WORKING FOR A HEALTHY FUTURE

Review of Health Risks for workers in the Waste and Recycling Industry

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Glossary

ACGIH	American Conference of Governmental Industrial Hygienists
ACH	air changes per hour
AM	arithmetic mean
ATSDR	(US) Agency for Toxic Substances and Disease Registry
Bioaerosol	Airborne particles composed of living organisms or fragments of previously live organisms such as fungi and bacteria
CI	confidence interval
cfu	colony forming units (used to describe quantity of viable bacteria or fungi
$cfum^{-3}$	calculated concentration of viable bacteria or fungi as cfu per m^3 of air
CNS	central nervous system
Defra	Department of Enviornment, Food and Rural Affairs
Endotoxin	constituent of the outer cell wall of Gram-negative bacteria that is associated with the adverse effects of many common infections
EU	endotoxin unit (about 9.5 ng)
FEV_1	forced expiratory volume in 1 second (measure of lung function)
FVC	forced vital capacity (measure of lung function)
GC-MS	gas chromatograph-mass spectrometer
GM	geometric mean
GSD	geometric standard deviation
Inhalable	Particles approximately less than 100 µm diameter that are capable of entering the respiratory system
IPCS	International Programme for Chemical Safety
LEV	local exhaust ventilation
MVOC	microbial volatile organic compound
NOAEL	no observed adverse effects level
ODTS	organic dust toxic syndrome
OEL	Occupational exposure limit
PCDD/Fs	Polychlorinated dibenzo dioxins and furans
PPE	personal protective equipment
PM_{10}	approximately particles of less than 10 µm diameter that are capable of penetrating the respiratory system to the lung (the thoracic fraction)

Respirable	Particles approximately less than 4 µm diameter that are capable of penetrating to the gas exchange region of lung
RPE	Respiratory Protective Equipment
Odds ratio	the ratio of the odds of an event occurring in one group (exposed) to the odds of it occurring in another group (control), or to a sample-based estimate of that ratio
OSHA	(US) Occupational Safety and Health Administation
NIOSH	(US) National Institute for Occupational Health and Safety
SD	standard deviation
TCDD	2,3,7,8- Tetrachlorodibenzo-para-dioxin
TEQ	toxic equivalents – method of expressing the toxicity of a mixture of related compounds in terms of the dose of a single marker compound that would be of equivalent toxicity
TLV	Threshold Limit Value (occupational exposure limit set by ACGIH or other bodies)
TWA	time weighted average
VOC	volatile organic compound
WEEE	Waste electrical and electronic equipment
WEL	Workplace Exposure Limit set by HSE
WHO	World Health Organization

Executive summary

INTRODUCTION

This study was commissioned by the British Occupational Health Research Foundation on the behalf of the Environmental Services Association Education Trust (ESAET). In recent years the waste and recycling industry has moved away from its reliance on disposal in landfill to much higher levels of recycling and recovery. In addition, new materials and technologies are entering the waste chain. These changes are likely to have led to significant changes in the nature and magnitude of the associated risks to worker health. The aims of the review were to:

Provide a resource that will assist operators in the identification of potential hazards, assessment of the health risks to their workers and implementation of appropriate exposure prevention or control measures;

Identify which of the occupational health issues selected by ESAET for review are associated with the industry's main activities and provide the basis for compiling risk assessments and identifying appropriate control measures; and

Identify any occupational health issues that present unacceptable levels of risk (if any), require unique or burdensome control measures or where additional research is required in order to come to a clearer conclusion.

The study involved a comprehensive review of relevant published literature and a limited survey of industry representatives about current practice in relation to health surveillance, exposure monitoring and their perceptions of the major health issues. In addition, exposure modelling was undertaken to inform the risk assessments that were undertaken for each of the hazards and processes considered.

POTENTIAL HAZARDS

After discussion with EASET representatives, this study focused on airborne dust, bioaerosol, chemicals used or liberated in specific operations, heavy metals and/or carcinogens liberated in recycling, infectious agents, high temperatures and heat related illness. The technologies considered were anaerobic digestion, composting, high temperature thermal treatments, auto-clave, Materials Recovery Facilities (MRFs), Mechanical Biological Treatment (MBT), Household Waste Recycling Centres (HWRCs) and Transfer Stations, glass, plastic and wood separation, Waste Electrical and Electronic Equipment (WEEE), fridge recycling, metal crushing and aluminium separation and paper and cardboard baling. Some consideration has also been given to landfill, as this is still an important disposal route for residual waste in large parts of the UK.

ASSESSMENT OF RISKS

Dust

The current UK regulatory limits for **inert** dusts are not intended to be protective for most dusts that are encountered in the waste industry which have elevated organic matter and/or metals contents and would be expected to be more hazardous to health. The HSE's own Working Group on Actions to Control Chemicals (WATCH) have advised that the current regulatory limits are not sufficient to protect against the risk of serious respiratory illness, even for exposures to inert dust. The IOM recommends that employers should aim to keep exposure to respirable **inert** dust below 1 mgm^{-3} and inhalable **inert** dust below 5 mgm^{-3}. Most dusts encountered in the waste industry have elevated organic matter or metals contents and may give rise to adverse effects at exposure concentrations well below 1 mgm^{-3}. The review findings suggest that exposures to dust at many waste handling sites are likely to be associated with significantly increased risks of chronic respiratory illness. Harmful levels of exposure to airborne dust may be a particular issue during cleaning and maintenance operations at most types of waste handling facilities. Frequent equipment failure, entry into relatively confined spaces and the use of compressed air to clear blockages may all contribute to elevated exposures to airborne dust at some sites. The use of compressed air should be discontinued in favour of other methods.

Bioaerosol

Exposures to bioaerosol at a substantial proportion of composting sites and associated with waste reception/stored wastes at many other waste facilities are likely to be associated with increased risks of respiratory illness and possibly gastrointestinal symptoms and fatigue. The risks are likely to be minimal where processes are entirely automated and enclosed with effective extraction ventilation and a good supply of fresh air to the workplace. Elevated exposures are most likely where workers are working on picking lines or in close proximity to processes such as crushing, shredding, grading, sieving, conveyor transfer or filling that are not entirely contained with extract ventilation.

Workers with pre-existing respiratory conditions such as asthma or who are previously sensitised to moulds are at particular risk and may experience an exacerbation of symptoms at very low exposure levels. It is probable that workers with increased susceptibility leave the industry because their symptoms become intolerable. Allergic illness is likely to be a significant issue for workers who remain in post for periods of months to years. About 5% of the population are sensitised to common moulds and a greater proportion of the population are atopic (have an increased likelihood of developing allergies) and are at increased risk of becoming sensitised. Any workers with compromised immune function (for example, due to medication) are also at risk of aspergillosis.

Metals

Exposures to harmful levels of heavy metals occurs at some metals recovery facilities such as scrap yards with a substantial proportion of scrap yard workers having blood lead levels that exceed the thresholds for the development of toxic effects. Some WEEE processing operations are also associated with exposures to harmful levels of heavy metals, particularly lead and mercury. Inadvertent ingestion is likely to be an important route of exposure in both metals recovery operations and WEEE processing. Inadvertent ingestion may arise as a result of subconscious hand to mouth contact and through contamination of cigarettes, food and drinking vessels as a result of dirty hands and can be a significant route of exposure to hazardous substances at work. It is possible that mixed metal exposures could give rise to toxicity as a result of additive effects even where the WELs of individual metals are met. Health effects may include liver, kidney or Central Nervous System (CNS) toxicity or even lung cancer.

VOCs, hazardous organic substances

Exposures to a range of volatile organic compounds (VOCs) and other hazardous organic substances such as brominated fire retardants, dioxins and polyaromatic hydrocarbons occur in a number of sectors of the waste industry including landfill and high temperature thermal treatments. Exposure levels are, however, likely to be low and not associated with any significant risk to health. Exposure to malodour where organic rich wastes are handled could adversely affect well-being and cause symptoms such as headache, fatigue and nausea that could contribute to sickness absence.

Infection risks

Occasional exposure to significant infection risks may occur wherever workers have direct contact with wastes, for example, on picking lines or during cleaning and maintenance. Provided workers use appropriate personal protective equipment (PPE) and there are well established procedures in place to manage high risk incidents, the risk to worker health should be small. Legionella has also occasionally been reported as an issue in the waste industry and is potentially an issue for any employer where there is the potential for employees to be exposed to aerosolised water from a stagnant source (eg infrequently used shower).

Heat exposure

Exposure to moderately hot environments may be an issue for much of the waste industry because of the widespread use of PPE and respiratory protective equipment (RPE). Workers undertaking even gentle physical tasks such as sampling at compost sites or handpicking at MRFs may be at risk of heat-related illness on a warm day because of the requirement to wear coveralls. Workers required to undertake maintenance tasks on hot equipment are at increased risk of heat related illness, particularly if this requires entry into a confined space before equipment has completely cooled. Individual workers vary considerably in their susceptibility to heat. It is possible that heat contributes to a significant burden of minor ill health and reduced worker performance in many sectors of the waste industry and also contributes to increased risks of more serious illness such as cardiovascular problems that are not directly attributed to the working environment.

EXPOSURE PREVENTION AND CONTROL

Process enclosure, ventilation that removes contaminated air from the workplace and the use of sealed cabs with filtered air are likely to have a major impact on reducing exposure to airborne dust and other hazardous substances. For ventilation to be effective, it has to be appropriately designed, properly installed and regularly maintained and tested. Concerns about emissions of bioaerosol, odour or hazardous vapours to outdoor air has led to many waste handling facilities recirculating air internally rather than emitting treated air to outdoors. This may greatly increase worker exposure to dust, bioaerosol and other substances, particularly if inadequate air treatment measures are in place.

Relatively simple measures such as good housekeeping, the provision of appropriate workwear, a workwear laundry service, gloves, coveralls, washing facilities and training can greatly reduce exposure to hazardous substances and infection risks. Poor housekeeping and poor personal hygiene in a traditionally “dirty” industry can lead to greatly increased exposures to hazardous substances by inhalation, skin contact and ingestion. Settled dust in the working environment can readily become airborne and also contribute to exposure by inadvertent ingestion to hazardous substances such as metals, infectious agents and oils.

RPE is widely used in the waste industry. In order to be effective, it must be correctly specified (including appropriate filter type),subject to regular inspection, cleaning and maintenance and workers must be face fit tested for the masks they are going to use and trained in RPE use. There is a risk that work in warm environments may lead to poor compliance with any requirements for RPE use.

Coveralls are likely to be an important tool in managing worker exposure to hazardous substances but are also associated with increased risks of heat-related illness. This risk may be partly controlled through better awareness of both workers and managers of the issue which could lead to revised working methods and the provision of different workwear that would help to minimise heat exposure.

The provision of appropriate training in relation to relevant health risks and control measures is required for both workers and site managers. Managers with extensive experience of working at traditional waste facilities may not appreciate the hazards associated with the exposures associated with new processes and this may lead to inadequate standards of control.

Special care is required in relation to agency workers in order to ensure that they have appropriate training, understand the risks and how to control them and are provided with appropriate PPE and on site facilities including washing facilities and a workwear laundry service. This includes ensuring that workers have been face fit tested for any RPE that they are required to use and trained in its use.

OCCUPATIONAL HEALTH ISSUES ASSOCIATED WITH SPECIFIC ACTIVITIES

Landfill

The requirement to control environmental emissions of dust and explosion hazard at landfill sites means that workplace exposures to dust, bioaerosol and toxic components of landfill gas are generally well controlled with little associated risk to worker health. Elevated exposures to dust with an associated risk of respiratory ill health are possible, if workers spend a significant part of their working day doing activities such as processing construction waste and/or operate plant that does not have a sealed cab with air filtration. Where there are gas management problems, exposure to malodour may contribute to symptoms such as headache, fatigue and nausea and have a negative impact on well-being. The potential harmfulness of exposure to malodour is often under-rated as the concentrations of individual substances in air are well below the levels that might cause toxicity.

Anaerobic Digestion

The exposures of most concern are dust and bioaerosol associated with handling waste prior to treatment and it is likely that current exposures at some plants exceed the threshold levels for the development of respiratory symptoms and increased risks of chronic respiratory illness at some plants. Exposure to microbial VOCs might exacerbate the adverse respiratory effects associated with dust and bioaerosol exposure. The risks to health are greatest where waste handling procedures are not entirely enclosed and workers are within the same space as the waste as opposed to working inside a sealed and ventilated cab. Exposures may be further increased where waste has been stored for a number of days as a result of process problems. Where workers are not working in an air conditioned cab or workplace, mild heat related illness may be an issue during warm weather as a result of the requirement to use coveralls possibly combined with RPE.

Workers are unlikely to experience high levels of exposure to process emissions (biogas). The requirement to control methane levels to well below the lower explosion limit is likely to result in exposures to other potentially hazardous substances to very low levels. No significant adverse effects would be expected to arise as a result of exposure to toxic process emissions, even in the event of process problems that could lead to aerobic conditions within the digestor.

Workers at anaerobic digestion plants are likely to be exposed to malodour, particularly, if wastes are inadequately contained prior to processing or process problems arise. This could give rise to symptoms such as headache, fatigue and nausea and impact negatively on well-being.

Composting (open windrow and in tunnels)

The exposures of most concern are dust and bioaerosol. Based on IOM's previous work for Defra, it seems likely that if dust levels are controlled below the lowest levels associated with adverse effects in workers exposed to organic dust (about 0.2-0.3 mgm^{-3}), exposures to bioaerosol would also be reasonably well controlled. Where waste has been stored for a number of days, however, it is possible that elevated bioaerosol exposures could arise at even lower levels of dust exposure giving rise to increased risks of respiratory symptoms and other effects including fatigue and nausea. It is likely that current levels of exposure to dust and bioaerosol at many sites exceed the threshold levels for the development of respiratory symptoms and increased risks of chronic respiratory illness. Exposure to microbial VOCs might exacerbate any adverse respiratory effects. Associated exposure to malodour could also be associated with negative effects on well-being.

Factors that are likely to lead to increased risks of respiratory illness would include; elevated exposures arising while workers are operating machinery such as excavators with the cab windows open or without air filtration, operatives operating screening or other fixed equipment (e.g. bagging operations) that is not fully contained, shovelling or sweeping spilt material or taking samples of partially processed waste or product. Dust exposures are likely to be particularly high if the product is allowed to dry out. Although exposure to dust and bioaerosol may be reduced by the use of appropriate RPE, it is essential that this is face fit tested for the individual and the mask and that there is good compliance in its maintenance, cleaning and use. Mild heat related illness may be an issue during warm weather as a result of the use of coveralls. Levels of exposure to dust and bioaerosol may be particularly high at sites where composting is undertaken indoors, if air is recirculated within the building without adequate treatment to remove bioaerosol and dust rather than extracted to the outdoor environment.

Repeated exposure to bioaerosol could lead to workers developing hypersensitivity pneumonitis similar to that traditionally known as farmers' lung. This is a disabling disease associated with serious damage to the lung and the development of severe respiratory symptoms in response to further exposure. It is likely that compost workers' lung will emerge as a new occupational illness within the next few years. Particularly high exposures to dust and bioaerosol could lead to organic dust toxic syndrome, a short lived 'flu-like syndrome.

High temperature waste treatment processes

Municipal solid waste (MSW) and other wastes may be treated by incineration, pyrolysis, gasification and plasma treatment. Most of these processes are relatively new within the UK and are conducted in modern plants with a high level of automation and containment and minimal potential for worker exposure to waste, emissions from waste or emissions from the waste treatment process.

Exposure to organic dust and bioaerosol are possible in the waste reception and storage areas and during any pre-combustion handling of waste. Particularly high levels of bioaerosol emission may result from the prolonged storage of waste prior to treatment. In a modern plant where processes are highly automated and contained, workers would not normally be in areas where dust and bioaerosol concentrations are raised. At older, less automated plants, workers may be exposed to dust and bioaerosol while moving waste using equipment such as a mechanical excavator or operating equipment such as conveyers or any shredding or grading processes undertaken prior to combustion. During normal operation, however, exposures should generally be below levels associated with increased risks of respiratory illness. Elevated exposures to dust and bioaerosol are likely to arise during cleaning and maintenance operations at both older and modern plants, although exposures can be controlled through the appropriate use of PPE. Frequent equipment failures could lead to repeated exposures and a lower level of compliance with PPE use, giving rise to shift mean exposures that would be sufficient to give rise to respiratory symptoms in some individuals.

Significant exposure to airborne dust could occur where workers are handling air pollution residues (flyash) or bottom ash from incinerators. Although exposure levels would be anticipated to be negligible during routine plant operation, significant exposure to airborne dust could occur during cleaning and maintenance operations. Where process problems lead to the frequent entry to confined spaces in order to clear blockages, it is conceivable that exposure levels could be sufficient to give rise to significantly increased risks of chronic respiratory illness, particularly where compressed air is used for cleaning. Limited published data indicates that cleaning and maintenance operations at incinerators are associated with elevated exposures to hazardous substances such as metals and dioxins but does not suggest that exposure levels are likely to be sufficient to cause adverse effects.

Exposure to heat is likely to be well controlled during the normal operation of thermal treatment plants but frequent breakdowns may contribute to an increased risk of heat-related illness, if operational pressures lead to workers undertaking maintenance operations before equipment has cooled down.

Autoclave

Autoclave processes are contained and waste gases are subjected to treatment such that exposures during routine operation are negligible. The processed waste is sterile and unlikely to be particularly dusty. Process problems could lead to short term exposure to process emissions that could cause short term respiratory effects in some individuals, particularly in those with asthma or other pre-existing respiratory illness, but are unlikely to give rise to significant long term adverse effects.

The health risks associated with waste reception and handling prior to treatment would be similar to those associated with waste reception and pre-treatment of MSW associated with other waste treatment processes. Some workers may be at increased risk of heat related illness if they are required to handle warm materials or undertake maintenance operations on hot equipment.

MRFs

The main issues associated with MRFs are the potential for exposure to dust and bioaerosol during primary waste reception, during manual or automated waste sorting operations, during any crushing or grading of separated recyclate fractions and during cleaning and maintenance operations. Waste materials are typically dry giving rise to an increased potential for dust emissions. Processes such as the shredding of waste materials, the transfer of recyclate by conveyor, any grading or screening operations or crushing are likely to be significant sources of airborne dust, particularly where they are not fully enclosed. Workers spending a substantial proportion of their working day in close proximity to these sources or who are involved in handpicking are likely to experience exposures to dust and bioaerosol that exceed the thresholds for respiratory symptoms and increased risk of longer term respiratory illness, even where local exhaust ventilation (LEV) is in place.

At plants that receive unsorted MSW or where householders have failed to properly segregate wastes, workers may be at risk of exposure to infections associated with hygiene waste such as disposable nappies and items that have been inappropriately disposed of such as needles. In practice, the infection risks associated with most hygiene waste are small because of the limited survival of most pathogens outside of the human body. The risk of infection is greatest for individuals with poor personal hygiene or who are immune-compromised and at facilities that do not provide adequate washing facilities and work wear. Needles present a particular risk as they may penetrate PPE and the inappropriate disposal of needles is likely to be associated with drug users who have an above average prevalence of blood borne infections. Any exposure to asbestos is likely to be small and infrequent and unlikely to be associated with a significant increase in lifetime cancer risk. Exposure to other chemicals may cause immediate respiratory and eye irritation and could cause burns but in the absence of immediate injury is relatively unlikely to lead to lasting adverse effects. It is relatively unlikely that a highly corrosive substance would be disposed of in household waste. Workers are likely to have occasional exposures to a variety of pesticides (as residues within plastic containers) but not at levels that are likely to be harmful.

Workers at MRFs may be at risk of mild heat related illness associated with the use of coveralls.

MBT

The main issues associated with MBT are the potential for exposure to dust and bioaerosol during waste reception and during cleaning and maintenance operations. MBT plants are highly automated and provided the process is fully enclosed with extract ventilation (and doesn't return contaminated air to the workplace), worker exposures to dust and bioaerosol should remain well below levels that are associated with increased risks of respiratory illness. Where process enclosure has been designed primarily to reduce the risk of large fragments of waste flying across the workplace rather than dust emissions, then significant release of dust and bioaerosol is likely and workers spending much of their working day in close proximity to such equipment would be at increased risk of developing respiratory symptoms. Repeated exposure would give rise to increased risks of chronic respiratory illness. Increased exposures to dust and bioaerosol could also arise during cleaning and maintenance operations unless appropriate PPE is employed.

Cleaning and maintenance operations could bring workers into close contact with untreated hygiene waste and other infection hazards including rat urine (Weils disease), pigeon faeces, animal wastes and contaminated food. The infection risks should be minimal provided that appropriate PPE is employed including disposable suits, strong waterproof gloves and a faceshield, adequate washing and changing facilities are provided, there is good separation of work and nonwork wear and strict standards of personal hygiene are imposed.

Workers at MBT plants may be at risk of mild heat related illness associated with the use of coveralls.

