute and disperse landfills'. Post-site monitoring and monitoring of groundwater should ensure that such sites do not pose a significant risk to human health.

2.8 Bioaerosols

The handling and processing of compostable organic waste material at landfill sites can generate an aerosol of micro-organisms (including pathogens and allergens such as bacteria, fungi and microbial toxins) suspended in air, termed a bioaerosol.

Most work on bioaerosols has been associated with commercial composting sites where waste material is enclosed within buildings or outdoors in open windrows*. Bioaerosols can also be emitted from domestic composting.

There is considerable uncertainty about health risks from bioaerosols, both to staff working at the composting site and to local residents living nearby. Health risks may include respiratory effects, infectious diseases, bacterial intoxications† and allergic reactions. The possible effects of bioaerosol exposure are difficult to assess because the mixture of organisms in compost is diverse, the methods for examining are not standardised, the exposure is difficult to estimate and epidemiological studies can be difficult to establish and interpret. In addition, within the general population there are people who may be more susceptible to bioaerosol-associated disease (eg people with a compromised immune system).

Data on bioaerosol levels on or around landfill sites are very limited. Monitoring at the boundaries of landfill sites provided results showing elevated levels of some micro-organisms (mainly fungi, moulds and mesophilic aerobes) which could possibly cause mild transient effects such as runny nose, throat irritation, cough and sneeze, and exacerbation of asthma in people living nearby (EA, 2010a). While the most likely source for these observed levels of bioaerosols was considered to be the handling of biodegradable wastes, local agricultural activities will also produce bioaerosols and would therefore have contributed to local concentrations.

Management of risks from bioaerosols at composting sites has focused on ensuring that operations are sufficiently far away from housing and businesses to limit bioaerosol exposures. Current evidence suggests that communities further than 250 m away from the site are unlikely to be exposed to harmful levels as the bioaerosol will disperse and concentrations will reduce to background levels over this distance. The amount of bioaerosol emitted from landfill sites should be far less than from a commercial composting facility which will handle significantly more biodegradable material. Activities to control dusts will further reduce the potential for any bioaerosol to be generated. However, the HPA would expect the risks from bioaerosols to be assessed as part of the permitting and regulation of landfill sites.

* Windrows are rows of composting material.

† Exposure (usually ingestion) of the toxin produced by the bacteria.

3 Epidemiological Studies: Landfills and Health Outcomes

3.1 Introduction

There have been a number of epidemiological studies which have investigated whether there is a higher than usual incidence of adverse health events, such as cancer or congenital anomalies*, in populations living near landfill sites. In general, these studies have used routinely collected data to compare the incidence of an adverse health outcome in the population living around a landfill site, or around a number of landfill sites, to the incidence in a reference area, such as the rest of the region or country. This type of epidemiological study is usually termed an ecological study.

There are a number of methodological problems with this type of study (COT, 2001). Such a study can only explore whether there is an association between potential exposures and the health effect under investigation. It cannot say whether or not the landfill site(s) caused the adverse health outcome (ie whether the association is 'causal'). There is no assessment of whether the study population is actually subject to harmful exposures. It is assumed that those living near to the landfill site are 'exposed' and those living further away are 'unexposed'. A further limitation is that this type of study can only make adjustments for other differences between the exposed and reference populations, such as socioeconomic deprivation, on a group level and not on an individual level. Also, they cannot adjust explicitly for confounders such as family history of disease, or lifestyle factors such as smoking, use of medicines and occupation, which might themselves be associated with the health outcomes being studied and which are unlikely to be completely accounted for by adjusting for deprivation alone. Therefore, there is a possibility that differences in the incidence of health outcome between the study and reference populations are due to one or more of these factors, and not to the landfill site(s). There may also be limitations in some of the health statistics datasets used in the study (COT, 2001).

3.2 Birth outcomes

In August 1998, a study of the incidence of congenital anomalies near hazardous waste landfill sites in Europe (the EUROHAZCON study) was published in *The Lancet* (Dolk et al, 1998). This study investigated pregnancy outcomes in women living within 7 km of 21 hazardous waste landfill sites in five countries, including the UK. Overall, it found a higher incidence of non-chromosomal congenital anomalies – specifically, neural tube defects and anomalies of the great arteries and veins – in babies whose mothers lived close to a landfill site than in babies of those mothers who lived further away. The authors concluded that there was a need for further investigation to determine whether landfill sites contribute to the risk of

* Anomalies that are not caused by a defect of the chromosomes.

these birth defects. This study was well conducted but there were a number of difficulties in interpreting the results, including inadequate estimates of exposure, variability between landfill sites, and the inability of the study to take account of other factors which might influence the outcome, such as socioeconomic status and ethnic group.