HWRC's and Transfer Stations

No active processing of waste occurs at HWRCs and waste transfer stations which limits the potential for exposure to hazardous substances during normal operations. Exposure to dust with a variable organic content is likely to arise at waste transfer stations as waste is deposited from collection vehicles and transferred to other containers for onward transport. Similarly, some exposure to dust may occur at HWRT as materials are transferred from one container to another. Shift mean dust exposure concentrations may exceed threshold levels for the development of respiratory symptoms at some waste transfer stations where dry wastes are handled, particularly if plant operators work with their cab windows open. Similarly cleaning and maintenance operations that create airborne dust at both HWRCs and waste transfer stations could lead to shift mean exposures that are sufficient to give rise to respiratory symptoms and increased risks of chronic respiratory illness. Exposure to bioaerosol is likely where garden waste, MSW, paper and cardboard or similar materials are handled. Published measurement data suggest that significant exposure to bioaerosol can arise at waste transfer stations, even where waste is handled remotely. Bioaerosol emissions may greatest during the handling of wastes following storage.

Workers at HWRCs and transfer stations may experience occasional exposures to hazardous substances such as asbestos that householders have inappropriately disposed of. Exposures are likely to be infrequent and unlikely to give rise to a significantly increased risk of future illness.

Workers at HWRCs and transfer stations may be at risk of experiencing mild heat related illness associated with the use of coveralls, particularly if they are undertaking physical activity such as helping to load household waste into the appropriate skips while outside in hot sunshine.

Glass, plastic and wood separation plants

The exposures of concern are bioaerosol and dust. The dust liberated for glass and plastics may be associated with bioaerosol arising from residual food and paper wrappers. The dust liberated from wood will also be associated with bioaerosol and will have a high organic component giving rise to a risk of respiratory irritation and irritation to the eyes at exposure levels well below the current UK WELs for dust. Long term exposures at concentrations that are 3% of the current inhalable dust limit may be associated with increased risks of chronic bronchitis and other respiratory illness. Wood dust is also classified as a carcinogen, although it is highly unlikely that exposure levels associated with timber reclamation would be sufficient to give rise to a significant increase in cancer risk. The adverse effects of dust are likely to be enhanced by the presence of bioaerosol and the presence of airborne fungi is likely to be associated with increased risks of the development of allergic illness.

The dust released from crushed glass will be relatively inert but workers who spend a significant proportion of their day exposed to dust released from inadequately enclosed processes involving the crushing of glass, grading crushed glass or transferring crushed are at increased risk of developing chronic respiratory illness. Exposures and risks are likely to greatest where these processes are undertaken within a relatively enclosed space (≤300 m^2 floorspace) with a limited supply of fresh air.

The reprocessing of plastic wastes using solvents may be associated with exposure to solvent vapours where processes are inadequately contained. The risks of exposure are probably greatest where such processes are performed at a waste handling site where there may be a relatively poor understanding of the potential risks to health associated with solvent exposure.

Workers may be at risk of mild heat related illness associated with the use of coveralls.

WEEE recycling

WEEE contains a wide range of hazardous metals and where processes are poorly designed and/or operated, there is a significant risk that workers may be exposed to toxic levels of lead, mercury or other metals. The HSE have identified issues of over-exposure to lead and mercury associated with activities such as processing fluorescent light tubes, CRTs or LCDs. WEEE also contains other hazardous substances such as brominated fire retardants, but although there is evidence that WEEE re-processing workers may have higher exposures to these substances than the wider population, there is no evidence that these exposures are of sufficient magnitude to be harmful to health.

Exposures to metal rich dust are most likely where materials are shredded or crushed, graded and handled in shredded or crushed form with the risks potentially being increased once different materials such as plastics, ferrous and non-ferrous metals are segregated. Inefficient segregation of different materials may increase risks of over-exposure to hazardous substances, if materials such as shredded plastic are contaminated with hazardous metals. The potential for exposure is likely to be highly variable between operations. Most processes are likely to be highly automated and in principle could be readily enclosed and fitted with extraction. Exposures could be further reduced if the operations hall is appropriately ventilated. Worker exposure will be determined by the tasks that they undertake and their proximity to dust sources in the work environment. Cleaning and maintenance may be associated with very high dust exposures, particularly if compressed air is used to clear equipment blockages and to clean surfaces. Workers may also experience high exposures if process containment is designed only to prevent material flying out that could cause injury rather than to prevent dust emissions and no extraction is in place. Other factors that could lead to e exposure would include the failure to appropriately filter recirculated air in the workplace and an insufficient supply of fresh air.

Dermal contact and inadvertent ingestion may be important routes of exposure to hazardous metals and other substances at some WEEE processing sites where housekeeping is poor, particularly if there is an inadequate provision of washing and welfare facilities and poor segregation of work and nonwork clothing.

Fridge recycling

The exposure of concern is to refrigerant gases, primarily CFCs and HCFCs. It is likely that some escape of refrigerant gases occurs at fridge recycling plants although the necessity to minimise emissions to the wider environment means that releases and exposures are likely to be small. Most refrigerant gases have a relatively low toxicity. It is highly unlikely that exposure to refrigerant gases associated with fridge recycling would give rise to a significant risk to worker health.

Subsequent to the extraction of the refrigerant gases, the exposures and health issues associated with processing waste fridges are similar to those associated with other types of WEEE.

Recovery of metal recyclate

There are few data describing exposures during metal recovery operations. Elevated exposure to metals may occur while cutting scrap metal, in association with crushing operations and during the separation of different types of metal waste. There are data that indicate that elevated exposures to lead are relatively common among scrap metal workers in the UK. In 2009-2010, about 20% of workers had blood lead levels that exceeded the thresholds for effects such as anaemia, fatigue, stomach cramps and effects on mood and cognitive functioning. It seems plausible that over-exposure to other widely used metals may also occur.

The crushing and separation of mixed metal waste at materials recovery plants may be associated with increased exposures to the range of metals that are contained in consumer goods. Where equipment is fully contained and fitted with extraction, there should be no significant exposure to dust containing metals during routine operation, provided that untreated air is not vented into the workplace. Provided that exposures to dust are controlled to below 1 mgm^{-3}, it is unlikely that excessive exposures to individual metals will arise, although the effects of exposure to a mixture of metals that are associated with similar effects are uncertain. Higher levels of exposure are likely to occur during cleaning and maintenance operations. Where workers are frequently clearing blockages through the working shift, this could give rise to potentially significant exposures to iron, copper, aluminium, lead, nickel, manganese and possibly other metals in relation to the UK WELs.

Inadvertent ingestion of dust at scrap yards and other material recovery facilities may be a substantially more important route of exposure than inhalation. The risks of inadvertent ingestion are greatest where personal hygiene is poor and is likely to be associated with inadequate washing facilities, the failure to provide a clean environment for breaks, poor or no separation of work and nonwork clothing and poor worker awareness of the potential hazard.

Dermal contact may be an important route of exposure to fuel and other hydrocarbons during the processing of end of life vehicles and similar wastes, particularly where workers have a poor awareness of hazard and do not use appropriate PPE. This could give rise to increased risks of impaired kidney or liver function, dementia and other neurodegenerative diseases and cancer, particularly leukaemia (associated with benzene in petrol) and skin cancer (associated with dermal contact with engine oil and diesel).

The downstream processing of metal recyclate occurs within the metals industry and exposures are likely to be similar to those associated with primary production.

Paper and cardboard baling

The dust liberated from paper and cardboard will have a high organic component giving rise to a risk of respiratory irritation and irritation to the eyes at exposure levels well below the current UK WELs for dust. Long term exposures at concentrations that are 3% of the current inhalable dust limit may be associated with increased risks of chronic respiratory illness. The adverse effects of dust are likely to be enhanced by the presence of bioaerosol including fungi that are likely to be associated with increased risks of developing allergic respiratory illness.

The baling of waste paper and cardboard is likely to be conducted indoors and to be highly automated but may not be fully contained. There are no measurement data but it seems likely that the potential for dust generation should be less than during the crushing and processing of other dry wastes. Operators working in close proximity to partially contained equipment are likely to have exposures sufficient to give rise to increased risks of chronic respiratory illness.

AREAS OF UNCERTAINTY

There are insufficient exposure (or health) data to determine the extent of work-related illness in the waste industry. The potential health risks at a well run facility are likely to be very low, where there is good staff training and hazard awareness combined with an appropriate level of process containment and ventilation, and appropriate welfare facilities. The mobility of the labour force and long time scale over which serious respiratory illness may develop means that there may be a hidden burden of ill-health associated with working in the waste and recycling industry. It is also possible that a substantial healthy worker effect is masking underlying problems. The preferential departure from the industry of workers who develop respiratory symptoms may not be noticed against the background of high labour turnover. A significant proportion of individuals employed in the industry are of low social status and may have difficulty in raising issues of work-related ill health with management.

CONCLUSIONS

The current regulatory limits for **inert** dust are not adequately protective for the types of dust encountered in the waste industry. Exposures to dust and/or bioaerosol at many waste handling sites are likely to give rise to significantly increased risks of chronic respiratory illness. Operations that are particularly likely to be associated with elevated worker exposure to dust and/or bioaerosol include composting, working on picking lines at MRFs and cleaning and maintenance operations. Workers with pre-existing respiratory conditions or who are previously sensitised to moulds may experience an exacerbation of symptoms at very low exposure levels. About 5% of the population are sensitised to common moulds and a greater proportion of the population are at increased risk of becoming sensitised as a result of mould exposure. Any workers with compromised immune function (for example, due to medication) are also at risk of aspergillosis.

Exposures to lead, mercury and other hazardous metals at some scrap metal yards, WEEE recycling operations and potentially during the handling of thermal treatment residues may be sufficient to give rise to toxicity. Inadvertent ingestion is a potentially important route of exposure, particularly where inadequate washing and welfare facilities and PPE are provided.

Workers who have direct contact with waste materials are potentially at risk of infection due to the presence of articles such as disposable nappies and discarded needles in wastes. The potential risks to health can be readily minimised through the use of measures including appropriate PPE, provision of adequate washing facilities, training and response procedures following suspected exposures. Workers with poor personal hygiene or who are immuno-compromised are at greatest risk.

The use of protective coveralls at many waste handling plants may be associated with an increased risk of mild heat-related illness with older individuals and those with cardiovascular conditions being at greatest risk. Heat exposure may reduce worker efficiency and contribute to sickness absence without being identifiable as distinct symptoms.

Factors that may give rise to increased risks of adverse health effects in the waste industry include:

- The extensive use of agency workers who may not have adequate training or PPE;
- Teething problems with new processes giving rise to repeated high exposures associated with cleaning and maintenance;
- Poor attitudes to personal hygiene and cleanliness in a traditionally dirty industry including a failure to provide adequate washing facilities, workwear and laundry services; and
- Poor appreciation of hazard and risk by both workers and site managers.

There are insufficient data about exposures or health to determine whether employment in the waste industry is associated with a substantial burden of potential ill health.

RECOMMENDATIONS

One of the main conclusions of this study is that exposures in the waste industry could give rise to a significant burden of ill health but there are too little data to determine whether a significantly raised risk of widespread work-related ill health actually exists. The most significant issues appear to be dust, bioaerosol and hazardous metals. We recommend that further work is undertaken to better characterise the extent of risk. Before waiting for the results of further investigation, however, we recommend that the industry is proactive in monitoring worker exposure to dust and other hazardous substances and that it adopts much lower exposure limits for respirable and inhalable dust than currently required under UK law. The IOM recommends that employers should aim to keep exposure to respirable “inert” dust below 1 mgm^{-3} and inhalable dust below 5 mgm^{-3}. Lower limits would be advisable for dusts with a high organic matter or metals content. We also recommend that the industry reviews the potential for heat related illness wherever it is necessary for workers to wear coveralls and they are not working within an air conditioned space. It is likely that mild heat related illness contributes to a hidden burden of mild ill-health in workers, although the impacts on worker health are likely to be smaller than those associated with exposure to dust, bioaerosol and/or metals. It is important to ensure that whoever undertakes any monitoring work for the industry is both qualified and knowledgeable in practical risk assessment and experienced in the establishment of practical occupational hygiene and health programmes at multisite locations. Exposure/measurement/control and survey work should be led by a suitably qualified and experienced occupational hygienist who is a Member or Fellow of the Faculty of Occupational Hygiene. Health surveillance and the analysis of occupational health data should be directed by a suitably qualified and experienced occupational physician who is a Member or Fellow of the Faculty of Occupational Medicine.

Our understanding of the risks to worker health that may be associated with employment in the waste industry is limited by the poor availability of exposure information in the public domain. We understand that most of the major players in waste industry already make/commission occupational hygiene measurements and that some operators are willing to release this data for the purposes of a future study. We recommend that the waste industry pools and reviews its existing exposure data in order to identify the types of process and other factors that are associated with elevated exposures that might represent a risk to health and where further/better data are required. It is likely that there is a paucity of information about exposures at sites operated by small operators who should be included in any initiative to better understand workplace exposures in the waste industry. There is also likely to be a paucity of information about exposure by dermal contact and inadvertent ingestion. Although it is difficult to undertake routine measurements of exposure by these routes, they should be included in any overall assessment of exposure and risk. Some indirect inferences about the likely importance of these exposure routes can be made from observations of levels of workplace cleanliness, provision and laundering of workplace clothing, required hygiene measures, the cleanliness of eating and rest areas and the use of PPE.

The industry may decide that its existing data are of insufficient quality to inform a review (for example, measurement data may not be clearly linked to processes and control measures) and decide to commission an independent measurement survey that includes representative sites for all the key processes. The advantages of a new survey are that it would be possible to ensure a systematic approach to measurement and recording of the factors that may influence exposure and it would provide information about current rather than past conditions. Provided appropriate quality assurance measures were included in the sampling and analytical protocols and the measurements were made by suitably qualified people there would be a high level of confidence in the resultant data. The disadvantage would be that it may be difficult to get sufficient coverage within reasonable cost to be confident that the survey results were representative for each process type. This could be addressed by undertaking a phased programme over several years focussed on specific sectors of the industry.

As a first stage in the review of existing data and/or developing a new measurement programme, it may be beneficial to start the process with a series of baseline reviews of operational sites by suitably qualified occupational hygienists. The aim would be to test the issues raised in this report and prioritise the actions for subsequent investigation and/or control. This iterative approach has been widely used in other industries to help focus resources rather than attempt to address all issues in depth simultaneously. With the multitude of potential issues identified, simple baseline reviews of typical conditions on operating sites by informed specialists would help in the development of a stratified programme where future actions can be derived from the outcome of the previous steps. By adopting a plan with a series of manageable and pragmatic steps, some issues may be eliminated at an early stage whereas other may benefit from greater attention.

In addition to reviewing exposures, the introduction of systematic industry-wide approaches to health surveillance and recording and sickness absence monitoring could provide key data to inform a future epidemiological investigation of the health risks associated with working in the waste industry. In order for data to be informative about work-related ill health, a specific focus on conditions that could be work-related such as respiratory ill health and infection is required.

1 Introduction

1.1 OVERVIEW

This study has reviewed the occupational health risks in the waste and recycling industry in the UK. In recent years the waste management industry has undergone a substantial transformation away from its traditional reliance on disposal in landfill to much higher levels of recycling and recovery. The changes in the systems and technologies used for waste collection, handling and processing are likely to have led to significant changes in the nature and magnitude of the associated risks to worker health. In addition, there have been changes in the types of materials that are entering the waste chain as households start to dispose of new technologies that employ new materials, for example, LCD televisions. Potentially hazardous exposures that may arise in the waste industry include:

- Bioaerosol such as endotoxin
- High temperatures and heat stress
- Chemicals used or liberated in specific operations
- Heavy metals and/or carcinogens liberated in recycling
- Infectious agents
- Manual handling
- Noise and vibration
- Stress

After discussion with industry representatives (Environmental Services Association Education Trust Limited - ESAET), this study has focused on:

- Airborne dust
- High temperatures and heat stress
- Bioaerosol such as endotoxin
- Chemicals used or liberated in specific operations
- Heavy metals and/or carcinogens liberated in recycling
- Infectious agents

The industry representatives felt they were sufficiently informed about manual handling, noise and vibration, although this does not imply that these factors do not represent a risk to the health of workers in the waste and recycling industry.

The technologies identified following a kick-off discussion with industry were:

- Anaerobic Digestion (and Aerobic if things go wrong);
- Composting (open windrow and in tunnels);
- High Temperature incineration;
- Pyrolysis;
- Plasma;
- Gasification;
- Auto-clave;
- Materials Recovery Facilities (MRFs) including Trommel mills and screens;
- Mechanical Biological Treatment (MBT);
- Household waste recycling centres (HWRCs) and Transfer Stations;
- Glass, plastic and wood separation plants and the reprocessing thereof (heat and chemicals);
- Waste electrical and electronic equipment (WEEE) recycling including destruction and reclamation of product (mercury switches in LCD screen);
- Fridge recycling (refrigerant gases);
- Metal crushing and aluminium separation (eddy current separators); and
- Paper and cardboard baling – dust and fumes.

Some consideration has also been given to landfill as this is still an important disposal route for residual waste in large parts of the UK.

This study has sought to identify which of the occupational risk factors considered in this review are relevant to the technologies that were of interest, the extent of exposure to these risk factors, the proportion of workers who might have their health affected by these exposures and the severity of any impacts. For each type of exposure, we have considered the potential health impacts associated with high levels of exposure and where possible identified the threshold for effects. We have assessed likely exposure levels on the basis of published data, exposure modelling and our experience in providing consultancy to the waste industry, and assessed the associated potential impacts on worker health. In considering impacts, we have taken account of potentially vulnerable groups of workers (eg workers in temporary posts or who do not have good English) and the life-style factors that may also impact on worker health. The outcomes of the review include an identification of the exposures that are of greatest concern in terms of potential impact and where there is the greatest need to better understand exposure and risk, or consider changes in practice and improved risk management. The potential scope of the study was very large in terms of processes and exposures. We have therefore focused on the processes and exposures identified by ESAET that are within the remit of the "waste industry" and not on the downstream reprocessing of recyclate, which is associated with different exposures and risks.

During the course of this study, it became apparent that there is very little published information about exposures and health risks to workers in the UK waste industry and little to underpin the risk assessments that we undertook for each process. We were also aware from our own experience of undertaking measurement surveys that standards of exposure control at different waste management sites are very variable. The outcomes of this study include an identification of a large number of processes and exposures that may represent a significant risk to human health at some sites but not at other sites where appropriate control measures are in place. We have therefore made some recommendations as to what additional investigation might be undertaken in order to better quantify the potential risk to health associated with the waste industry. The outcomes of this review also include the identification of some processes and operating conditions where adequate exposure control is likely to be very difficult to achieve without radical changes in practice.

1.2 AIMS

The aims of the review were to:

- Provide a resource that will assist operators in the identification of potential hazards, assessment of the health risks to their workers and implementation of appropriate exposure prevention or control measures;

- Identify which of the occupational health issues selected by ESAET for review are associated with the industry's main activities and provide the basis for compiling risk assessments and identifying appropriate control measures; and

- Identify any occupational health issues that present unacceptable levels of risk (if any), require unique or burdensome control measures or where additional research is required in order to come to a clearer conclusion.

1.3 REPORT STRUCTURE

The first part of the report describes the methods used in the study (Chapter 2) and reviews the limited health information available for UK waste workers (Chapter 3). Chapters 4 to 10 reviews each of the identified hazards of concern: dust, bioaerosol, metals, other hazardous substances – gases and volatiles including landfill gas, toxic organic compounds such as dioxins and brominated fire retardants, and heat. Each of the chapters on individual hazards includes a description of the health effects associated with the hazard, an assessment of the exposures (if known) associated with different waste technologies and an assessment of the associated risk to health (if possible). The final part of the report (Chapter 11) summarises the hazards associated with each of the waste technologies identified by ESAET and, where possible, assesses the potential health risks based on the exposure assessments made in earlier chapters. Where appropriate, processes and conditions leading to exposures that are likely to be harmful to health are identified and the methods available to reduce exposures described. In addition, this section of the report identifies processes for which there are insufficient data to determine whether risks are adequately controlled and provide recommendations on the further work that might be undertaken in order to better characterize the risk.

2 Methods

2.1 LITERATURE REVIEW

The aim of the literature review was to gather information about the key processes associated with each of the identified hazards, the types of adverse health effects associated with these hazards, potential levels of exposure associated with different activities and the likely numbers of affected individuals. We focussed on the UK waste industry but also took account of studies undertaken elsewhere in the world and included information from these studies that we believed to be relevant to the UK context. In practice we identified very little information about exposures in the UK waste industry or the numbers of people employed in different types of waste handling processes. Where information about the effects of specific agents on health was not available for the waste industry, information was sought about the health effects of similar exposures in other related industries.

An internet based literature search was undertaken using tools including the search engine Google Scholar and PubMed – an open access database of abstracts of the peer reviewed medical literature maintained by the US National Library of Medicine. Both peer-reviewed literature and "grey literature" was included as well as taking account of material that was previously reviewed as part of a comprehensive review of bioaerosol exposure and effects undertaken for Defra by IOM (Searl, 2010). Other information sources included reviews and guidance relating to the health effects of workplace exposure to individual agents or working in different sectors of the waste industry published by the UK Health and Safety Executive (HSE), Defra's WasteNet, the International Programme for Chemical Safety (IPCS), the US Agency for Toxic Substances and Disease Registry (ATSDR), the US Environmental Protection Agency (USEPA), the US National Institute for Occupational Safety and Health (NIOSH), the US Occupational Safety and Health Administration (OSHA), the EU Scientific Committee on Occupational Exposure Limits (SCOEL), the Dutch Expert Committee on Occupational Standards (DECOS) and the Nordic Expert Group (NEG) on Occupational Exposure Limits (OELs).