In response to the concerns raised, a number of government bodies commissioned the Small Area Health Statistics Unit (SAHSU) at Imperial College to carry out a large study of the incidence of birth outcomes around landfill sites in England, Scotland and Wales. The study also investigated the incidence of certain cancers (see below). SAHSU was provided by the Environment Agency with data on the location of landfill sites for use in this study, which indicated that there was a total of 19,196 known, open or closed landfill sites in England, Scotland and Wales and that most of the population lived within a few kilometres of a site. The study found a small increase in congenital anomalies in populations living close to landfill sites, but the increase (1% higher than the reference population for all sites but 7% around hazardous waste sites) was much smaller than had been reported in the EUROHAZCON study. With respect to specific anomalies, an increased incidence close to the sites was seen for neural tube defects, hypospadias/epispadias (defects of the penis) and abdominal wall defects. An increased risk of low birth weight was also seen in the study population (Elliott et al, 2001). The COT considered this study and noted that the findings for birth outcomes were not consistent, and that the study provided no evidence that the rates of anomalies increased after sites had opened (COT, 2001). The COT reiterated the limitations of ecological studies stated above and also noted that this study may have had problems of data quality, both in the landfill data and in some of the health statistics datasets used.

Results from subsequent EUROHAZCON studies have been reported. In January 2002, Vrijheid et al (2002a) reported an increased incidence of birth defects due to chromosomal congenital anomalies (a category which includes Down syndrome) in babies whose mothers lived close to a hazardous waste landfill site. However, this study was of the same design as the first study and, therefore, subject to the same difficulties in interpretation as noted above. In November 2002, a further study by the same group found 'little evidence' for a relationship between the risk of congenital anomaly and a rough measure of the 'hazard potential' of landfill sites as judged by an expert panel (Vrijheid et al, 2002b). In 2004, the group investigated the risk of low birth weight near the ten EUROHAZCON sites in England and found a small, non-statistically significant increase in the risk of low birth weight within 3 km of the sites (Morgan et al, 2004).

Palmer et al (2005) investigated whether the opening of new landfills in Wales was associated with increased rates of congenital anomalies in nearby residents by comparing rates before and after sites opened. Data on anomalies for the period 1983 to 1997 were obtained from the Office for National Statistics and, for the period 1998 through 2000, from the newly established Wales Congenital Register and Information Service (CARIS) which has substantially increased reporting rates, producing more reliable data. The study found that, for the 20 sites that opened from 1983 through 1997, there was a 39% increase in the rate of anomalies in populations living close to the sites after they opened. For sites that opened between 1998 and 2000, since no data on anomalies were available from CARIS for the period before the landfills opened, only the rates after opening could be studied. Using these data, the authors found no increased risk of congenital anomalies in populations living close to the 20 landfill sites studied in this period compared to expected rates. They concluded that it was difficult to draw conclusions about the findings because of the lack of data on individual exposures and on socioeconomic and lifestyle factors.

SAHSU has carried out a number of further studies on landfill sites, including a study in Scotland which found no excess risk of adverse birth outcomes in populations living near hazardous waste landfill sites (Morris et al, 2003) and another which found no increased risk of Down syndrome in babies born to mothers living near 6,829 landfill sites in England and Wales (Jarup et al, 2007). A further study investigated the risk of congenital anomalies in relation to the geographical density of landfill sites across England. For hazardous waste sites, it found small increased risks for specific anomalies in the areas with the greatest density of landfill sites but there were no excess risks in relation to sites handling non-hazardous or unknown waste types (Elliot et al, 2009). The HPA agrees with the views of the COT in that this study does not give grounds for any specific concerns or recommendations relating to the health of pregnant women or those wishing to start a family who live in the vicinity of a landfill site (COT, 2010).