The identified literature was systematically reviewed in order to determine the:

a) Exposures/activities which without appropriate controls would pose a material risk to the health of workers in the industry, at least in some circumstances; and

b) Exposures/activities for which, because of an absence of data on levels of exposure or the relation of exposure to health outcomes, the likelihood of material risks to health is uncertain.

2.2 INDUSTRY QUESTIONNAIRE

A short questionnaire was made available to industry representatives in order to gather some high level information about the exposures and health issues that are perceived to be of most importance for different activities. We also asked about the control measures that are typically in place to manage exposures, the availability of exposure measurements or health surveillance data that could be used in a future study and typical airborne dust concentrations in relation to the UK workplace exposure limits (WELs) in order to gain an insight into how well the industry thinks exposure is controlled. The questionnaire and responses are contained in Appendix 1.

2.3 EXPOSURE ASSESSMENT

The exposure assessment was based on published measurements, where available, the outcomes of exposure modelling, the response to our industry questionnaire and our own experience of providing occupational hygiene services for the waste industry. The exposure modelling was undertaken with the Advanced REACH Tool (ART). The use of ART for workers exposure assessment under REACH is described in the European Chemical Agency's updated Guidance on Information Requirements and Chemical Safety Assessment. The ART tool was developed by IOM and its scientific partners in close collaboration with a range of stakeholders from industry and member states. A list of publications describing the development of ART can be found at www.advancedreachtool.com. The ART model requires a number of input parameters describing the material (eg whether granules, coarse dust or fine dust, proportion of fine dust present), the process (eg how much agitation of the material, scale, broad category of activity), information about process enclosure and the positioning of the worker relative to the process, information about exposure control measures (eg type of ventilation system) and information about the working environment (size of workroom, if indoors, in m^2 or proximity of buildings outside, and general ventilation characteristics). For most of these parameters, there is a choice of options within the model and the development of an exposure scenario involves selecting the most appropriate of these options.

2.4 RISK ASSESSMENT

The potential risks to health associated with each hazard for each process was assessed through comparison of the relative magnitude of predicted exposures versus threshold and no effects levels of exposure identified during the literature review. The risk assessment including investigation of the relative effectiveness of different control measures in reducing exposure to safe levels. It also identified those processes where it is likely to be very difficult to achieve an adequate degree of control.

3 Occupational ill health in the UK waste industry

3.1 INTRODUCTION

This chapter reviews the limited information available about occupational ill health in the UK waste industry and related information about the HSE enforcement activity that identifies some of the industry's failings in relation to health protection. The record of HSE enforcement activity does not provide any indication of the prevalence of the types of issue that have arisen and only a small proportion of UK waste sites have been subject to HSE enforcement activity. Practices at these sites may be extremely atypical of the wider industry. There are two main sources of information about worker health in the waste industry: a study of sickness absence data undertaken for the HSE (HSL, 2009) and a small number of published epidemiological studies.

3.2 SICKNESS ABSENCE DATA AND ROUTINE HEALTH SURVEILLANCE

The HSL (2009) undertook a review of sickness absence in the waste industry based on submissions from 16 local authorities and 2 private companies. It is unclear whether these respondents are broadly typical of the industry or whether rates and causes of sickness absence in other waste management companies are very different. In addition, many employees in the waste industry are employed through agencies and are likely to have untracked or poorly tracked sickness absences, and may have very different health issues from the permanent workforce.

The local authorities reported an average absence rate of 12.8 days per year per employee compared with the public sector 2007 average of 9.6 days per year per employee. Waste workers identified as drivers, loaders or operators had an average of 13.2 days per employee, although this estimate may have been inaccurate due to inaccuracies in the recording of job description. The private companies reported a much lower rate of absence of 7.0 days per year per employee which was comparable to the average of 6.8 days reported by the Engineering Employers' Federation for 2008. Inconsistencies in the recording of the reasons for absence meant that the HSL could not determine the most frequent causes of sickness absence. The most common causes of absence reported by public sector workers by the Local Government Employers' survey were musculoskeletal disorders (22.5% of absences) and stress (22.5%). Examination of the data available for waste workers led the HSL to conclude that musculoskeletal causes led to 21% and 11% of absences in local authority and private company waste workers respectively, and that stress led to only 4 and 2% of absences for public sector and private company waste workers respectively. The study did not provide information about absences due to respiratory ill health, infections or other illnesses that might have been related to employment in the waste industry.

The industry has recently initiated a programme to systematically collect sickness absence data but these data have not generally been reviewed. Only five of the six respondents to our questionnaire collected sickness absence data and only three had undertaken a review, indicating that much better use could be made of sickness absence monitoring in order to identify health issues within the industry. In addition, all six respondents to our questionnaire indicated that they undertake routine health surveillance that includes: general fitness for job/ vision/ audiometry, hand arm vibration, respiratory including lung function testing and testing for sensitisation, skin testing and musculoskeletal fitness. The exact scope of the surveillance undertaken depends on the job function of the individual with a risk-based approach to determining health surveillance needs.

3.3 HSE ENFORCEMENT ACTIVITY

The activities of the HSE in relation to waste operators provide an indication of the major issues that the HSE have encountered in the waste industry. It is not clear, however, whether the operators that have been subject to Improvement or Prohibition Notices or those that have been prosecuted are highly atypical of the waste industry or whether the HSE's activities have merely addressed the tip of an iceberg. Most notices and prosecutions relate to safety rather than health issues. It is possible that the relatively large number of safety issues arising in the industry mean that the HSE have not properly investigated potential health issues such as the potential for excessive dust exposure. The HSE also have a limited budget and are therefore likely to have focussed on where they perceive that it is likely that problems may exist. It is likely that many waste-handling operations are rarely or never inspected and that inspections may focus on the potential for accidents to cause immediate death or injury rather than exposures leading to longer term health problems. The failings reported by the HSE that could lead to ill health rather than immediate injury include:

Exposure to asbestos;
Exposure to mercury;
Eye injuries relating to exposure to lime dust;
Hydroclave process gases
Petrol draining and storage;
Exposure to lead in glass;
Rubber shredding plant;
Recycling of fluorescent lamps and tubes;
Legionella in emergency showers;
Noise;
Failure to provide adequate workplace washing facilities,
Failure to provide adequate health and safety training;
Failure to provide supervision;
Communication difficulties with Polish workers;
Manual handling; and
Lack of health and safety management;

It is apparent from the published HSE record, that workers in the waste industry are exposed to a wide range of different agents that could give rise to ill-health and that these exposures are not always adequately controlled. Poor management, training and supervision may give rise to increased risks of exposure to hazardous agents at some sites and poor communication with workers who do not have English as a first language may contribute to increased risks of exposure at some sites.

3.4 PEER REVIEWED LITERATURE

There are extremely few published epidemiological studies of the health of workers in the UK waste industry and only a relatively small number of published studies of the health of waste workers elsewhere in Europe. Most studies have focussed on the effects of bioaerosol and dust and have been undertaken for workers involved in waste collection and sorting, composting or other recycling activities. Most, but not all, found some evidence of adverse effects on acute health endpoints including mucous membrane irritation, evidence of upper airways irritation, cough and increased risks of gastrointestinal illness. Other reported effects include cross shift declines in lung function and evidence of an immune response to bioaerosol exposure (Searl, 2010). There have been almost no European epidemiological studies of the long term health effects that may be associated with employment in the waste industry. A German study reported a significant decline in lung function and increase in prevalence of chronic bronchitis over a 5 year period in composting workers in comparison to full time office staff not exposed to organic dust (Bunger et al, 2007). A US study of workers in two refuse-derived fuel plants with more than 5 years exposure found no evidence of adverse effects on lung function (Mahar et al, 2002). The absence of apparent adverse impacts may reflect a “healthy worker” effect as workers who were particularly prone to respiratory illness may have left the industry. In addition, the findings in workers with over 5 years of exposure may not be predictive of effects after a much longer working lifetime. An earlier study in the same plants reported that workers with more than 7 years exposure showed a significantly greater cross shift decline in lung function than those employed for shorter periods, implying that some degree of progressive lung damage had occurred (Mahar et al, 1999). Studies by Hours et al (2003) and Charbotel et al (2005) reported that skin irritation and cough were more common in a group of French incinerator workers than in a control group from other industries and that the workers also showed a slight decline in lung function. A small but significant increase in white blood cell count was reported in the exposed group that might reflect adverse effects on the immune system.

There is a small amount of information indicating that the downstream processing of recycled materials may be hazardous to health. For example, Zuskin et al (1998) reported an increased risk of chronic respiratory illness associated with working in the paper recycling industry and Rix et al (1997) reported that workers employed in five paper recycling plants had significantly increased risks for pharyngeal cancer. However, activities involving the processing of recyclate are beyond the scope of this study.

3.5 INDUSTRY PERCEPTION OF THE MAJOR HEALTH ISSUES

In the questionnaire respondents indicated that the health issues of concern varied by activity. Noise related hearing loss, hand arm vibration, manual handling and exposure to airborne contaminants including bioaerosol were identified as major issues by several operators. One respondent was concerned about age-related impacts on musculoskeletal fitness, the development of age-related arthritis and age related deterioration in hearing / vision in employees with an average age of about 50 and about 10 years employment in the industry. Exposure to skin contaminants in workshops and carcinogens, sensitisers and other toxic substances in hazardous waste were identified as issues by individual respondents. The noise and vibration issues were outside the agreed scope of this review but the industry’s concern about these issues is consistent with the picture provided by the reported enforcement activity of the HSE. None of the questionnaire respondents indicated that work-related stress was of concern, despite its importance in the wider workforce. The information provided by respondents about shift working and the requirement to undertake repetitive tasks suggests that factors associated with increased risks of stress such as repetitive tasks, changing shift patterns and limited or no control on work speed may be an issue at a minority of plants.

3.6 DISCUSSION AND CONCLUSIONS

There is no information about the prevalence of respiratory ill health, infections or other illnesses that could be related to workplace exposure to dust and bioaerosol in the UK waste industry or in workers formerly employed in the waste industry. This could reflect an absence of systematic study rather than an absence of effect. Although it is arguable that it is unlikely that a substantial increase in risk would have gone unnoticed, there are a number of factors that could obscure any increased risks of ill health. For example, many workers employed in the waste industry only remain in post for short periods and the number of workers at an individual site may be quite small. Effects could easily be overlooked in a mobile and fragmented workforce. Many workers are employed through agencies rather than being directly employed by the waste industry and there is unlikely to be any feedback to the industry if they leave as a result of ill-health. In addition, many workers may be of low educational status or have English as a second language and may not be able to or feel able to communicate any concerns about their health to management. It is noted that adverse health effects associated with exposure to dust, bioaerosol or toxic substances was only raised as a concern by a minority of respondents in the questionnaire survey. It is unclear whether this indicates an absence of serious adverse impacts or a lack of awareness of the potential harmfulness of these exposures arising from the focus of the HSE’s activities on safety issues or hazards such as noise and vibration.

4 Exposure to airborne dust

4.1 INTRODUCTION

This chapter describes the health effects that are associated with exposure to airborne dust and the exposure levels that may be harmful to health, the levels of dust exposure that may be experienced in different sectors of the waste industry and the associated risks to health. Dust exposure is relatively easy to measure and is widely measured in the waste industry. It can be a good proxy for related exposures to bioaerosol and other hazardous components within airborne dust, provided that the interpretation of the measurement data takes account of the presence of these hazardous components and does not assume that dust is inert. The first part of this chapter outlines the health effects that may arise following exposure to different types of dust that would typically be regarded in the waste industry as “low toxicity dusts” in the context of meeting UK WELs. The health effects associated with specific toxic components of dust such as metals or dioxins are considered in later chapters. The second part of the chapter describes the published information describing workplace exposure to dust in the waste industry and the outcomes of exposure modelling using the ART tool for different types of waste processes. The third part of the chapter assesses the potential risk to workers health associated with exposure to airborne dust in different sectors of the waste industry based on the outcomes of the exposure assessment. The final part of the chapter discusses the outcome of the risk assessment and draws some conclusions. The exposure assessment and risk assessment have not assumed the use of any respiratory protective equipment (RPE). Although RPE may be used to reduce exposures associated with particularly dusty tasks, the Control of Substances Hazardous to Health (COSHH) Regulation Approved Code of Practice (ACOP) indicates that it should only be employed where adequate control of exposure cannot be achieved by other means (HSE, 2005). The use of RPE was not assumed because of uncertainties about the extent of use and its effectiveness which is dependent on factors such as the appropriateness of the RPE for the type of exposure, the goodness of fit for the operator, appropriate training in its use and an appropriate maintenance regime. The COSHH ACOP provides information on the requirements for employers that are associated with the use of RPE.

4.2 HEALTH EFFECTS

“Low toxicity dusts”

These materials were traditionally termed “nuisance dusts”. This term dates from a period when respiratory irritation was not considered worthy of serious concern and occupational hygienists were focussed on the prevention of pneumoconiosis and the associated disability and early mortality. Over the last 2 decades there has been an increasing awareness of the permanent respiratory damage that may arise as a result of repeated irritation of the respiratory tract. Long term exposure to relatively low concentrations of “nuisance dust” is associated with increased risks of chronic obstructive pulmonary disease (COPD) which includes both chronic bronchitis and emphysema. The HSE Working Group on Actions to Control Chemicals (WATCH, 2004) noted that there were 900,000 diagnosed cases of COPD in the UK with probably a total number of cases of about 1.5 million. Although cigarette smoking is the main cause of COPD, occupational exposures to dusts, fumes and irritant gases can give rise to COPD in non-smokers and increase the risk of COPD in smokers. WATCH noted that a survey of UK households in 2001/02 had reported that 168,000 people attributed breathing and lung problems to work. This was consistent with the American Thoracic Society’s estimate that the population attributable risk for work-related COPD is 15% which would suggest 135,000-180,000 work-related cases in the UK. The HSE has stated that:

> Around 15% of COPD may be caused or made worse by work
> 4000 COPD deaths every year may be related to work exposures
> 40% of COPD patients are below retirement age
> A quarter of those with COPD who are below retirement age are unable to work

FEV_1 (forced expiratory volume in one second) and FVC (forced vital capacity, the maximum volume of air that can be exhaled following a deep inhaled breath) are widely used measures of pulmonary function in epidemiological studies. An increased decline in FEV_1, over and above that due to ageing, is an indicator of COPD development. COPD is associated with a reduction in FEV_1 to 80% of the predicted value in combination with an FEV_1/FVC ratio of less than 0.7. A 20% decline in FEV_1 following bronchial challenge with an agent known to provoke constriction of the airways is indicative of asthma. Whereas normal aging is associated with a decline in FEV_1 of about 30 ml per year, the decline in subjects who develop COPD is more than 40 ml per year (WATCH, 2004). Reductions in FEV_1 are associated with reduced life expectancy. WATCH (2004) reported that there was evidence from two studies that showed more than additive effects on FEV_1 due to the combined effects of dust and smoking, indicating that smokers are particularly sensitive to the adverse effects of dust exposure at work.

In 2004, WATCH noted that there was evidence of significant work-related declines in FEV_1 following 40 years exposure in workers exposed to respirable coalmine dust at 2 mgm^{-3} (8-hr TWA), respirable kaolin dust at 2.5 mgm^{-3} and respirable carbon black at concentrations of 1, 2 or 3.5 mgm^{-3}. WATCH also considered that the available data suggested exposure to any poorly soluble dust will affect lung function in a roughly linear fashion, and that it was not possible to identify a threshold for effects. Subsequently the HSE (2006) concluded that the average additional loss (over normal age-related loss) of lung function after a 40-year working life exposure to 4mgm^{-3} respirable dust was of no clinical significance or health concern for most individuals, although some individuals would be much more severely affected. The loss of lung function in a moderate proportion (around 12%) of workers would be sufficient to raise concern for occupational health.

The IOM (Miller et al, 2006) reviewed data it had collected on the respiratory function of more than 7000 miners exposed to coal dust and also compared the effects of exposure to coal dust with exposure to other dusts. The study results indicated that on average, exposure of UK miners to 4 mgm^{-3} of respirable coal dust over a 40 year working life led to a reduction of FEV_1 of 178 ml in non-smokers, 6 % of the average FEV_1 at age 60 (Table 4.1). However, 37% of the miners would have a reduction of 627 ml, and in 17%, the reduction would be 993 ml, or almost a third of their lung function. This added to the effect of aging would be expected to have a profound effect on a person's physical activity. Even average exposure levels as low as 1 mgm^{-3} for 40 years would be predicted to give rise to sizeable reductions in FEV_1. The comparison to other “low toxicity” dusts indicated that low level exposures to these materials could have an even greater impact on lung function than coal mine dust, although the data are less robust as fewer dust measurements were available.

Table 4.1: Predicted reduction in lung function following exposure to respirable dust concentration of 4 mgm^{-3} for 40 years for a man of 1.75 metres in height

Dust	**Loss of FEV_1 (ml/sec)**
Coal dust	178
Talc	240
PVC	608
Carbon black	386
Kaolin	440

The IOM study also reviewed the relationship between respiratory symptoms and dust exposure. Significant associations were found among talc workers, underground coalminers, PVC workers and heavy clay workers but not in opencast workers or in wool textile workers. This may have been because cumulative exposures were not analysed for the opencast or wool textile workers, which would have substantially reduced the power of these studies to detect effects. In addition the opencast workers had relatively low exposures to dust as a result of working outdoors. In the PVC workers, an association between PVC dust and mild breathlessness was found in smokers only, and was not thought to be of clinical significance. In both the heavy clay workers and underground coalminers, significant associations were found between cumulative exposure to respirable dust and symptoms of both chronic bronchitis and breathlessness (defined as breathlessness when walking with other people of your own age on level ground). Odds ratios for coalminers expressed per 57 mgm^{-3}.years (equivalent to exposure to 1.425 mgm^{-3} for 40 years at work) were 1.3 for chronic bronchitis and 1.4 for breathlessness. In heavy clay workers the odds ratios per 40 $mg.m^{-3}$.years (equivalent to exposure to 1 mgm^{-3} for 40 years) were 1.5 for both symptoms.

Separately WATCH (2007) reviewed the health effects associated with low levels of exposure to several types of insoluble dust for which exposure limits have been set (Table 4.2). These dusts were traditionally regarded as being of low toxicity and the summary presented by WATCH (2007) provides further evidence that adverse health effects could arise following exposure to low toxicity dusts at concentrations well below the existing Workplace Exposure Limit (WEL) of 4 mgm^{-3} for respirable dust as an 8 hour time weighted average (TWA).

Table 4.2: WELs (8 hour time weighted average: TWA) for respirable dust considered by WATCH (2007)

Dust	**WEL mgm^{-3} 8 hour TWA**	**Basis of WEL**
Kaolin	2	Single study indicating that exposure to 2.5 mgm^{-3} respirable dust would result in pneumoconiosis that could be diagnosed in chest X-rays but not necessarily symptoms. Clinically significant disability was expected to result from 40 years exposure to 5 mgm^{-3}.
Talc	1	Single study in talc miners/millers suggesting that exposure to 1 mgm^{-3} of respirable talc over 40 years would not lead to any form of pulmonary toxicity. This value is 6-fold lower than the level producing pulmonary toxicity (including lung tumours) in animals.
Portland cement	4	Respiratory symptoms were linked with exposure but no dose-response relationship could be determined. OELs were based on the view that there was no evidence of irritation or other respiratory effects at levels not exceeding 10 mgm^{-3} total inhalable dust and 4 $mg.m^{-3}$ respirable dust (both 8-hour TWA).
Aluminium oxides	4	Limited human data - lung fibrosis had been reported in workers but may have been due to co-exposure to mineral oil. Limited animal inhalation studies showed not respiratory effects at 20 to 100 mgm^{-3}.
Pulverised fuel ash	4	Study in a UK power plant showing increased chronic cough, breathlessness and wheeze in high exposure group (2.53 mgm^{-3}) relative to less exposed group with the greatest effect in workers exposed for over 20 years. Small changes in chest X-rays for 33 of 208 men. Findings viewed with caution as symptoms subjective
Carbon black	3.5	OEL based on ACGIH TLV* set to protect against dirtiness New data considered by WATCH in 2002 showed 40 years exposure to 1, 2, and 3.5 mgm^{-3} (8-hour TWA) (inhalable dust) in non-smoking male would lead to reductions in FEV_1 of 48, 96, and 169 ml respectively.
Barium sulphate	4	Old reports identified 'baritosis' in workers exposed to large amounts of $BaSO_4$ but there was no evidence of fibrosis or evidence associating baritosis with ill-health. The available data support the view that no health effects would be anticipated with long-term repeated exposure to 4 $mg.m^{-3}$ respirable barium sulphate.
Titanium dioxide	4	OEL based on ACGIH TLV set to minimise the potential for respiratory tract irritation and potential overload of pulmonary air-space architecture and normal clearance mechanisms. Negligible human data were available.

*American Conference of Governmental Industrial Hygienists Threshold Limit Value

The HSE (2010) argued that only limited benefits would accrue from reducing the current British limit values for respirable and inhalable dust (4 and 10 mgm^{-3}, respectively) and that it would not therefore be seeking to do this in pursuit of a long-term reduction in respiratory disease. Other EU member states, however, apply much lower limits for equivalent dusts. Since the autumn of 2011, the IOM has been advising its clients that the current British limit values for respirable and inhalable dust are unsafe and it would be prudent to reduce exposures as far below these limits as is reasonably practicable. IOM advice is that employers should aim to keep exposure to respirable dust below 1 mgm^{-3} and inhalable dust below 5 mgm^{-3}. These guidelines should only be applied to inert insoluble dusts such as calcium carbonate and barium sulphate that have been shown to have low toxicity in experimental systems.

Studies of the effects of airborne particles in large urban populations (specifically PM_{10}, the thoracic fraction, which comprises the fraction that is able to penetrate into the lungs) provide further evidence of the adverse effects of low level exposure to airborne dust. These studies have found associations between PM_{10} and small changes in the daily death rate, the number of hospital admissions for cardiovascular and respiratory illness and increased numbers of GP consultations for respiratory illness at the concentrations of PM_{10} present in ambient air (typically <0.1 mgm^{-3}; COMEAP, 1998; WHO 2000). Other studies of selected panels of individuals have shown associations between PM_{10} and increases in respiratory symptoms, particularly in those with pre-existing respiratory illnesses such as asthma (COMEAP 1998; WHO, 2000a). In addition, associations have been found between variations in daily concentrations of PM_{10} or $PM_{2.5}$ (high risk respirable fraction, particles that penetrate to the gas exchange region of the lung in people with compromised respiratory health) and various circulatory parameters that help to substantiate the association with heart disease (e.g. Gold et al, 2000). The results of studies of ambient PM suggest that mortality and cardiovascular effects are more strongly associated with $PM_{2.5}$ than with larger particles in the PM_{10} size range, which may be more strongly associated with respiratory effects such as chronic obstructive pulmonary disease, asthma and respiratory hospital admissions (COMEAP 2009; Brunekreef and Fosberg, 2005). Long term exposure to $PM_{2.5}$ in the UK is associated with an average loss of life expectancy of about 6 months. The health effects of air pollution have been established in the general population which is likely to include a much wider range of susceptibility than in workers, who would be expected to have a higher baseline fitness. The long term effects of $PM_{2.5}$ on life expectancy, however, are likely to include effects arising from exposures experienced by people who are fit enough to be in work. There is no evidence that dust exposure in the workplace is associated with adverse cardiovascular effects, but it seems plausible that cardiovascular effects could arise, particularly if workers are exposed to fine particles.

Most dusts encountered during waste handling and treatment are unlikely to be comprised of completely inert, insoluble particles. There is evidence that for a given mass concentration, particle toxicity increases with reducing particle size (and increasing specific surface area). This indicates that particular care is required where workers are exposed to unusually fine dusts, particularly those described as “ultrafine” particles which have an aerodynamic diameter less than 100 nm in diameter. This may be of potential concern to the waste industry as increasing quantities of nanomaterials are entering into widespread use (for example the use of nano-silver in socks and other clothing as an antimicrobial or nano-titanium oxide in sunscreen). These materials would be expected to then enter into waste. Currently, however, most or all of nanomaterials entering the waste chain are likely to be bound within a matrix (eg clothing or lotion) or contained within a liquid suspension, with little potential to become airborne. In addition to particle size, dust composition is likely to have an important impact on toxicity and the potential risk to workers’ health. The following sections describe the specific issues associated with dusts that contain a high component of organic material or have a significant metals content.

In conclusion, the HSE’s own advisory committee, WATCH, have advised HSE that the current regulatory limits of 4 and 10 mgm^{-3} for respirable and inhalable **inert** dusts respectively are not sufficiently protective. The IOM advises that exposures should be controlled to below 1 and 5 mgm^{-3} for respirable and inhalable **inert** dusts respectively. Most of the dusts that workers are exposed to in the waste industry are not inert dusts, although specific exposure limits may not have been set. Under COSHH, there is an existing obligation on the waste industry to control exposures to dusts that are likely to be more harmful than inert substances to safe (unspecified) levels which by implication would be well below the exposure limits for inert dusts. While the waste industry should as a minimum control dust exposure to the regulatory limits for inert dusts, this is unlikely to provide adequate protection of health, particularly as most dust exposures are likely to be associated with exposure to bioaerosol, metals and/or other hazardous substances.

Organic dusts

Organic dusts contain variable quantities of bacteria and fungae as well as other debris composed of formerly living material. The bacterial, fungal and related endotoxin and beta-glucan contents of dust are considered separately in Chapter 5 on bioaerosol and the health effects associated with exposure to organic dust as described below are likely to be partly or largely attributable to the bioaerosol fraction within organic dust. Endotoxin may play a particularly important role in determining organic dust toxicity (see chapter 5) but is not the sole causal agent of adverse effects. Data from a recent study of 4 large composting sites in the UK indicated that there was a significant correlation between exposures to dust and to bioaerosol (Sykes et al, 2011).

The IOM (Searl, 2010) have previously reviewed the health effects of exposure to organic dusts in the waste industry for DEFRA. Two conditions are specifically linked to exposure to organic dusts in a range of different settings:

> Organic Dust Toxic Syndrome (ODTS) is a flu-like syndrome that can occur after inhalation of cotton, grain, wood chip dusts, or other organic dusts or aerosols. ODTS is a non-allergic response that occurs 4-8 hours after exposure and is characterised by chest tightness, shortness of breath, dry cough, fever, chills, aching muscles and fatigue. The condition resolves within a few days.
>
> Hypersensitivity pneumonitis (inflammation of the lungs, also known as extrinsic allergic alveolitis) is an immunologically mediated (i.e. allergic) inflammatory disease of the lung involving the terminal airways.

The dust concentrations associated with ODTS are about ten times higher than those typically associated with hypersensitivity pneumonitis. Hypersensitivity pneumonitis, which is discussed further in chapter 5 (bioaerosol) includes conditions such as farmers' lung and mushroom workers' lung. Several fungal and bacterial components of organic dusts have been specifically linked with hypersensitivity pneumonitis. Other conditions that are specific to organic dusts include byssinosis, an obstructive respiratory disease specific to the cotton industry characterised by coughing, wheezing and chest tightness. Other less specific conditions that are associated with exposure to organic dusts include chronic bronchitis, mucous membrane inflammation syndrome, rhinitis and asthma. Some individuals may develop hypersensitivity to specific components in organic dust giving rise to occupational asthma (Sigsgaard and Schlunssen, 2004).

The outcome of our earlier review indicated that short-term workplace exposure to organic dusts in the waste industry is associated with irritation of the eyes, nose, throat and respiratory symptoms. The results of some studies suggest that eye and nasal irritation may arise at dust levels of 0.2 mgm^{-3} in some workplaces, respiratory symptoms such as chest tightness and wheeze may arise at exposure levels of about 1-2 mgm^{-3} and there are limited data that suggest an increased prevalence of respiratory symptoms at dust levels exceeding 5 mgm^{-3}. These effects are an immediate response to dust inhalation rather the result of prolonged exposure. The results of studies in the cotton industry and in some agricultural settings suggest that some workers may develop a degree of tolerance to organic dust on repeated exposure.

There is no good data describing the effects of long term exposure to organic dust in the waste industry (Searl, 2010). Prolonged high levels of workplace exposure to organic dust in other industries are associated with chronic respiratory illness including ODTS and byssinosis-like obstructive respiratory conditions (Searl, 2010). These conditions have not been described in the waste industry. This may reflect differences in dust composition compared with other organic dust exposures, differences in the pattern of exposure or the relatively short periods typically spent in the waste industry by waste workers. It could also reflect an absence of studies of chronic health effects in waste workers and may represent an information gap rather than a real absence of disease. We previously identified that the recent changes in the waste industry leading to greatly increased numbers of workers at composting and recycling facilities may lead to a greater prevalence of these conditions in the future if adequate measures to control exposures are not in place (Searl, 2010). There is no evidence that these serious irreversible respiratory conditions arise at workplace exposure levels less than 0.3 mgm^{-3} (inhalable dust) and most reports of adverse effects are associated with much higher levels of exposure (>1.2 mgm^{-3}).

Metals in mixed dusts

Chapter 6 considers the health effects of individual metals and the potential for adverse health effects associated with metals exposure during waste handling and treatment processes involving metal risk dusts. In other mixed dusts however, transition metals are believed to be one of the factors that are associated with particle toxicity, particularly the leachable or surface metal content.

The results of toxicological studies involving cell cultures and animals suggest that oxidative stress plays an important role in particle toxicity. Oxidative stress involves the production of reactive oxygen species by cells including free radicals and peroxides such as superoxide, nitric oxide and peroxynitrite. Some of the less reactive of these species (such as superoxide) can be converted by reactions with transition metals into more aggressive radical species that can cause extensive cellular damage including damage to DNA. Low levels of most of these oxygen-derived species are produced by normal aerobic metabolism and the damage they cause to cells is constantly repaired. However, if the production of these species exceeds the cellular capacity for repair, cellular damage may occur. Reactive oxygen species are normally produced as part of the cellular defence against pathogens such as bacteria. When cells respond in this manner to particles of nonbiological origin, in the absence of a biological target, the resultant oxidative activity can cause extensive tissue damage.

Transition metals such as iron, copper, chromium, vanadium and cobalt can induce cellular damage through oxidative stress mechanisms, the generation of oxygen-free radicals, oxidative damage to DNA, mutagenicity and the stimulation of pro-inflammatory factors (Valavanidis *et al*, 2008; Donaldson *et al*, 2005; Hoet and Boczkowski, 2008). Different metals and metals in different oxidation states appear to have differing potentials to cause inflammation (Hoet and Boczkowski, 2008).

There has been little investigation of the health effects of exposure to mixed dust with a raised metals content in the waste industry. In a French study of lung function in 83 incinerator workers from two incinerator plants, comparing and a group of 76 non-exposed workers, Charbotel et al (2005) reported that base-line lung functions were lower among incinerator workers than among non-exposed workers. The few significant differences were indicative of obstructive symptoms after smoking habits (pack-years), medical history of allergy or lung diseases and the examination centres had been taken into account in a linear regression, there was evidence of some loss of lung function linked to exposure in incinerator plants. The extent of impairment of respiratory function was, however, relatively small, consistent with the low measured levels of exposure to pollutants in workplace air. The study was relatively small, however, and it is possible that a larger study would have identified a small number of individuals showing much greater levels of respiratory impairment.

Crystalline silica

Dust generated by operations involving soils, many construction wastes, some filtration media and some combustion residues is likely to contain crystalline silica, most commonly as quartz. Exposure to crystalline silica is associated with the development of silicosis – a scarring disease of the lung that leads to severe respiratory impairment, associated adverse effects on cardiovascular health and premature mortality. Crystalline silica is also associated with the development of lung cancer, most commonly in association with silicosis. Statistically significant increases in deaths or cases of bronchitis, emphysema, chronic obstructive pulmonary disease, autoimmune-related diseases (i.e., scleroderma, rheumatoid arthritis, systemic lupus erythematosus), and renal diseases have also been reported in silica-exposed populations (IPCS, 2000). The threshold level of workplace exposure for the development of silicosis is equivalent to <0.05 mgm^{-3} as an average over a 40 year working lifetime.

Asbestos

Exposure to asbestos is associated with increased risks of lung cancer, mesothelioma (a cancer of the lung lining), and non-malignant lung conditions such as asbestosis (development of scar tissue within the lungs following high levels of exposure) and changes in the pleura (lining of the chest cavity, outside the lung). Both lung cancer and mesothelioma may develop following quite low levels of exposure and there may be a 30-50 year gap between exposure and the development of disease. Asbestosis is associated with exposure to high concentrations of airborne fibre over a prolonged period and would not be expected to arise in the waste industry. Three different models have been widely used in the prediction of cancer risks arising from exposure to airborne asbestos: the Health Effects Institute (HEI, 1991) model, the results of the Hodgson and Darnton study (2000) study and the Berman and Crump (2004) model developed for the US Environmental Protection Agency. The UK HSE (HSE, 2006) used Hodgson and Darnton's model in their regulatory impact analysis for the Control of Asbestos Regulations (2007).

4.3 HAZARD ASSESSMENT

Most waste handling and treatment processes are associated with exposure to dusts that have a much greater potential to cause ill health than "inert" mineral dusts and are likely to cause adverse effects at much lower levels of exposure.

Table 4.3 below summarises the differences in dust composition associated with different waste processes and provides a broad indication of relative hazard. For dusts with a high organic content the threshold for irreversible respiratory effects is believed to be 0.3 mgm^{-3} (above), although short term irritation of the mucous membranes could develop in some individuals at lower levels of exposure. For dusts with a lower but still substantial organic component, the threshold for respiratory effects is probably higher than for an organic dust, but will be lower than for an inert mineral dust. The threshold of 0.5 mgm^{-3} shown below has been selected to indicate the likelihood of a raised level of risk relative to an inert dust. Those with pre-existing respiratory illness and smokers are likely to be particularly sensitive to the effects of dust exposure.

Table 4.3: Estimated threshold for effect (as an 8 hour TWA) for different types of (respirable) dust that would currently be regulated as low toxicity dusts

Waste process	**Dominant components in dust**	**Threshold mgm^{-3}**	**Comments**
Landfill	Mixed waste residues from other waste treatment processes	0.5	Mixture of inert and more toxic materials
	Asbestos	<0.01 fml^{-1}	Threshold for re-occupation of buildings following asbestos removal operations; Concentration measured as respirable airborne fibres. No threshold level of exposure below which cancer risks are not increased - 40 years exposure to 0.01 fml^{-1} at work may be associated with a lifetime cancer risk of about 1%.
	Other hazardous wastes	<< 1	Toxicity will depend on materials disposed of but likelihood of dust emissions small
Construction waste	Inert mineral compounds, quartz content typically <<10% Inert mineral dust Crystalline silica Asbestos	 < 1 mgm^{-3} <0.05 mgm^{-3} <<0.01 fml^{-1}	Concrete and other construction materials typically contain crystalline silica; modern construction waste should be free of asbestos but pre-1990 construction wastes could contain asbestos; no threshold levels of exposure for chronic respiratory illness
Anaerobic digestion – waste reception and storage	Organic dust	0.3	Bioaerosol likely to be present
Composting	Organic dust	0.3	Bioaerosol likely to be present
Incineration etc – Waste reception and storage Ash	 Mixed dust with organic component Dust containing heavy metals, dioxins, PAHs, other hazardous combustion products	 0.5 Likely to be <0.5	 Bioaerosol likely to be present Elevated metals content combined with trace levels of toxic organic compounds is likely to give rise to higher levels of toxicity than associated with an inert dust
Materials recovery facilities MRFs	Mixed dust with organic component	0.5	Organic component likely to be elevated, inert mineral dust and metals also likely to be present; possible accidental exposure to asbestos
Mechanical biological treatment MBT	Mixed dust with organic component	0.5	Organic component likely to be relatively high, inert mineral dust and metals also likely to be present
HWRC Waste transfer station	Mixed dust with organic component	0.5	Organic component likely to be elevated, inert mineral dust and metals also likely to be present; possible accidental exposure to asbestos
Separation/reprocessing of glass, plastic wood	Mixed dust with organic component	0.5	Organic component relatively high for wood, lower for glass and plastic
WEEE	Metals – steel, lead, mercury, cadmium and other heavy metals; plastics	Will depend on metals present, likely to be <0.2	Threshold for effects with lead, manganese, tin and other metals is <0.15 mgm^{-3}, considerably lower for cadmium, arsenic, nickel, beryllium, mercury (may be absorbed onto dust particles); Iron less reactive, threshold may be >0.15 mgm^{-3}
Fridge recycling	Metals and plastics	Likely to be <0.2	Dust will contain iron and other more harmful metals
Metal recycling	Metals Plastics, paint etc	Likely to be <0.2	Dust will contain iron and other more harmful metals
Paper and cardboard recycling	Organic dust	0.3	Will contain fungi and other bioaerosol components

4.4 EXPOSURE

Overview

Exposure to airborne dust in the waste industry was assessed on the basis of published data and exposure modelling.

Published data

There are limited published dust exposure data for the UK but some data has been published for sites in other EU countries.

Organic dust

Table 4.4 is a summary of the published data that was reviewed in our study of bioaerosol exposure for DEFRA (Searl, 2010) together with a small quantity of more recent data. It is not known whether these data would be representative for the UK waste industry. Elevated dust exposures have been reported during the manual sorting and screening of waste (Sykes, 2011) and screening (Schlosser et al, 2009) at composting sites with some measured exposures greatly exceeding the UK limits for respirable and inhalable dust.

Table 4.4: Summary of published measurement data (central tendency and range) for waste industry

Source, activity, job type or environment	Study location	Dust (mg m^{-3})	Reference
Household organic waste collection	Norway	0.37 (0.10-2.10)	Heldal *et al* (2003b)*
Source segregated and mixed household waste collection	Norway	0.2	Heldal & Eduard (2004)*
Household Waste collection: Driver Loader	Poland	 6.3 (1.1-16) 7.7 (0.6-24)	Krajewski *et al* (2002)*
Waste collection	Netherlands	0.58 (<0.2-9.1)	Wouters *et al* (2002)*
Waste collection	Germany	Inhl: 2.6; Resp: 0.41	Neumann *et al* (2005)*
Waste Transfer Station (Remote operation; Plant A) Indoor waste storage pit (Manual operation; Plant B) Enclosed outside area	Netherlands	1.1 (0.3-3.4) 1.5 (0.3-7.9)	van Tongeren *et al*, (1997)*
Composting Plant	Netherlands	4.5(0.7-55.1)	van Tongeren *et al* (1997)*
Composting (mean range across 2 sites): Screening Turning Shredding	UK	Inhl: 1.37-3.32 0.39-1.23 1.46-1.54	Wheeler *et al* (2001)*
Compost workers at 4 sites	UK	0.39-2.88	Crook *et al* (2007)*
Compost Production workers Compost technical personnel Compost supervisors Compost bulldozer drivers Composting Site Process Hall Composting Site Workshop Composting site Canteen & offices	Netherlands	1.3 (<0.3-5.3) 1.5 (0.7-7.3) 1.8 (0.5-22.8) 0.5 (<0.3-12.2) 0.6 (<0.3-3.8) 0.4 (<0.3-2.2) 0.4 (<0.3-0.8)	Douwes *et al* (2000)*
Composting Plant site worker Composting Plant machine operator Bulldozer operator (reloading machine operator)	Poland	4.6 (0.8-10) 4.9 (2.3-10) 2.5 (1.9-3.2)	Krajewski *et al* (2002)*

Source, activity, job type or environment	Study location	Dust (mg m^{-3})	Reference
Drum composting plant treating catering waste receiving hall Drum composting hall. Control room - static samples	Finland	0.6-0.7	Tolvanen *et al* (2005)*
6 composting plants Mixing-fermentation Screening Maturation Shredding	Spain	Geomean (range) 3.6 (<0.2-17.9) 7.5 (1.0-226.0) 11 (<0.1-35.9) 1.2 (0.1-5.5)	Schlosser et al (2009)
4 composting sites in the UK Manual sorting Shredding Turning Screening	UK	Geomean (range) 1.47 (0.22-11.92) 0.92 (0.08-4.70) 0.77 (0.07-7.22) 1.24 (0.20-17.73)	Sykes et al (2011)
RDF Plant (range across 2 plants) Static 35 personal samples	US	0.42-0.58 0.50 mean	Mahar *et al* (1999)*
MRF: Dry waste (plastic & paper) unloading & pre-crushing (static samples)	Finland	0.9 (LOD-1.3)	Tolvanen (2001)*
MRF waste delivery area	Germany	Short term peaks > 6 Full shift << 6	Knop *et al* (1996b)*
Big waste sorting plant Small waste sorting plant	Poland	Inhalable dust 2.38 1.12	Kozajda et al (2009)
Personal exposure measurements for MRF workers Box Bag Twin-bin Mixed	England and Wales	Median (Range) 2.21 (0-8.95) 2.85 (0-18.59) 8.21 (2.01-62.61) 4.09 (0-45.02)	Gladding *et al* (2003)*
Waste sorting plant Large plant Small plant	Poland	Mean inhalable 2.38 1.12	Kozajda et al (2009)
MBT: static samples Pre-treatment & crushing Bioreactor Hall Drying Hall	Finland	0.4 (<0.01-0.7) 0.1 (<0.01-0.5) 0.4 (<0.01-1.5)	Tolvanen and Hanninen (2006)*
Incineration Combustion area – static samples Office level Slag pool level Bunker Crane room	Finland	0.2 (<0.01-1.0) 0.3 (<0.01-0.5) 3.3 (1.0-13.7) 0.4 (0-1.3)	Tolvanen and Hänninen (2005)*

*Reference given in Searl (2010).

Dusts with a low organic content

Maitre et al (2003) reported dust concentrations measured at an incineration plant in France and Raemdonck et al (2006) reported dust exposures for maintenance workers during the temporary shutdown of a municipal solid waste (MSW) incinerator (Table 4.5). The dust concentrations during maintenance operations were considerably higher than the UK exposure limits.