3.3 Cancer

The 2001 SAHSU study investigated the incidence of certain cancers as well as birth outcomes and found no excess risk of cancer in the population living close to landfill sites (Jarup et al, 2002). The cancers studied – leukaemias and cancers of the liver, bladder and brain – were selected either to test hypotheses arising from previous studies of cancer around landfill sites or on the basis of the established human carcinogenicity of certain chemicals known to be present in them.

Other epidemiological studies of the association between cancer and landfill sites have been reviewed recently by Porta et al (2009), although it should be noted that some of the sites in the papers included in this review might be better described as uncontrolled or poorly managed waste dumps rather than controlled landfill sites. The authors concluded that there was inadequate evidence of an increased risk of cancer for communities in the proximity of landfills.

3.4 Other effects

Although most epidemiological studies have investigated rates of adverse birth outcomes or cancer around landfill sites, some have considered other effects. Vrijheid (2000) reviewed the health effects of residence near hazardous waste sites and noted an increased prevalence of self-reported health symptoms such as fatigue, sleepiness and headaches in ten of the reviewed papers. These papers largely studied populations living near to or on old and poorly controlled waste dumps with clear evidence of odour and leakage of noxious chemicals rather than controlled landfill sites. Where specific landfill sites were studied, it is not clear how far the results are applicable to landfill sites in general.

As previously discussed, ecological studies have a number of limitations and risk estimates derived from such studies are typically small. Therefore, it is not possible to discriminate effects due to confounders and bias from those which might be causally associated with the hazard under investigation and there is little value in undertaking further studies of this type on landfills (COT, 2010).

4 Recommendations for Future Research

The HPA has considered exposure data from sites chosen to be typical of modern landfill sites. However, emissions from individual sites will undoubtedly vary due to a range of factors such as the composition of the waste, the age and design of the landfill, pollution abatement measures, the underlying geology and the location of the site. As a result, the HPA believes that it is important that research continues to increase the evidence base around landfill sites.

It is clear from this review that some further research is needed to improve toxicological and exposure assessments around landfill sites. Future research should consider further surveys of pollutant concentrations around more sites and the development of more sensitive sampling and analytical methods for pollutants detected at low concentrations, particularly for those chemicals where the detection limits in the studies considered were below health criteria values. This would include compounds such as arsine and hexavalent chromium.

There is also a need for more complete toxicological data for some of these pollutants, as indicated in the Environment Agency exposure studies (EA, 2010a–c) and the second COT statement on landfill sites (COT, 2010).

Odours can have a detrimental impact on health and this review notes that a number of chemicals capable of causing odour problems have been measured at the boundaries of landfill sites.
Further research is needed to improve assessments of the impact that odours can have on the health of local residents.

The exposure data considered in this report have been taken from work around active landfill sites. More research is needed to assess the potential impact of emissions from closed landfill sites.

The HPA will be exploring research opportunities to improve knowledge of exposures to chemicals released from landfill sites and their toxicological impact.

5 Conclusions

The disposal of waste materials to landfill can undoubtedly present a pollution risk and a potential health hazard. Improvements in landfill design and management, restrictions in the types of waste that can be handled, and environmental legislation designed to minimise pollution should all ensure that there is no significant risk to the health of the local population.

The evidence base on the potential of exposure to emissions from landfill sites in the UK is limited due to the inherent variability in the composition of waste. It can be argued that all landfill sites are different. Intensive research has been carried out by the Environment Agency, which measured 60 chemicals or groups of chemicals at the boundaries of four landfill sites between 2002 and 2009. The results for this large dataset are reassuring and suggest that exposure to chemicals and other substances are typically low, comparable to existing background levels of pollution, and unlikely to present a significant risk to health.

While these sites were chosen to be typical of modern landfill sites, emissions from individual sites will vary and it is important that such research continues to improve assessment of the risk of exposure from UK landfill sites. The HPA will be exploring research opportunities to improve knowledge of exposures to chemicals released from landfill sites and their toxicological impact.

After considering the current information on landfill sites, including the results of a number of epidemiological studies, the detailed monitoring study by the EA and advice sought from the COT, the HPA concludes that a well-managed modern landfill site does not pose a significant risk to human health. This view remains consistent with the research sponsored by Defra in 2004, which was reviewed by the Royal Society. The HPA will continue to work with primary care trusts, local health boards and the regulator to ensure that individual landfill sites do not contribute significantly to ill-health. Detailed site-specific risk assessment should remain an important part of the permitting and management process.

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