Table 4.5: summary of dust measurements reported for incinerators

Samples	Number of samples	Dust ($mg\ m^{-3}$)	Dust ($mg\ m^{-3}$)	Study
France: routine operation Plant 1 Plant 2 Control site	 16 personal 20 static 6 personal	Inspirable dust 1.44 (0.20-5.22) 1.46 (0.13-6.43) 0.06 (0.01-0.17)	Respirable dust 0.30 (0.07-0.80) 0.46 (0.07-0.80) .03 (0.02-0.06)	Maitre et al (2003)
Belgium: maintenance operations		$PM_{2.5}$ 11.5	Total PM 60.3 22.1 61.3	Raemdonck et al (2006)

Asbestos

There is some evidence from the record of HSE enforcement activities that waste workers are occasionally accidentally exposed to asbestos. Asbestos containing materials (ACMs) would not normally enter the general waste stream but could be found in construction waste, particularly construction waste that has been recovered from a site that has been derelict for over 20 years. ACMs could also enter the general waste stream as a result of inappropriate disposal either knowingly or unknowingly by householders.

Waste workers are at risk to exposure to asbestos when ACMs turn up in waste streams that should be asbestos free. The HSE (2007) have provided guidance on the handling of ACMs at civic amenity sites (HWRCs), but there is a small risk that ACMs could turn up at waste transfer stations, MRFs, MBT facilities and other facilities taking mixed waste including wastes where some segregation (eg removal of paper) has already occurred. The risks of asbestos exposure at landfills that are specifically licensed to take asbestos waste is small. Asbestos wastes must be double bagged and procedures in place to ensure that there is no release of fibre to ambient air during the deposition of waste in dedicated cells. Asbestos wastes must be covered immediately after deposition.

Exposure to airborne fibres arising from asbestos appearing in the general waste stream at non-dedicated facilities can be readily minimised through ensuring that workers who may encounter ACMs have appropriate awareness training and that clear procedures are in place to deal with suspect ACMs including the use of appropriate PPE.

Exposure to asbestos is likely to be infrequent, exposure levels may exceed the control limit concentration but events are likely to last for less than an hour and exposures are highly unlikely to exceed the control limit over the 4 hour averaging period. It is unlikely that these occasional incidents would give rise to a significant exposure in terms of fml^{-1}.hours. If a worker was exposed 2 or 3 times a year over a 20 year period and the average exposure on each occasion was 0.01 fml^{-1} as a 4 hour average (eg 0.2 fml^{-1} over 30 minutes), their annual exposure would equate to 0.12 fml^{-1} hours and their exposure over 20 years would equate to 2.4 fml^{-1} hours.

Exposure levels predicted using ART

Overview

Given the paucity of published exposure data for many parts of the waste industry, exposure modelling was undertaken in order to better understand probable exposure levels and the effectiveness of different control measures in limiting exposure. One of the major limitations in this exercise was that we have little information on the control measures that are in place. The design of waste processing equipment has focussed on the production of usable products from recyclate and worker health and safety may be secondary issue in equipment design. Where equipment design has taken account of work health and safety, the main focus has been on the prevention of immediate injury such as severed limbs or cuts from flying debris. There is much less awareness of the requirement to minimise dust emissions and dust containment may not be an important influence on equipment design.

The exposure modelling was undertaken using the Advanced REACH Tool that has been developed for the purposes of exposure prediction for the purposes of preparing a chemical safety report for the Regulation for the Evaluation, Authorisation and Restriction of Chemicals (REACH). The tool was used to model the median and 75th percentile exposure concentrations associated with a wide range of tasks in different settings in the waste industry. The model allows the impact on dust exposure levels of different control measures and other factors such as room size (expressed as floor area) to be tested. The 75th percentile exposure was modelled because this is the exposure level used for the purposes of risk assessment under the REACH Regulation, which is the major piece of legislation governing exposure to hazardous substances within the EU, although only partly applicable in the waste industry. The ART model provides estimates of dust concentrations as inhalable dust.

Landfill sites

In the absence of appropriate control measures, landfill sites can be significant sources of dust nuisances for local communities. In practice, however, landfill sites are subject to regulatory scrutiny and would typically have a dust management system in place to minimise offsite nuisance. The measures that are required to prevent off-site nuisance such as the use of sprays to prevent uncovered soils drying out, will also help to minimise workplace exposure. In general dust exposures on landfill sites would be anticipated to be well below 1 mgm^{-3}. A number of activities may be conducted on landfill sites including the processing of construction waste or waste segregation and other materials processing within a MRF. The exposures associated with construction waste or a MRF are discussed separately below. Workers on landfill sites will typically operate plants such as mechanical excavators, bulldozers and compactors. Provided that cabs are sealed and fitted with air filtration, then levels of dust exposure should be low (Table 4.6). A high proportion of the material that is handled is likely to have a moisture content that exceeds 5% which will further limit dust exposure. Asbestos wastes are kept contained and covered at landfill sites such that there is very little potential for dust release to occur.

Table 4.6: Modelled exposures to inhalable dust (median and 75th percentile) associated with work at a landfill site (mgm^{-3})

Activity	**Assumptions made in modelling exposure**	**Moisture content**	
		<5% moisture	5-10% moisture
Movement of waste, cover material (eg low grade compost) or soil using a mechanical digger 10% fine dust content	Cab windows open	0.58 2.1	0.058 0.21
	Cab doors/ windows closed	0.25 0.92	0.025 0.092
	Cab doors/windows closed and air filtration	0.083 0.31	0.0083 0.031

Construction waste

Construction wastes are generally handled outdoors which gives rise to a greatly reduced potential for exposure to airborne dust relative to the confines of an indoor environment. In addition, even a low level of moisture in waste is likely to greatly reduce potential exposure concentrations. The potential for exposure to dust is most likely during movement of waste with a mechanical digger or associated with crushing and grading. Some dust control measures may be in place in order to minimise off-site nuisance. The exposure concentrations modelled for the operator of a mechanical excavator are likely to be reasonably representative of full shift exposure concentrations (Table 4.7). It is unlikely that individuals spend a substantial proportion of their working day in the close vicinity of crushing and grading equipment and shift mean exposures are likely to be lower than the modelled values. It is anticipated that shift mean exposures would generally be less than 1 mgm^{-3}. For inert dusts, the risk to health would be extremely small. Provided that the mean crystalline silica content of dusts was less than 5%, shift mean exposures to crystalline silica are likely to be well below 0.05 mgm^{-3}. There is a small risk that workers would experience occasional exposure to asbestos as the result of the inappropriate disposal of asbestos containing material as described above.

Table 4.7: Modelled exposures to inhalable dust (median and 75th percentile) associated with activities involving construction waste (mgm^{-3})

Activity	Assumptions made in modelling exposure	Moisture content	
		<5% moisture	5-10% moisture
Movement of waste using a mechanical digger 10% fine dust content	Cab windows open	0.58 2.1	0.058 0.21
	Cab doors/ windows closed	0.25 0.92	0.025 0.092
	Cab doors/windows closed and air filtration	0.083 0.31	0.0083 0.031
Crushing of waste 100% coarse powder	Open process	2.8 10	0.28 1
	Limited containment	0.83 0.31	0.083 0.031
Grading 10% fine powder	Open process	0.28 1.0	0.028 0.1
	Limited containment	0.083 0.31	0.0083 0.031

Composting and Anaerobic Digestion

Dust exposures associated with handling raw waste and the final products of composting and anaerobic digestion are likely to be similar so only a single set of model results is presented here (Table 4.8). It is likely that the activities associated with anaerobic digestion are conducted indoors rather than outside. These processes would include the “biological” component of MBT. The results of the exposure modelling indicate that there is a high potential for workers to experience shift mean exposures that exceed 0.3 mgm^{-3} and are consistent with reported measurement data from compost sites across Europe (see Table 4.4). There appears to be a significant potential for dust exposure associated with handling the waste as it arrives on site and during the turning of composting material. The highest potential for exposure, however, may arise during handling of the final product, if it is allowed to dry out. These findings are consistent with published measurement data (eg Sykes et al, 2011). The modelled exposure concentrations for the operator of a mechanical digger are likely to be representative of shift mean exposures as these operations are likely to be undertaken throughout the shift. The model results suggest that the use of sealed cabs and air filtration is essential for both indoor and outdoor operations. The modelled exposures for screening of the product may be higher than shift mean exposure concentrations as workers may not spend the entire shift in close proximity to the process. Complete enclosure of screening operations is desirable in order to reduce dust concentrations in the immediate vicinity. The modelled concentrations for cleaning may be more than 8 times the shift mean exposure as workers are likely to spend only a small proportion of the shift cleaning. The potential for composting operations to cause odour and dust nuisance in local communities has led to a trend for composting and other operations involving organic wastes to be conducted indoors. This is likely to give rise to a greatly increased potential for exposure, particularly where there is limited ventilation and/or air is re-circulated within the building (in order to minimise the risk of environmental nuisance) rather than extracted to the outdoor environment. The exposure modelling has assumed that indoor composting operations would be conducted within a large space. The use of smaller buildings would lead to significantly higher exposures.

Table 4.8: Modelled exposures to inhalable dust (median and 75th percentile) associated with activities involving organic wastes

Environment	Activity	Assumptions made in modelling exposure		Concentration for activity mgm^{-3}
Outdoors	Waste reception, turning composting material, transport of end product	Movement of waste using a mechanical digger 10% fine dust content, 5-10% moisture content	Cab windows open	0.22 0.46
			Cab doors/ windows closed	0.094 0.2
			Cab doors/windows closed and air filtration	0.031 0.066
	Screening of product, 10% fine dust content, 5-10% moisture content	No enclosure		0.28 1.0
		Partial enclosure		0.083 0.31
	Movement of dried product	Movement of waste using a mechanical digger 10% fine dust content, 5-10% moisture content	Cab windows open	2.2 4.6
			Cab doors/ windows closed	0.94 2
			Cab doors/windows closed and air filtration	0.31 0.66
Indoors – Floor area* 3000 m^2, no ventilation (a low rate of ventilation of 1 air change an hour would reduce exposure concentrations by 20%)	Waste reception, turning composting material, transport of end product	Movement of waste using a mechanical digger 10% fine dust content, 5-10% moisture content	Cab windows open	0.22 0.46
			Cab doors/ windows closed	0.094 0.2
			Cab doors/windows closed and air filtration	0.031 0.066
	Screening of product, 10% fine dust content, 5-10% moisture content	No enclosure		3.1 6.5
		Partial enclosure		2.2 4.6
		Complete enclosure and extraction		0.31 0.66
	Movement of dried product	Movement of waste using a mechanical digger 10% fine dust content, 5-10% moisture content	Cab windows open	2.2 4.6
			Cab doors/ windows closed	0.94 2
			Cab doors/windows closed and air filtration	0.31 0.66
	Cleaning – shovelling waste 10% fine dust content	Moist materials	5-10% moisture	0.48 1.0
		Dry materials	<5% moisture	0.048 0.1
	Cleaning – sweeping – 100% coarse powder (1000 m^2 room), <5% moisture			14 30

*The ART model provides a choice of room sizes based on floor area

Incineration and other high temperature thermal treatments

The dust associated with handling waste as delivered to plant and prior to its combustion or treatment by pyrolysis, gasification or plasma arc is likely to have a high organic content and include bioaerosol (see chapter 5). Waste incineration gives rise to bottom ash whereas other thermal treatments give rise to slag that may have a lower potential to emit dust. All the processes will give rise to air pollution control residues composed of fine particulate (flyash). The dust associated with handling solid residues arising from thermal treatments will have a higher metals content than the original waste (see chapter 6). Incineration residues may also contain dioxins (see chapter 8). The exposure to dust associated with working in a modern thermal treatment plant should be negligible during routine plant operation, where the process is entirely enclosed and automated from the initial reception of the waste to the transfer of ash to trucks for removal (Table 4.9). Potential exposure to dust is only likely during planned and unplanned maintenance operations. The highest exposure concentrations are likely to be associated with operations that involve the disturbance of dry ash, with flyash being potentially much dustier than bottom ash. The use of compressed air to clear blockages in an automated ash transfer system, for example, could give rise to exposure concentrations that exceed 1000 mgm^{-3} (Table 4.9). Even if such activities were only undertaken for a small proportion of the shift, shift mean exposures could easily exceed 50 mgm^{-3}. Dust exposure concentrations associated with cleaning and maintenance operations in the waste reception area or associated with the transfer line linking the waste reception area to the grate are likely to be generally below 10 mgm^{-3} as the waste will be damp and have a limited fine dust content. Long term mean exposure concentrations are likely to be less than 1 mgm^{-3}, assuming that cleaning and maintenance will only be undertaken on some shifts. However, in some plants the raw waste transfer line may be prone to blockages and jams arising from the heterogeneous nature of the waste delivered to the plant. This could lead to some individuals spending a significant proportion of their working day clearing blockages and jams giving rise to shift mean dust exposures that may be between 1 and 5 mgm^{-3}. The dust exposure of process operators in less automated plants will depend on the proportion of each shift spent in close proximity to dust sources such as conveyors, the extent to which dust sources are enclosed and the use of ventilation and extraction to minimise dust exposures. Dust exposures are likely to be greatest where process operators spend a substantial part of their working day dealing with blockages and other process problems. Even in the absence of significant process problems, shift mean dust exposures could exceed 1 mgm^{-3} if operators spend a significant proportion of the shift in close proximity to unenclosed or partially enclosed dust sources, particularly if no local exhaust ventilation (LEV) is employed and the general ventilation of the area is poor.

Table 4.9: Modelled exposures to inhalable dust (median and 75th percentile) associated with activities at waste incineration plants (ACH – air changes per hour)

Activity	**Assumptions made in modelling exposure**		**Concentration for activity mgm^{-3}**	**Comments**
Automated waste reception and transfer to grate: Routine operation, no people	Process entirely enclosed			Exposure levels during routine operation would be anticipated to be well below detection limit levels (0.05-0.1 mgm^{-3} depending on sampling time)
Maintenance (planned or unplanned) in reception area	Indoors 1000 m2 mixed waste 5-10% moisture, 10% fine dust 1 ACH	Shovelling	0.48 1	Potential for shift mean and long term exposures to approach modelled values, if there are persistent operational difficulties such as frequent blockages and jams; however it is unlikely that anybody would spend a full shift working with compressed air, and the 75th percentile shift mean exposure is unlikely to exceed 1 mgm^{-3}
		Sweeping	0.44 0.93	
		Clearing mixed waste with compressed air	4.4 9.3	

Activity	Assumptions made in modelling exposure		Concentration for activity mgm^{-3}	Comments
Older waste reception facility– waste moved by mechanical excavator	Indoors, floor area 1000 m^2 mixed waste 5-10% moisture, 10% fine dust 1 ACH	Enclosed cab	0.104 0.22	Individuals are likely to perform these activities for the entirety of their shift and the modelled concentrations are likely to be representative of shift mean exposures.
		Enclosed cab with air filtration	0.034 0.072	
Conveyor to grate	Mixed dry waste 5-10% moisture 10% fine powder 300 m^2 space No ventilation	No containment	2.6 5.4	Operators are likely to be in immediate vicinity of the conveyers for only a proportion of each shift and the median and 75th percentiles shift mean exposures could be much less than half the concentrations shown; Concentrations have been modelled for a relatively small space and predicted concentrations for a larger space would be lower by a factor of up to 10, depending on the size of the space
		Partial segregation	1.8 3.8	
		Segregation with extraction	0.26 0.54	
Removal of ash from grate by conveyor	Coarse powder <5% moisture 300 m^2 space No ventilation	No containment	86 180	
		Partial segregation	60 130	
		Segregation with extraction	8.6 18	
Transfer of bottom ash to trucks for removal – truck driver, site staff	Enclosed automated process; Coarse powder <5% moisture 1000 m^2 1 ACH	No extraction	0.017 0.035	The ash loading operation is likely to represent only a small proportion of the driver's shift and their shift mean exposure to dust would be much lower than the modelled concentrations. Incinerator site staff are likely to be in immediate vicinity of the ash transfer operations for only a small proportion of each shift their median and 75th percentiles shift mean exposures associated with this activity would be expected to much less than half the concentrations shown (although they may be exposed to dust elsewhere in the plant).
		With extraction	0.0055 0.012	
Transfer of fly ash to trucks for removal – truck driver, site staff	Enclosed automated process; Fine powder <5% moisture, floor area 1000 m^2 I ACH	No extraction	0.05 0.1	
		With extraction	0.016 0.035	
Movement of bottom ash using a mechanical excavator	Coarse powder <5% moisture, floor area 1000 m^2 1 ACH	Enclosed cab	5.5 12	Individuals are likely to perform these activities for the entirety of their shift and the modelled concentrations are likely to be representative of shift mean exposures.
		Enclosed cab with air filtration	0.55 1.2	
Movement of fly ash using a mechanical excavator	Fine powder <5% moisture 1000 m^2 1 ACH	Enclosed cab	17 35	Individuals are likely to perform these activities for the entirety of their shift and the modelled concentrations are likely to be representative of shift mean exposures.
		Enclosed cab with air filtration	1.7 3.5	
Cleaning and maintenance – disturbance of ash – entry into confined/semi confined spaces 30 m2 No specific ventilation	Shovelling spilt fly ash	Fine powder	260 550	These activities are likely to undertaken for a relatively short period within each shift. If cleaning was undertaken for one hour/shift, however, exposure concentrations would still be likely to greatly exceed 10 mgm^{-3}.
	Shovelling spilt bottom ash	Coarse powder	87 180	
	Sweeping spilt fly ash	Fine powder	230 490	
	Sweeping spilt bottom ash	Coarse powder	78 160	

Activity	Assumptions made in modelling exposure		Concentration for activity mgm^{-3}	Comments
requirements <5% moisture	Clearing blockage with compressed air: fly ash	Fine powder	1000 1000	These activities are likely to be undertaken for a relatively short period within each shift. If cleaning was undertaken for 30 minutes /shift, however, exposure concentrations would still be likely to greatly exceed 50 mgm^{-3}.
	Clearing blockage with compressed air: bottom ash	Coarse powder	780 1000	
Cleaning and maintenance – disturbance of ash – within larger indoor space – 1000 m2 No specific ventilation requirements <5% moisture	Shovelling spilt fly ash	Fine powder	53 110	These activities are likely to be undertaken for a relatively short period within each shift. If cleaning was undertaken for one hour/shift, however, exposure concentrations would be likely to greatly exceed 2 mgm^{-3} and the 75th percentile of exposure might approach 15 mgm-3
	Shovelling spilt bottom ash	Coarse powder	18 37	
	Sweeping spilt fly ash	Fine powder	48 100	
	Sweeping spilt bottom ash	Coarse powder	16 33	
	Clearing blockage with compressed air: fly ash	Fine powder	480 1000	These activities are likely to be undertaken for a relatively short period within each shift. If cleaning was undertaken for 30 minutes /shift, however, exposure concentrations would still be likely to greatly exceed 10 mgm^{-3}.
	Clearing blockage with compressed air: bottom ash	Coarse powder	160 340	

MRFs

The potential for dust exposure in MRFs is high as the waste materials are typically dry and therefore likely to emit dust. Processes such as shredding and then sorting waste materials and recyclate are likely to be significant sources of airborne dust. The results of the ART modelling exercise indicate that exposures to dusts with variable organic contents in MRFs are likely to exceed 0.3 mgm^{-3} (Table 4.10). Dust is likely to contain a significant bioaerosol component as even materials such as recycled glass are potential sources of bioaerosol (eg from residual food, see chapter 5). Typical full shift exposure levels may be within the range of 1-5 mgm^{-3} as an 8 hour TWA where some basic exposure control measures are in place, consistent with the measurement data shown in Table 4.4. In the absence of exposure control measures, exposure levels could be very much higher. The greatest exposure levels and potentially highest shift mean exposures are likely to be associated with cleaning activities. Activities that would be predicted to be associated with relatively high shift mean exposures include handling of waste in the waste reception area and working in the vicinity of conveyors, shredders or sieving/grading systems (depending on the proportion of each shift spent near these dust sources). Predicted exposures for handpicking are also likely to exceed 0.3 mgm^{-3}, even where LEV is in place. The correct installation, operation and maintenance of LEV, should lead to a significant reduction in exposure levels for workers in MRFs. As with indoor composting facilities, the trend towards limiting emissions to outdoor air in order to minimise dust and odour issues in the local community may lead to increased levels of workplace exposure to dust.

Table 4.10: Modelled exposures to inhalable dust (median and 75th percentile) associated with activities at MRFs

Activity	Assumptions made in modelling exposure		Concentration for activity mgm^{-3}	Comments
Waste reception – operator of mechanical excavator Moving dry mixed waste (eg from recycling boxes)	3000 m^2 space, No ventilation Unenclosed cab		8.3 31	Activity is likely to be undertaken over most of the shift and the predicted median and 75th percentiles are likely to be representative of full shift exposure.
	3000 m^2, No ventilation Enclosed cab plus filtration		0.83 3.1	
Working in the vicinity of a moving waste - conveyor Mixed dry waste <5% moisture 10% fine powder 300 m2	No containment		26 54	Operators are likely to be in immediate vicinity of the conveyers for only a proportion of each shift and the median and 75th percentiles shift mean exposures could be much less than half the concentrations shown; Concentrations have been modelled for a relatively small space and predicted concentrations for a larger space would be lower by a factor of up to 10, depending on the size of the space
	Partial segregation		18 38	
	Segregation with ventilation		2.6 5.4	
Handpicking Mixed dry waste <5% moisture 10% fine powder	3000 m2	No ventilation	4.2 8.9	Activity is likely to be undertaken over most of the shift and the predicted median and 75th percentiles are likely to be representative of full shift exposure. LEV has a significant impact on exposure levels
		LEV	0.42 0.89	
	1000m2	No ventilation	4.8 10	
		1ACH	4.4 9.3	
		LEV	0.48 1	
Shredding – dry 5% fine powder content	Partial segregation without ventilation	3000 m^2 floor area	1.1 2.3	Operators are likely to be in immediate vicinity of the conveyers for only a proportion of each shift and the median and 75th percentiles shift mean exposures could be much less than half the concentrations shown;
		300 m^2 floor area	9 19	
	Segregation with extraction	3000 m^2 floor area	0.16 0.33	
		300 m^2 floor area	1.3 2.7	
Grading – dry 10% fine powder content	Partial segregation without ventilation	3000 m^2 floor area	2.2 4.6	
		300 m^2 floor area	18 38	
	Segregation with extraction	3000 m^2 floor area	0.31 0.66	
		300 m^2 floor area	2.6 5.4	
Moving product – conveyor Dry product <5% moisture 100% granules, assumed room area 300 m2	No containment		26 54	Operators are likely to be in immediate vicinity of the conveyers for only a proportion of each shift and the median and 75th percentiles shift mean exposures could be much less than half the concentrations shown; Concentrations have been modelled for a relatively
	Partial segregation from workplace		18 38	
	Segregation with ventilation		2.6 5.4	
Transfer to hopper - Dry	No segregation from workplace		0.29 0.6	

Activity	Assumptions made in modelling exposure		Concentration for activity mgm^{-3}	Comments
product <5% moisture, 100% granules, assumed room area 300 m^2, low level containment	Partial segregation		0.2 0.42	small space and predicted concentrations for a larger space would be lower by a factor of up to 10, depending on the size of the space
	Segregation with ventilation (LEV would reduce exposure by a further factor of 10)		0.029 0.06	
Cleaning and maintenance operations in the absence of ventilation (working in a well ventilated space could reduce exposures by up to a factor of 10)	Shovelling waste, 10% fine dust content or Sweeping spillage of powdered product – 100% coarse powder	1000 m^2 floor area	5.3 11	If conducted for 1 hour within a shift, the 75th percentile predicted 8 hour TWA would be 1.4 mgm^{-3}
		30 m^2* floor area	16 33	High exposures may arise while working in restricted spaces
	Clearing material from jammed/blocked equipment with compressed air (<5% moisture)	1000 m^2 coarse powder	160 340	If conducted for 30 minutes within a shift, the 75th percentile predicted 8 hour TWA would be 21.25 mgm^{-3}
		30 m^2* coarse powder	780 1000	If conducted for 30 minutes within a shift, the 75th percentile predicted 8 hour TWA would be >60 mgm^{-3}
		1000 m^2 granules	48 100	Exposure associated with granules much lower than for dust
		30 m^2* granules	230 490	

*entry into enclosed space that would be unoccupied during routine operations (eg under a conveyor or in the enclosure of crushing or shredding plant)

HWRCs and Waste transfer stations

HWRCs and waste transfer stations are depots where waste is deposited from collection vehicles and transferred to other containers for onward transport. The main potential for exposure to dust is during movement of waste with a mechanical digger or associated with cleaning operations. These activities would be anticipated to be undertaken within a large indoor space (1000-3000 m^2) that would not necessarily have forced ventilation. Shift mean dust exposure concentrations may exceed 1 mgm^{-3} where dry wastes are handled, particularly if plant operators work with their cab windows open. The mixed wastes handled at many waste transfer station are likely to be damp, which would lead to lower exposure levels. The exposure concentrations associated with cleaning and maintenance operations are likely to greatly exceed 5 mgm^{-3} but these operations would typically be undertaken for only part of a working shift. Shift mean exposure concentrations may, however, still exceed 1 mgm^{-3}.

Table 4.11: Modelled exposures to inhalable dust (median and 75th percentile) associated with activities waste transfer stations (mgm^{-3})

Activity	Assumptions made in modelling exposure	Moisture content	
		<5% moisture	5-10% moisture
Movement of waste using a mechanical digger (3000 m^2) 10% fine dust content	Cab windows open	2.2 4.6	0.22 0.46
	Cab doors/ windows closed	0.94 2	0.094 0.2
	Cab doors/windows closed and air filtration	0.31 0.66	0.031 0.066
Cleaning – shovelling waste (1000 m^2), 10% fine dust content		18 37	1.8 3.7
Cleaning – sweeping – 100% coarse powder (1000 m^2)		16 33	1.6 3.3

Some waste transfer stations may incorporate a MRF or undertake more limited waste sorting in order to segregate materials that may potentially be recycled. The exposures associated with these activities would be anticipated to be similar to those predicted for workers in a MRF.

MBT, other materials recovery operations

Exposure to dust during the initial handling in the waste reception area are likely to be similar to those associated with handling mixed wastes in the reception area for other processes.

Exposure to dust during the mechanical treatment of waste is likely to be similar to that associated with processes such as shredding, grading and material transfer operations in a MRF. Where processes are highly automated and enclosed and effective ventilation is present, exposures would be predicted to be very low.

Exposure to dust during the biological treatment of waste will be similar to that associated with working in a dedicated anaerobic digestion or composting facility.

WEEE and metals recycling

Exposures to dust are most likely where materials are shredded or crushed, graded and handled in shredded or crushed form (Table 4.12). The potential for exposure is likely to be highly variable between operations. Most processes are likely to be highly automated and in principle could be readily enclosed and fitted with extraction. Exposures could be further reduced if the operations hall is appropriately ventilated. Worker exposure will be determined by the tasks that they undertake and their proximity to dust sources in the work environment. Cleaning and maintenance may be associated with very high levels of dust exposure, particularly if compressed air is used to clear equipment blockages and to clean surfaces. Other workers may experience high exposures if process containment is designed only to prevent material flying out that could cause injury rather than to prevent dust emissions and no extraction is in place. Other factors that could lead to high levels of exposure would include a limited supply of fresh air and the failure to appropriately filter recirculated air where emissions are discharged into the workplace rather than to outdoor air.

Table 4.12: Modelled exposures to inhalable dust (median and 75th percentile) associated with activities during the processing of WEEE

Activity	Assumptions made in modelling exposure		Concentration for activity mgm^{-3}	Comments
Crushing/grading granules Open process	$3000m^2$ space	No containment	7.3 15.5	Operators are likely to be in immediate vicinity of these processes for only a proportion of each shift and the median and 75th percentiles shift mean exposures could be much less than half the concentrations shown; exposures would be lower if good room ventilation was employed; operational difficulties leading to the requirement to undertake frequent cleaning and maintenance activities could give rise to significantly higher shift
		Partial segregation, no ventilation	5.2 11	
		Segregation with ventilation	0.74 1.5	
	$300m^2$ room	No containment	26 54	
		Segregation with ventilation	2.6 5.4	
Crushing/grading granules; Restricted contact between product and air	$3000m^2$ floor area	No containment	2.2 4.7	
		Segregation with ventilation	0.22 0.47	
Grading of shredded/crushed product, mixed particle sizes,	$3000m^2$ floor area, open process	No containment	3.1 6.5	
		Segregation with ventilation	2.2 4.6	

Activity	Assumptions made in modelling exposure		Concentration for activity mgm^{-3}	Comments
10% fine dust content		No containment	0.31 0.66	mean exposures
Moving product – conveyor, Dry product <5% moisture 100% granules,	assumed room area 3000 m^2	No containment	0.35 0.73	Operators are likely to be in immediate vicinity of these processes for only a proportion of each shift and the median and 75th percentiles shift mean exposures could be much less than half the concentrations shown; exposures would be lower if good room ventilation was employed; operational difficulties leading to the requirement to undertake frequent cleaning and maintenance activities could give rise to significantly higher shift mean exposures
		Partial segregation from workplace	0.24 0.51	
		Segregation with ventilation	0.035 0.073	
Moving product – conveyor Dry product <5% moisture 100% granules,	assumed room area 300 m^2	No containment	2.9 6.0	
		Partial segregation from workplace	2.0 4.2	
		Segregation with ventilation	0.29 0.6	
Transfer to hopper - Dry product <5% moisture 100% granules, assumed room area 300 m^2, low level containment	No segregation from workplace		0.29 0.6	
	Partial segregation		0.2 0.42	
	Segregation with ventilation (LEV would reduce exposure by a further factor of 10)		0.029 0.06	
Cleaning and maintenance 1000 m^2 room	Clearing blockages with airline	Coarse powder	160 340	If conducted for 30 minutes within a shift, the 75th percentile predicted 8 hour TWA ≤21.25 mgm^{-3} depending on material and activity, much higher exposures would arise in more confined spaces
		Granules	48 100	
	Sweeping	Coarse powder	16 33	
		Granules	4.7 9.9	

Other information on dust exposure

The IOM has experience of undertaking dust measurements for a number of operators and a large number of sites. Although we have not formally reviewed these data, generally we have found that dust exposure levels are below the UK WELs of 4 mgm^{-3} for respirable dust and 10 mgm^{-3} for inhalable dust but typically exceed the 1 and 5 mgm^{-3} levels for respirable and inhalable dust that have been recommended by IOM. The sites that have commissioned dust surveys may not be representative of the wider industry. The commissioning of a survey implies an awareness of dust issues and therefore it is probable that these sites would have more effective dust control measures in place than other sites. Dust concentrations at other sites that have not commissioned a survey could be very much higher. Our measurements at composting and other waste sites are generally compatible with the outputs of the exposure modelling described above. Without undertaking a formal analysis, which would require the extraction of data from a large number of reports to client, it is our impression that typical personal exposure concentrations for respirable dust range between about 0.5 and 3 mgm^{-3}. This is consistent with the published data. We do not know whether the samples analysed at the IOM are typical for the waste industry. The information provided by the respondents to our online survey was consistent with our informal impression of levels of dust exposure in the waste industry (Table 4.13). One respondent highlighted the potentially high exposures that may be associated with cleaning and maintenance operations, consistent with the conclusions of our exposure modelling exercise.

Table 4.13: Information on dust exposure levels in the UK waste industry provided by survey respondents

Activities	All measurements well below WEL	Most measurements below WEL	Rare measurements exceed WEL
Anaerobic digestion	1	0	0
Composting	3	0	1
Incineration, other thermal treatments	2	0	0
MRFs	2	1	0
Waste transfer station	2	1	0
Separation and reprocessing of glass, plastic or wood	0	1	0
Paper and cardboard recycling	0	1	0
MBT	1	0	0

Dust exposures in the UK waste industry are likely to vary widely between different sites for individual processes, depending on the extent of process automation and enclosure. Our own experience and the responses to our questionnaire indicate that the extent of automation and enclosure in the waste industry is highly variable (Table 4.14). Dusty operations such as composting may be highly automated and enclosed and fitted with effective extraction at some sites whereas at other sites there is no process enclosure and a much higher potential for exposure to airborne dust. Many processes are remotely operated or workers are contained within a sealed cab, which greatly reduces exposure whereas it is much more difficult to eliminate dust exposure associated with operations such as the manual screening of waste prior to composting or working on picking lines. The response to our survey suggests that extensive manual handling of waste occurs at some MRFs and some manual handling occurs at other MRFs but generally relatively little manual handling of waste occurs (Table 4.15). Concerns about emissions to ambient air mean that at some plants there are no emissions to the outdoor environment and re-circulation of air within the workplace, which may increase the potential for dust exposure, particularly if air is not filtered prior to recirculation or the filtration process is inefficient. The wide variability in the control measures applied within the industry contribute to the very variable dust exposures experienced within single sectors of the industry.

Table 4.14: Information on dust control measures provided by survey respondents: number of respondents who picked each of the 12 options for each of the processes (omitting processes for which no responses were received)

Activity	Process entirely automated and enclosed			Process automated and partly enclosed			LEV where exposure possible			No discharge of treated air to outdoors		
	All	Some	None	All	Some	None	All	Some	None	All	Some	None
Anaerobic digestion	1	0	1	1	0	0	0	1	0	1	0	0
Composting	1	0	1	1	0	0	0	1	0	0	1	0
Incineration, other thermal treatments	0	1	0	0	1	0	0	0	0	0	0	0
MRFs	0	0	1	0	1	0	0	1	0	0	0	1
Waste transfer station	0	0	1	0	1	0	0	0	1	0	0	1
MBT	0	1	0	1	0	0	1	0	0	0	1	0

Table 4.15: Information on extent of manual handling of waste provided by survey respondents: number of respondents who picked each of the 6 options for each of the processes (omitting processes for which no responses were received)

Activity	Some manual handling of waste			Extensive manual handling of waste		
	All	Some	None	All	Some	None
Anaerobic digestion	0	0	1	0	0	1
Composting	0	0	1	0	0	1
Incineration or other thermal treatments	0	1	0	0	0	1
MRFs	0	1	0	0	1	0
Waste transfer station	0	0	1	0	0	1
Separation and reprocessing of glass, plastic or wood	0	0	0	0	0	0
Paper and cardboard recycling	0	0	0	0	0	0
MBT	0	0	1	0	0	1

Based on the response to our questionnaire (Table 4.16) and our own experience, respiratory protective equipment (RPE) is widely provided in the UK waste industry at sites where processes such as composting are undertaken but its use is only compulsory at some sites. In our experience, the type of RPE employed is variable and is not always face fit tested such that the protection afforded by RPE may be much less than intended. Where processes are entirely automated and enclosed, the potential for exposure to airborne dust should be small and no use of RPE would be anticipated during routine operations. The use of RPE is likely to be appropriate during cleaning and maintenance operations when operators have to enter enclosures.

Table 4.16: Information on use of RPE provided by survey respondents: number of respondents who picked each of the 6 RPE options for each of the processes (omitting processes for which no responses were received)

Process	Site where OH monitoring undertaken*	Compulsory RPE			RPE/gloves provided, not compulsory		
		All	Some	None	All	Some	None
Anaerobic Digestion	2	1	0	0	0	0	1
Composting	4	2	0	0	1	0	1
Incineration or other thermal treatments	2	1	0	0	0	0	1
MRFs	2	2	0	0	1	1	0
Waste transfer station	2	0	0	1	0	1	0
Separation and reprocessing of glass, plastics or wood	1	0	0	0	0	0	0
Paper and cardboard recycling	2	1	0	0	1	0	0
MBT, general handling of household waste	2	1	0	0	0	0	1

*assumed to equate to sites undertaking these activities and where exposure is likely

Conclusions

Dust exposures associated with routine operations in the waste industry are generally below the UK WELs of 4 mgm^{-3} for respirable dust and 10 mgm^{-3} for inhalable dust but may widely exceed the 1 and 5 mgm^{-3} guideline values for respirable and inhalable dust that have been recommended by the IOM. The highest dust exposures are associated with composting and materials recovery operations where the UK WELs for dust are exceeded at some plants. The potential for high dust exposure exists in other parts of the waste industry including the processing of WEEE and metal scrap (for which we have no data). The results of exposure modelling indicate that some cleaning and maintenance operations across a broad spectrum of waste processes could give rise to shift mean exposures that greatly exceed the UK WELs for dust. Persistent problems in plant operation could give rise to significant long term exposures, particularly where dry powders or granules are handled such as incineration residues, crushed glass or other dry crushed material and in association with any dry waste shredding or crushing operations.

4.5 RISK ASSESSMENT

Dust exposure levels, dust composition and the associated risks to health are highly variable in different sectors of the waste industry. Even in individual sectors, there is likely to be substantial variability in exposure levels and dust composition. Although it is likely that dust exposure levels are generally (but not consistently) controlled to meet the UK WELs of 4 mgm^{-3} for respirable dust and 10 mgm^{-3} for inhalable dust, these limits are not sufficiently protective to prevent the development of chronic respiratory illness, even for relatively inert "low toxicity" dusts. In most sectors of the waste industry, exposures are not to inert dust but to dusts with a high organic matter, including bioaerosol, or metals content or containing other toxic substances such that adverse effects could potentially arise at much lower levels of exposure than for "inert" dusts. Table 4.17 below summarises the potential health risk associated with exposure to airborne dust in different sectors of the waste industry based on the limited published exposure data plus the output of the exposure modelling. The assessments shown in Table 4.17 do not assume the use of RPE which may be used by workers while undertaking particularly dusty tasks such as cleaning and maintenance operations involving incinerator flyash. Elevated exposures leading to increased risks of chronic respiratory illness are particularly likely to arise at composting plants, MRFs and other sites where organic rich materials are handled in the absence of complete containment and associated extraction ventilation. Cleaning and maintenance operations may lead to elevated dust exposures in all sectors of the waste industry and frequent process problems leading to frequent interventions could give rise to long term exposures to airborne dust at levels exceeding the thresholds for the development of chronic respiratory illness. Exposures to dusts with particularly contents of toxic metals and/or organic compounds such as dioxins such as incinerator ash or dust generated during the treatment of WEEE, may also be associated with substantial risks of systemic toxicity such as kidney disease or cancers as discussed in chapters 6 and 8.

Table 4.17: Summary of the risks to health associated with exposure to airborne dust associated with different processes within the waste industry

Waste process	Health risk
Landfill	Typical dust exposures are likely to be well below the levels associated with a significant increase in risk of chronic respiratory illness provided that the plant is operated with sealed cabs and air filtration. If workers operate the plant with open cab windows, then dust exposures could potentially be high enough give rise to an increased risk of chronic respiratory illness.
Construction waste	Provided that operations are undertaken outside, it is anticipated that shift mean exposures to inert mineral dusts would be well below the levels associated with a significant increase in risk of chronic respiratory illness including the early stages of pneumoconiosis. Provided that the mean crystalline silica content of dusts was less than 5%, there should also be no significant risk of developing silicosis
Anaerobic digestion – waste reception and storage	See composting; dust exposures and associated risk to health may be slightly greater for indoor anaerobic digestion operations than for outdoor composting operations

Waste process	Health risk
Composting	There is a high potential for exposure to dust and levels of exposure are likely to exceed the 0.3 mgm^{-3} threshold for adverse effects on respiratory health even where workers are provided with a sealed cab and air filtration. Long term employment at a composting site is likely to be associated with a significantly increased risk of developing chronic respiratory illness, particularly if processes are not enclosed and/or workers are operating diggers and similar equipment with the windows open. In the absence of control measures, there is a significant risk that workers could develop fibrotic lung disease, OTDS and/or hypersensitivity pneumonitis (compost workers' lung) – see chapter 5 on bioaerosol. Exposure levels on individual shifts are likely to be sufficient to cause irritation of the mucous membranes in sensitive individuals and may cause exacerbation of pre-existing respiratory conditions such as asthma.
Incineration, other thermal treatments –	The exposure to dust during routine operation of a highly automated incineration plant in which conveyors and other handling processes are entirely enclosed should be negligible and not give rise to any adverse impacts on health. Dust exposures for operatives in less automated plants are likely to be higher than those experienced in more automated processes but will vary according to the degree of process enclosure and the tasks undertaken by individuals. Where there is little enclosure and operatives spend a significant proportion of their shift in close proximity to dust sources, then long term exposures to dust could be sufficient to give rise to increased risks of chronic respiratory illness. Regardless of the degree of plant automation, both planned and unplanned routine maintenance operations could give rise to significant exposures to dust, particularly where process problems lead to frequent interventions. The acute effects of high dust exposures are likely to include irritation of the mucous membranes, respiratory irritation and exacerbation of pre-existing respiratory illnesses such as asthma. Repeated dust exposure associated with clearing jams and blockages and cleaning equipment used for handling the waste prior to combustion is likely to be associated with a significant risk that workers could develop fibrotic lung disease, OTDS and/or hypersensitivity pneumonitis (compost workers' lung). Heavy repeated exposures to dust arising from clearing jams and blockages and cleaning equipment used for handling ash is likely to give rise to chronic respiratory illness and, if continued over a period of months to years, could lead to the development of pneumoconiosis. In addition the associated intake of metals and dioxin present in ash could be sufficiently to adversely affect health as discussed in chapters 6 and 8.
MRFs, Separation and reprocessing of glass, plastic and wood, Paper and cardboard recycling, the mechanical component of MBT	There is a high potential for exposure to dust with a relatively high organic content. Levels of exposure to organic-rich dusts are likely to exceed the 0.3 mgm^{-3} threshold for adverse effects on respiratory health, even where exposure control measures are in place. Long term employment in MRFs on a picking line or where processes such as shredding are poorly contained is likely to be associated with a significantly increased risk of developing chronic respiratory illness. In the absence of control measures, there is a risk that workers could develop fibrotic lung disease and/or hypersensitivity (see chapter 5 on bioaerosol). Exposure levels on individual shifts are likely to be sufficient to cause irritation of the mucous membranes in sensitive individuals and may cause exacerbation of pre-existing respiratory conditions such as asthma.

Waste process	Health risk
Waste transfer station	There is a high potential for exposure to dust with a moderate organic content. Levels of exposure to organic-rich dusts are likely to exceed the 0.3 mgm^{-3} threshold for adverse effects on respiratory health but shift mean exposures would not be expected to exceed 1 mgm^{-3}. Long term exposure to dust may give rise to an increased risk of chronic respiratory illness.
WEEE, fridge recycling, metal recycling	Significant exposures to dusts containing high concentrations of toxic metals are possible and the associated risks to health are discussed in chapter 6
Asbestos	It is unlikely that occasional exposure to airborne fibre will give rise to a significant increase in lifetime cancer risk – see Table 4.18 below

The risks of a waste worker with occasional accidental exposure to asbestos developing cancer are extremely small. Table 4.18 shows the estimated cancer risks for a worker accidentally exposed to asbestos through unexpected encounters with ACMs on 2 or 3 occasions a year over a 20 year period, starting from the age of 20. It seems unlikely that workers experience more than very occasional exposures to asbestos. The risks vary depending on the type of asbestos encountered. The most widely used asbestos mineral was chrysotile. Amosite was less widely used but it was used in more applications where it is present in friable material that is likely to release fibres. Crocidolite was much less widely used than amosite. It is likely that accidental exposure to airborne asbestos is most likely for chrysotile and amosite giving rise to cancer risks that would be intermediate between the estimated risks for these two minerals. The three available models for risk prediction also give slightly different results, but overall it seems likely that the increase in lifetime risk of death from cancer arising from occasional accidental exposure to asbestos would be much less than one in 100,000.

Table 4.18: Predicted cancer risks for waste workers with occasional exposure to airborne asbestos: deaths per 100,000

Model	Asbestos mineral	Mesothelioma	Lung cancer
HEI nonsmoker	Chrysotile	0.06	0.022
	Amosite	0.19	0.022
HEI smoker	Chrysotile	0.044	0.8
	Amosite	0.87	0.8
Hodgson & Darnton	Chrysotile	0.44	0.00025
	Amosite	0.87	0.015
	Crocidolite	6.3	0.015
Bernam & Crump	Chrysotile	0.0013	0.014
	Amosite/ Crocidolite	0.41	0.034

Evidence for increased respiratory illness associated with dust exposure in the UK waste industry

None of the six respondents to our online survey identified respiratory health as of major concern, although two expressed concern about the potential effects of exposure to substances in workplace air. The HSL (2009) sickness absence study did not identify respiratory health as a major issue but this could have been due to the limited information available to the study rather than the absence of excessive absence arising from respiratory causes. Measurement data suggest that there are a number of sites where bioaerosol exposures are likely to exceed thresholds for adverse effects, particularly at some compost sites and MRFs. The lack of awareness of respiratory health problems may reflect a strong healthy worker effect as described above and/or the highly mobile workforce such that few remain in the industry long enough to develop chronic respiratory conditions while still within the industry. In addition, factors such as smoking may conceal work-related respiratory illness.

4.6 DISCUSSION AND CONCLUSIONS

Dust exposure levels, dust composition and the associated risks to health are highly variable within and between different sectors of the waste industry. Even in individual sectors, there is likely to be substantial variability in exposure levels and dust composition. Although it is likely that dust exposure levels are generally (but not consistently) controlled to meet the UK WELs of 4 mgm^{-3} for respirable dust and 10 mgm^{-3} for inhalable dust, these limits are not sufficiently protective to prevent the development of chronic respiratory illness, even for relatively inert "low toxicity" dusts. In most sectors of the waste industry, dusts are likely to be substantially more harmful than "inert" dusts. Both published exposure data and the outputs of exposure modelling indicate that typical exposure levels across much of the waste industry exceed the threshold levels associated with a substantial risk of chronic respiratory illness following long term exposure. Where composting or materials recovery operations involving shredding and grading of materials are undertaken indoors, exposure levels may be sufficient to give rise to increased risks of hypersensitivity pneumonitis (see bioaerosol, chapter 5) or even ODTS where dusts have a high organic content or fibrotic lung diseases such as pneumoconiosis for exposure to mixed or "inert" dusts. Exposures to dusts with elevated contents of toxic metals and/or organic compounds such as dioxins such as incinerator ash or dust generated during the treatment of WEEE, may also be associated with substantial risks of systemic toxicity such as kidney disease or cancers as discussed in chapters 6 and 8. The absence of a widely reported excess of respiratory illness in the waste industry may be due to several factors:

- Lack of systematic investigation;
- Small proportion of employees who remain in post for significant periods of time;
- A strong healthy worker effect;
- Adverse respiratory effects may be masked by the adverse effects of smoking;
- Many waste sites employ agency workers and no systematic health surveillance is undertaken;
- Many of the workers with the highest exposure levels may be socially marginalised with little capacity to express concern about conditions or their health (eg low educational status, English as a second language); and
- The link between respiratory illness in individuals and their earlier working life may not be recognised.

It is possible that the timescale over which chronic respiratory illness would typically develop is longer than most employees remain in post and the industry is unaware of any respiratory problems that individuals may subsequently develop. Individuals may not attribute their respiratory illness to former employment in the waste industry. Workers who do develop respiratory symptoms while in employment may leave the industry giving rise to a strong healthy worker effect. There is no information about why workers leave the industry and as many workers are employed through agencies, it is possible that the industry could be unaware that respiratory health issues are contributing to their high staff turnover.

5 Bioaerosol

5.1 INTRODUCTION

This chapter reviews the health effects of bioaerosol and reported exposure levels in the waste industry and assesses the potential impact of bioaerosol on waste workers' health in the UK. Bioaerosol comprises micro-organisms, fragments of micro-organisms and other fragments of biological material in air. It is emitted from all types of wastes that have an organic component including green and food wastes, MSW, and, less obviously, traces of food in glass or metal recyclate, segregated paper or textiles. Exposure to bioaerosol in other industries has caused serious adverse health effects. For example, the prevalence of work-related respiratory symptoms such as wheeze, cough and breathlessness among farmers is believed to be between 23 and 50%, with effects being largely attributed to bioaerosol (Linaker and Smedley, 2002). Concerns about bioaerosol exposure levels were raised by respondents to our industry survey. This chapter describes the major components of bioaerosol that have been measured in workplace air, the health effects associated with each of these components including the available exposure-response information, and reported exposure levels. The final part of the chapter assesses the likely impact of bioaerosol exposure on the health of workers in the UK waste industry. This chapter is largely based on an earlier IOM review of the health effects of bioaerosol that was undertaken for Defra (Searl, 2010) but includes some new exposure data.

5.2 BIOAEROSOL COMPONENTS

Bacteria

The range of bacteria found in waste and in bioaerosol generated from waste depends on the nature of the waste and conditions during storage and handling. Most bacteria can be described as being - Gram-positive cocci, Gram-positive bacilli, Gram-negative cocci or Gram-negative bacilli. Gram positive/negative refers to whether bacteria do (+) or do not (-) retain crystal violet dye in the Gram staining protocol. Cocci are close to spherical in shape whereas bacilli are rod-shaped.

Concentrations of bacteria in air are described in terms of counts of viable (culturable) as colony forming units (cfu) or total (viable and non-viable bacterial particles) per unit volume air.

Actinomycetes are a group of Gram-positive bacteria that play an important role in decomposition of organic materials, such as cellulose and chitin and are therefore abundant in compost. Most members of the species are aerobic, but a few, such as *Actinomyces israelii*, can grow under anaerobic conditions. Some Actinomycetes species produce external spores, similar to fungi.

The term thermophilic is applied to bacteria (or fungi) that thrive at high temperatures (above 45 ^{o}C). Mesophilic bacteria (or fungi) thrive at moderate temperatures (25-40 ^{o}C). Xerophilic is used to describe organisms that can survive under extremely dry conditions.

Fungi

Fungi play a major role in causing decomposition of organic material and are important during waste decomposition and composting. The term mould specifically refers to species of microscopic fungi that grow in the form of multicellular filaments, called hyphae. Microscopic fungi that grow as single cells are termed yeasts. Fungi proliferate through sporulation leading to the production of spores or conidia. Fungi are generally present in ambient air in the form of spores. Spores degrade rapidly in air and both viable spores and the remains of spores that are no longer viable may be present in air.

The common fungal mould *Aspergillus fumigatus* presents a potential risk of opportunistic infection in immunocompromised individuals. The species most commonly associated with allergic disease are *Aspergillus fumigatus* and *Aspergillus clavatus*. *Aspergillus* species are found in almost all oxygen-rich environments and are common contaminants of starchy foods (such as bread and potatoes), and grow in or on many plants and trees. In addition, many species of *Aspergillus* are capable of growing in nutrient-depleted environments, or environments in which there is a complete lack of key nutrients.

Endotoxins

An endotoxin is a toxic structural component of a bacterium that is released if the bacterium is damaged. Endotoxins are lipopolysaccharide (LPS) or lipo-oligo-saccharide (LOS) compounds found in the outer membrane of various Gram-negative bacteria. LPS consists of a polysaccharide (sugar) chain and a lipid moiety, known as lipid A, which is responsible for the toxic effects. The polysaccharide chain is highly variable amongst different bacteria. The symptoms of many infections with pathogenic Gram-negative bacteria are due to endotoxin. Systemic effects include fever, a lowering of the blood pressure, and activation of inflammation and coagulation. Endotoxin is not a single uniform substance and there are uncertainties in its measurement and in the comparability of endotoxin levels measured in different environments.

Endotoxins are frequently present in organic dusts arising from waste handling activities and can persist long after the death of the source bacteria. Endotoxin concentrations are normally expressed in terms of Endotoxin Units (EU) per unit volume air.

Glucans

Beta (1→3) glucans (more correctly (1→3) beta D glucans) are polysaccarides that form part of the cell wall of certain fungi, particularly *Aspergillus* species and are commonly present in dusts generated from waste. Beta glucans consist of linear unbranched polysaccharides (sugars) of linked β-(13)- and β-(14)-D-lucopyranose units in a non-repeating but non-random order. In addition to forming a component of fungal cells, beta-glucans occur in some cereals such as barley, oats, rye and wheat.

5.3 HEALTH EFFECTS

This section is summarised from our report for Defra (Searl 2008). Domingo and Nadal (2009) provide a brief review of the health effects that may be associated with the composting of domestic waste but their review was based on a relatively small number of published references and provides no information on the specific process conditions associated with elevated exposures to bioaerosol or increased risk to health.

Exposure to airborne bacteria could be associated with a range of different adverse effects depending on the species present and the associated exposure to endotoxin may play an important role in giving rise to adverse effects (below). Bacterial exposures have not been widely measured in epidemiological studies of the waste industry. Adverse effects on respiratory and more general health (excessive tiredness) have been reported in waste workers exposed to concentrations exceeding 10^6 total bacteria/m^3 or 10^5 cfum^{-3}. There are few data from studies in other sectors relevant to the waste industry. A study of paper mill workers found an association between bacterial concentrations of 10^4 - >10^5 cfum^{-3} and increased risks of cough, breathlessness, gastrointestinal symptoms, skin infections and systemic infection. It is likely that workers in the waste industry, particularly in composting plants, are exposed to elevated levels of some Actinomycetes species. High levels of exposure to Actinomycetes species have been associated with hypersensitivity pneumonitis also known as farmers' lung. The acute symptoms of farmers' lung include airways inflammation and a reduction in lung function and efficiency. Prolonged exposure leads to collagen deposition and destruction of the lung structure leading to reduced lung volume.

Endotoxin has been the most widely used measure of bioaerosol exposure in workplace studies. Acute inhalation exposure to endotoxin may give rise to dry cough, breathlessness accompanied by diminished lung function, fever and general malaise with bronchoconstriction, headache and/or aching joints developing after several hours (DECOS

2010). The exposure of people with asthma or inflammations of the nasal mucosa to endotoxin can lead to bronchial obstruction and increased reactivity, giving rise to an exacerbation of symptoms. Long term exposure may lead to chronic bronchitis and diminished lung function and increased risks of asthma-related conditions. The results of a number of studies in the waste industry suggest that concentrations of 50 EUm^{-3} or greater are typically associated with adverse effects on health and there are limited data that suggest minor health effects may occur at levels of exposure below 50 EUm^{-3}. These effects include nasal symptoms, cough, unusual tiredness and diarrhoea at exposure levels <10 EUm^{-3}. In studies of workers from other industries there is limited evidence for thresholds of about 50 EUm^{-3} for respiratory effects and eye irritation, 900 EUm^{-3} for fever, and between 130 and 450 EUm^{-3} for effects on lung function, although the results of one study suggest possible impacts at less than 20 EUm^{-3}. Significantly increased risks of long term respiratory illness have been reported in workers repeatedly exposed to concentrations between 20 and 5500 EUm^{-3}. In a cross sectional study across 9 industries, the prevalence of symptoms ranged from 3% at 1 ngm^{-3}, 10% at 10 ngm^{-3}, 18% at 100 ngm^{-3} to 25% at 1000 ngm^{-3} (approximately 10, 100, 1000 and 10000 EUm^{-3}). The pooling of data across a number of industries may reduce the confounding effects of other dust components. The presence of other components within bioaerosol is likely to have an important influence on apparent exposure-response relationships and there are also significant technical difficulties in the sampling and analysis of endotoxin in workplace air that may have contributed to apparent differences in the potency of endotoxin in different studies (Searl, 2010). In addition, endotoxin is not a uniform substance. The Dutch expert committee on occupational exposure limits (OELs) has recently recommended a health-based OEL of 90 EUm^{-3} (8-hour TWA) based on a study of the effects of six-hour exposure to endotoxins in volunteers (DECOS, 2010). In addition, epidemiological data suggested that long term exposure to the OEL would cause only a small decrement in lung function over a 40 year working lifetime.

Exposure to airborne fungi is associated with a range of adverse effects on respiratory health including the development of allergic asthma and allergic rhinitis. Short term effects of exposures to airborne fungi may cause irritation of the eyes, nose and throat and symptoms such as runny nose and cough. Longer term exposure is associated with increased risks of chronic respiratory illness. There is a limited quantity of data linking exposure to fungi to gastrointestinal symptoms, but this may have been due to co-exposure to other bioaerosol components. Most airborne fungi are not pathogenic to man but some are capable of invasive infection. The Health Protection Agency estimates that there are about 4200 cases of aspergillosis in immunocompromised individuals in the UK each year, of which about 60% may be fatal (HPA, 2006). The exposure-response information available for airborne fungi is highly inconsistent and the use of variety of measurement metrics limits interstudy comparison, as does the variation of the species present in different environments. Adverse effects on respiratory health have been generally reported in workers in the waste and other industries at concentrations of exceeding 10^4 cfum^{-3} with limited data suggesting that gastrointestinal effects may arise at concentrations of less than 10^5 cfum^{-3}. There is also limited evidence of an absence of adverse health effects at workplace exposure concentrations of about 10^3 cfum^{-3}. Mild inflammation of the upper airways has been observed in workers exposed to concentrations of 10^3 to 10^6 total spores/m^3 as assessed by SEM and gastrointestinal symptoms have been observed at 10^5 spores m^{-3}. The Nordic Expert Group (2006) identified a lowest reported effects level of 10^5 spores/m^3 for lung function decline, respiratory symptoms and airways inflammation in studies of woodworkers and farmers. More severe respiratory symptoms including hypersensitivity pneumonitis have been reported at concentrations of 10^6-10^9 cfum^{-3}. Studies of the general population have demonstrated that a significant proportion (5%) of individuals are sensitised to one or more common moulds. There is some evidence to link increased levels of immunological markers of common moulds to asthma and allergic rhinitis but there is little evidence of a close association between these conditions and measured concentrations of fungi in air. There is extremely limited evidence to suggest that indoor mould exposures of more than 2000 cfum^{-3} or outdoor exposures of more than 1000 spores m^{-3} may be associated with increased risks of respiratory symptoms. The results of studies in children suggest that exposure levels as low as 350 cfum^{-3} in indoor air, may be sufficient to cause mild adverse effects on respiratory health. The Nordic Expert Group (2006) identified a NOEL (no observed effect level) of 700 spores/m^3 for nasal irritation.

There is relatively little information about the health effects of beta (1→3) glucan. Rylander (2006) suggested that inhaled beta (1→3) glucan suppresses the immune system causing an increased susceptibility to inflammation or sensitisation. Beta glucan is, however, marketed as a nutritional supplement to boost and modulate immune response and to enhance various therapeutic healing effects generated by the immune cells. The results of some studies have suggested an association between beta (1→3) glucan exposure, airway inflammation and symptoms. There are insufficient data to determine whether beta (1→3) glucan is itself a cause of ill health or merely a marker of fungal exposure with observed effects being caused by some other fungal component. The results of several studies in the waste industry suggest that respiratory symptoms and airways inflammation are more prevalent in workers exposed to concentrations exceeding 25 ngm^{-3} than at lower levels of exposure. Studies in other work environments have linked low level exposure to beta (1→3) glucan to respiratory symptoms, headache and fatigue.

5.4 EXPOSURE RESPONSE INFORMATION

The findings of a large number of individual studies and reviews of the published literature indicate that workplace exposure to bioaerosol in the waste and other industries is associated with increased risks of developing upper and lower respiratory symptoms and chronic respiratory illness. There is more limited evidence of increased risks of gastrointestinal illness or fatigue. Table 5.1 summarises the key exposure-response information for bioaerosol reported in the Defra study (Searl, 2010). There are no clear thresholds of effect for different bioaerosol components and some individuals may experience adverse effects at background levels of exposure in ambient air.

Table 5.1: Summary exposure-response information for bioaerosol

Bioaerosol component	Health endpoint	Exposure-response information	Study population
Bacteria	Respiratory symptoms, nausea, headache etc	Symptoms reported at 10^5 cfu m^{-3} or 10^6 total bacteria	Waste workers
Fungi	Respiratory symptoms, nausea, headache etc	Symptoms reported at >10^4 cfu m^{-3} and between 10^3-10^6 spores m^{-3}	Waste workers
		Increased symptoms associated with concentrations of 2000 $cfum^{-3}$ in indoor air or 1000 spores m^{-3} in outdoor air	General community
		Mild adverse respiratory effects may arise at concentrations ≥ 350 $cfum^{-3}$ in household air	Children
Total microbes	Respiratory symptoms, nausea, headache etc	Symptoms reported at 10^3 $cfum^{-3}$, very limited evidence of increase in symptom prevalence with increasing exposure	General community near compost operations
Endotoxin	Respiratory symptoms, fatigue	Greater prevalence of symptoms at concentrations >50 EUm^{-3}, but indications of nasal irritation reported in one study of waste workers at 4.5 EUm^{-3}, clear evidence that risks increase with increasing exposure	Workers in various industries
Beta(1→3) Glucan	Respiratory symptoms, nausea, headache etc	Limited evidence of adverse effects at concentrations 100 ngm^{-3}, no adverse effects at 1 ngm^{-3}	Studies of indoor air quality

5.5 EXPOSURE

Micro-organisms

Elevated levels of workplace exposure to airborne bacteria and fungi are found widely throughout the waste industry including waste collection, materials recovery, composting and the storage of waste material prior to incineration. Measurement data are available for the waste industry in the UK, Europe and North America that are likely to be reasonable representative for processes undertaken in the UK (Tables 5.2 and 5.3). It is likely that similar exposures could occur in the waste reception areas for other processes involving organic wastes (e.g. anaerobic digestion) or untreated MSW (e.g. gasification, pyrolysis, MBT, autoclave treatment). Exposure levels in most sectors tend to be higher during the summer but are not clearly linked with waste composition. There is limited evidence that waste storage may lead to increased exposure concentrations and more substantive evidence that activities that involve vigorous disturbance of waste materials are associated with increased bioaerosol exposures. Exposure levels vary within individual sectors suggesting that there is potential to reduce exposures through good practice, although some differences may also arise from differences in the type of waste being handled. For example, bioaerosol emissions associated with food wastes are likely to be different from those associated with garden waste. Bioaerosol levels also vary by location and activity in individual plants and are also likely to vary in different climates. Persoons et al (2011) reported that airborne bacterial concentrations at a composting site were highest during the initial rotting and sieving states. The highest levels of thermophilic actinomycetes arose during sieving whereas the highest concentrations of gram negative bacteria were associated with pile turning. Fungal concentrations were highest during initial loading and shredding of waste, fermentation and maturation. In a Spanish study of both indoor and outdoor composting processes, Schlosser et al (2009) reported that concentrations of both bacteria and fungi were highest in the shredding area. In contrast, Tolvanen et al (2005) reported that the highest airborne microbial concentrations arose in the waste reception area at an in-vessel compost plant where food waste was handled, which may reflect the higher bacterial and mould content of waste foodstuffs in comparison to the green wastes handled at other plants.

Table 5.2: Measured concentrations of bacteria at waste handling sites based on Searl (2010) and some more recent studies (central tendency and range). Key: **MB**: Mesophilic bacteria, **TB**: Thermophilic bacteria, **GNB**: gram negative bacteria; **MA**: Mesophilic actinomycetes, **TA**: Thermophilic actinomycetes,; GM: geometric mean

Activity, job type or environment	Study location	Total Bacteria (number m^{-3})	Viable bacteria (cfu m^{-3})	Actinomycetes (cfu m^{-3})	Reference
Biowaste collection	Germany	10^5			Bunger *et al* (2000)*
Household organic waste collection	Norway	0.80 x10^6 counts m^{-3} (0.06-3.80 x10^6)			Heldal *et al* (2003b)*
Source segregated and mixed household waste collection	Norway	0.4x10^6			Heldal & Eduard (2004)*
Household Waste collection	Finland	1700 (35-4500)			Kiviranta *et al* (1999)*
Household Waste collection:	Poland				Krajewski *et al* (2002)*
Driver			MB: 267 x10^3 (22-750) TB: 1.7 x10^3 (0.3-3.3)		
Loader			MB: 59 x10^3 (3.8-190) TB: 1.4 x10^3 (0.13-6.3)		
Waste collection	Germany	10^4-10^5			Neumann *et al* (2002)*

Activity, job type or environment	Study location	Total Bacteria (number m^{-3})	Viable bacteria (cfu m^{-3})	Actinomycetes (cfu m^{-3})	Reference
Household waste collection	Various	10^3-10^4			From studies reviewed in Swan *et al* (2003)*
Waste Transfer Remote operation; Indoor waste storage pit Manual operation; Enclosed outside area	Netherlands		 13.2×10^3 (0.4-1018.2×10^3) 11.2×10^3 (0.3-795.1×10^3)		van Tongeren *et al* (1997)*
Composting plant area	Germany	10^7		10^5	Bunger *et al* (2000)*
On-site Samples	US	4.5×10^3 (0.48-78.9×10^3)	GNB: 2.05×10^3 (0.24-41.2×10^3)	84 (0-1520)	Hryhoczuk *et al* (2001)*
Compost Plant	Nether-lands	166.2×10^3 (33.2-10665×10^3)	GNB: 1.6×10^3 (0.1-171.0×10^3)		van Tongeren *et al* (1997)*
Compost plant: Windrow turning[a] Shredding[b] Screening[b]				 1-3000×10^3 12-29×10^3 29-42×10^3	Taha *et al* (2007)* [a] Range across 4 locations [b] Range across 2 locations
Composting Screening Turning Shredding	UK	 6.9-60.5×10^3 22.2-48.1×10^3 91.4-146.9×10^3	GNB x 10^3 22.4-24.1 6.1-32.8 51.6-59.8	 3.7-41.8×10^3 16.7-42.4×10^3 19.3-37.2×10^3	Wheeler *et al* (2001)* (mean range across 2 sites):
Compost workers at 4 sites	UK			TA: 6500-114000	Crook et al (2006)*
4 Compost sites 4 Compost sites Inside cabs: static Outside cabs: static 50m from compost handling: static Personal exposure outside cabs	UK		 $<10^3$-$>10^6$ 10^5-10^6 10^3-10^4 10^{3}-10^5	 10^3-10^6 10^4-10^5 10^3 5×10^{3}-10^5	HSL (2010)
Composting Centre	Various		GNB: 10^2	TA: 10^4	Studies reviewed by Forcier (2002)*
Compost site Mixing of raw materials with water Loading of the final compost piles to pasteurization tunnels	Poland		 MB 4.17×10^4 MB 3.54×10^4		Buczyńska et al (2008)
Enclosed composting plant: by rotating sieve, Biofilter exhaust	Various	 7.67×10^4 33			Studies reviewed by Prasad *et al* (2004)*
Composting Plant site worker Plant machine operator Bulldozer operator (reloading machine operator)	Poland		MB: 919×10^3 (26-6278) TB: 64×10^3 (4.4-390) MB: 323×10^3 (19-540) TB: 257×10^3 (9.8-890) MB: 78×10^3 (31-170) TB: 29×10^3 (6.1-59)		Krajewski *et al* (2002)*

Activity, job type or environment	Study location	Total Bacteria (number m^{-3})	Viable bacteria (cfu m^{-3})	Actinomycetes (cfu m^{-3})	Reference
Composting Plant area after work shift	Germany	10^3		10^3	Bunger *et al* (2000)*
Drum composting plant treating catering waste receiving hall Drum composting hall. Control room	Finland	GM total microbial concentration 21.8 x10^6 m^{-3} 13.9 x10^6 m^{-3} 1.4 x10^6 m^{-3}			Tolvanen *et al* (2005)*
Composting facility Summer Winter Shredding Fermentation Maturation/storage Washing tower Quiescent piles Turning piles	France		GM (GSD) 1.4x10^4 (3.8) 976 (10.3) 3.8x10^4 (2.2) 3.2 x10^3 (9.8) 6x10^3 (8.3) 2.7x10^3 (7.2) 3.6x10^3 (9.8) 7.4x10^3 (9.8)	GM (GSD) 363 (9.8) 159 (16.8) 3300 (5.6) 275 (11.4) 562 (4.6) 70 (24.6) 229 (7.1) 778 (12.7)	Persoons et al (2010)
6 compost plants Mixing-fermentation Screening Maturation Shredding	Spain		MB GM (range) 1x10^7 (1.7x10^3-1.6x10^9) 2.7x10^7 (5.4x10^3-3.1x10^9) 3.3x10^6 (1.9x10^3-3.1x10^9) 7.2x10^6 (1.1x10^4-1.6x10^9)	GM (range) 2.4x10^5 (8x10^3-5.2x10^6) 5.5x10^5 (5.3x10^3-2.0x10^6) 1.4x10^5 (3.4x10^3-7.1x10^6) 4.0x10^4 (6.1x10^3-3.6x10^5)	Schlosser et al (2009)
Composting site Sorting cabins Reception Anaerobic digestion Composting tunnels	Spain		GM 1743 155 1 123		Nadal et al (2009)
MRF: Dry waste (plastic & paper) unloading & pre-crushing (impactor collection results)	Finland	MB: 14200 (2600-38400); 1400 when process was off TB: 15000 (3500-98900); 530 when process was off		MA: 1100; 70 when process off TA: 590 (90-3600) as spores per m^3	Tolvanen (2001)*
MRF waste delivery area	Germany	Total microbes: ≤6.9 x 10^5 cfum^{-3}			Knop *et al* (1996b)*
Waste sorting: Summer Winter	Canada	 9600 – 13000 1840-6110			Lavoie & Guertin (2001)*
RDF Plant (range across 2 plants) Mean personal exposure (35 workers)	 6.8 x 10^5 organisms m^{-3} (determined using fluorescence microscopy)				Mahar *et al* (1999)*
MBT Pre-treatment & crushing Bioreactor Hall Drying Hall static samples	Finland	MB: 55290 (7370-236960) TB: 12450 (1010-55210) MB: 2620 (710-6500) TB: 80 (20-250) MB: 120 (35-490) TB: 30 (0-70)	MA: 610 (90-4150) TA: 220 (35-1200) MA: 260 (0-710) TA: 30 (0-35) MA: 20 (0-20) TA: No growth		Tolvanen and Hänninen (2006)*

Activity, job type or environment	Study location	Total Bacteria (number m^{-3})	Viable bacteria (cfu m^{-3})	Actinomycetes (cfu m^{-3})	Reference
Incineration – Combustion area (office level) Combustion area (slag pool level) Bunker Crane room static samples	Finland		MB: 335 (90-1310) TB: 50 (0-95) MB: 1245 (175-27370) TB: 65 (0-175) MB: 24500 (6700-62545) TB: 2670 (880-4150) MB: 470 (42-3270) TB: 135 (0-350)	MA: 25 (0-70) TA: 50 (10-320) MA: 70 (0-580) TA: 23 (0-23) MA: 2170 (280-25070) TA: 990 (390-5160) MA: 120 (20-810) TA: 130 (0-900)	Tolvanen and Hänninen (2005)*
Domestic waste incineration			10^7		From studies reviewed in Swan *et al* (2003)*
Landfill – unloading, disposal, compaction Site 1-6 Site 2-5	Poland		1000 400		Buczyńska et al (2006)

*Full reference in Searl (2010)

Table 5.3: Measured concentrations of fungae at waste handling sites based on Searl (2010) and some more recent studies (central tendency and range). **TF**: Thermophilic fungi; **MF**: Mesophilic fungi[GM – geometric mean

Source, activity, job type or environment	Study location	Aspergillus fumigatus (cfu m^{-3})	Fungal spores cfu m^{-3})	Reference
Biowaste collection	Germany		10^5	Bunger *et al* (2000)*
Household organic waste collection	Norway		0.2×10^6 spore m^{-3} (0-0.2 $\times10^6$)	Heldal *et al* (2003b)*
Source segregated and mixed household waste collection	Norway		0.1×10^6	Heldal & Eduard (2004)*
Household Waste collection	Finland		XF: 1200 (70-23000)	Kiviranta *et al* (1999)*
Household Waste collection: Driver Loader	Poland		 30 (6.2-61) 63 (6.8-132)	Krajewski *et al* (2002)*
Waste collection	Germany	7-200x10^3	10^3-10^4	Neumann *et al* (2005)*
Waste collection	Germany		10^3-10^4	Neumann *et al* (2002)*
Household waste collection	Various		10^4-10^5	From studies reviewed in Swan *et al* (2003)*
Waste Transfer Remote operation; Indoor waste storage pit Manual operation; Enclosed outside area	Netherlands		16.2 x10^3 (0.2-1487 x10^3) 39.8 x10^3 (0.8-826.9 x10^3)	van Tongeren *et al* (1997)*
Compost Plant	Germany		10^7	Bunger *et al* (2000)*
Composting Plant	Netherlands		40.0x10^3 (7.0-686.7 x10^3)	van Tongeren *et al* (1997)*
Composting plant: Windrow turning[a] Shredding[b] Screening[b]		 1-4400x10^3 23-70x10^3 14-18 x10^3		Taha *et al* (2007)* [a] Range across 4 locations [b] Range across 2 locations

Source, activity, job type or environment	**Study location**	**Aspergillus fumigatus** (cfu m^{-3})	**Fungal spores** cfu m^{-3})	**Reference**
Composting (mean range across 2 sites): Screening Turning Shredding	UK		 1.0-6.5 x10^3 6.1-7.5 x10^3 6.4-12.7 x10^3	Wheeler *et al* (2001)*
Compost workers at 4 sites	UK	1000-3500	TF-2600-16700 MF2800-73900	Crook et al (2006)*
4 Compost sites Inside cabs: static Outside cabs: static 50m from compost handling: static Personal exposure outside cabs	UK	 <10^3-5x10^5 <10^3->10^6 <10^3-10^4 <10^3-5x10^5	 <10^3-5x10^5 <10^3->10^6 <10^3-5x10^4 10^3-10^6	HSL (2010)
Composting Centre	Various		10^4	Studies reviewed by Forcier (2002)*
Enclosed composting plant: Near rotating sieve Biofilter exhaust	Various	 2.03 x10^3 6 x10^2	 2.48 x10^3 9.4 x10^2	Studies reviewed by Prasad *et al* (2004)*
Composting Plant site worker machine operator Bulldozer operator (reloading machine operator)	Poland		 19 (1.6-56) 27 (5.8-69) 16 (11-26)	Krajewski *et al* (2002)*
Composting Plant area after work shift	Germany		10^4	Bunger *et al* (2000)*
Compost site Manual unrolling of straw Dosing of mycelium to the compost	Poland		 1.62x10^4 1.15x10^4	Buczyńska et al (2008)
Composting facility Summer Winter Shredding Fermentation Maturation/storage Washing tower Quiescent piles Turning piles	France	GM (GSD) 6.8x10^3 (5.0) 1.4x10^3 (9.2) 4.1x10^4 (4.2) 3.7x10^3 (5.7) 7.6x10^3 (3.4) 886 (3.8) 2.9x10^3 (4.6) 1.1x10^4 (6.3)	GM (GSD) 7.9x10^3 (3.2) 2.8x10^3 (7.5) 6.8x10^4 (5.3) 4.5x10^3 (4.0) 9.6x10^3 (3.6) 1.3x10^3 (3.6) 3.7x10^3 (3.8) 1.5x10^4 (4.8)	Persoons et al (2010)
6 composting plants Mixing-fermentation Screening Maturation Shredding	Spain	1.8x10^4 (<21-1.4x10^6) 8.0x10^3 (<18-3.5x 10^6) 4.0x10^3 (<18-7.1x10^6) 1.5x10^3 (<20-1.8x10^5)	4.1x10^5 (1.2x10^3-1.2x10^8) 3.2x10^5 (1.6x10^3-1.7x10^8) 1.2x10^5 (190-1.9x10) 8.6x10^5 (6.2x10^3-1.1x10^7)	Schlosser et al (2009)
Composting site Sorting cabins Reception Anaerobic digestion Composting tunnels	Spain	GM 60 35 <2 60	GM MT 2394 2025 76 1662	Nadal et al (2009)
Dry waste (plastic & paper) unloading & pre-crushing (static samples)	Finland		MF: 55200 (5400-202000); 3000 when process was off TF: 6500 (330-21800); 450 when process was off	Tolvanen (2001)*
MRF waste delivery area	Germany		6.6 x 10^4 cfum^{-3}	Knop *et al* (1996b)*

Source, activity, job type or environment	Study location	Aspergillus fumigatus (cfu m^{-3})	Fungal spores cfu m^{-3})	Reference
Waste sorting plants: "big" plant - Work area Office "small" plant- Work area Office	Poland		 2.9 x 10^4 3.6 x 10^3 7.8 x 10^4 2.5 x 10^3	Kozajda et al (2009)
MBT static samples Pre-treatment & crushing Bioreactor Hall Drying Hall	Finland		 MF: 96620 (30460-226240) TF: 3070 (180-155900) MF: 440 (265-850) TF: 35 (0-35) MF: 20 (0-35) TF: 20 (0-20)	Tolvanen and Hänninen (2006)*
Incineration – static samples Combustion area (office level) Combustion area (slag pool level) Bunker Crane room	Finland		 MF: 1725 (405-10105) TF: 120 (15-1925) MF: 1380 (160-4100) TF: 75 (0-140) MF: 118225 (13920-221840) TF: 5235 (390-293990) MF: 1945 (230-20350) TF: 195 (10-2665)	Tolvanen and Hänninen (2005)*
Domestic waste incineration			10^7	From studies reviewed in Swan *et al* (2003)*
Landfill – filled part of site Site 1-4 Site 2-1	Poland		 800 1200	Buczyńska et al (2006)

*Full reference in Searl (2010)

Endotoxin and beta(1->3)glucan

Reported concentrations of endotoxin and beta(1->3) glucans for individual waste processes are highly variable which may partly reflect very different levels of exposure control but may also reflect considerable measurement uncertainty (Searl, 2010). Endotoxin concentrations that exceed the DECOS OEL have been reported in some but not all studies of waste collection and composting plants (Table 5.4). Individual studies of MBT, a MRF and a waste storage at an incinerator also reported concentrations exceeding the DECOS OEL whereas the concentrations reported in a single study of a waste transfer station were less than the DEOCS OEL. Schlosser et al (2009) report endotoxin concentrations that are several orders of magnitude higher than the DECOS OELs in a study of 6 Spanish composting sites, although this might plausibly be due to measurement or reporting error. Concentrations of endotoxin are not clearly correlated with overall dust concentrations at a global level, but may be correlated with dust concentrations at individual sites (Fig 5.1). In a study of UK compost site, Sykes et al (2011) report mean concentrations of endotoxin that were within the DECOS OEL but maximum concentrations that were more than 20 times the OEL. The highest mean exposures were associated with the manual sorting of waste. Exposures to inhalable dust exceeding 1 mgm^{-3} were likely to be associated with exposures to endotoxin exceeding the DECOS OEL (Fig. 5.1). It is likely that elevated exposures to endotoxin and/or beta(1->3) glucans could occur in the waste reception areas for other processes involving organic wastes (e.g. anaerobic digestion) or untreated MSW (e.g. gasification, pyrolysis, autoclave treatment).

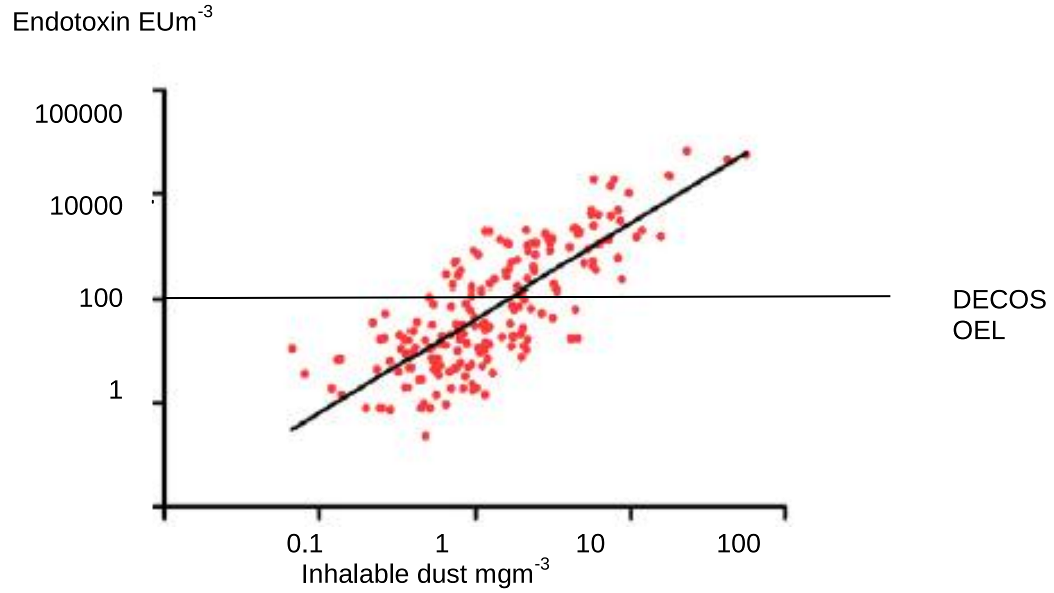
Table 5.4: Measured concentrations of endotoxin and beta(1->3) glucan at waste handling sites based on Searl (2010) and some more recent studies (central tendency and range).

Source, activity, job type or environment	Study location	Endotoxin (EU m^{-3})	Beta(1→3) glucans (ng m^{-3})	Reference
Household organic waste collection	Norway	13 (7-180)	52 (5-220)	Heldal *et al* (2003b)*
Source segregated and mixed household waste collection	Norway	1.8		Heldal & Eduard (2004)*
Household Waste collection: Driver Loader	Poland	 360 (9-1010) 360 (18-1090)		Krajewski *et al* (2002)*
Household waste collection	Sweden	0-90	10.4 (1.3-34.1) (highest in summer)	Thorn (2001)*
Waste collection	Netherlands	39.4 (<4-7182)	1290 (<260-30800)	Wouters *et al* (2002)*
Waste collection	Germany	19 summer >50 winter <10		Neumann *et al* (2005)*
Waste collection	Germany	10-50		Neumann *et al* (2002)*
Household waste collection	Various	0-200[3]		From studies reviewed in Swan *et al* (2003)*
Waste Transfer Remote operation; Indoor waste storage pit Manual operation; Enclosed outside area	Netherlands	 51 (23-137) 45 (16-130)		van Tongeren *et al* (1997)*
On-site Samples	US	119.9 (1.2-60.6)	0.79 (0.12-14.45)	Hryhoczuk *et al* (2001)*
Composting Plant	Nether-lands	51 (2-1862)		van Tongeren *et al* (1997)*
Compost workers at 4 sites	UK	3.3-3.6		Crook *et al* (Draft, 2006)*
Enclosed composting plant: Near rotating sieve Biofilter exhaust	Various	 207 0.08		Studies reviewed by Prasad *et al* (2004)*
Production workers	Nether-lands	527 (220-1712)	3620 (<150-13180)	Douwes *et al* (2000)*
Composting Plant site worker machine operator Bulldozer operator (reloading machine operator)	Poland	 760 (100-3240) 610(91-1140) 140 (92-200)		Krajewski *et al* (2002)*
Composting Site Technical personnel Supervisors Bulldozer operator Static samples Process Hall Workshop Canteen & offices	Netherlands	 373 (141-3544) 418 (107-1678) 75 (<6-357) 133 (10-366) 74 (8-2016) 101 (30-231)	 4850 (1.03-53.23) 4280 (1400-10380) 0.54 (<0.15-4.83) 650 (<150-16210) 570 (<150-12300) 364 (<150-1930)	Douwes *et al* (2000)*
4 large-scale composting facilities Manual sorting Shredding Turning Screening	UK	GM (range) 86.11 (706-1954.15) 48.68 (0.80-1837.73) 21.14 (0.95-2144.44) 33.76 (0.75-22656.25)	GM (range) 1.55 (0.09-127.42) 1.32 (<0.01-95.77) 0.6 (<0.01-83.38) 1.25 (<0.01-274.51)	Sykes et al (2011)

Source, activity, job type or environment	**Study location**	**Endotoxin** (EU m^{-3})	**Beta(1→3) glucans** (ng m^{-3})	**Reference**
Drum composting plant treating catering waste receiving hall Drum composting hall. Control room	Finland	 >200 >200		Tolvanen *et al* (2005)*
6 composting plants Mixing-fermentation Screening Maturation Shredding	Spain	 $1.2x10^5$ (408-$6.8x10^5$) $1.3x10^5$ (486-$3.2x10^6$) $2.3x10^4$(213-$1.5x10^6$) $5.2x10^5$ (1.6x104-$3.6x10^5$)		Schlosser et al (2009)
MRF Dry waste (plastic & paper) unloading & pre-crushing (static samples)	Finland	 4400 (47-10000) summer and autumn: 3400 to 10000 winter: 47 – 330		Tolvanen (2001)*
MRF Dry waste treatment plant: In processing hall Near a conveyor belt Near a jigger Near a bailer. Near the after crusher	Finland	 >200 >200 >200 >200 60		Tolvanen (2004)*
MRF Personal exposure Box Bag Twin-bin Mixed	England and Wales	Median (Range) 41.1 (12.9-402) 41.7 (3.1-272) 113.1 (12.9-1982) 47.4 (1.9-361)	Median (Range) 13.99 (0.32- 7.17) 23.16 (0.13-137.37) 20.12 (4.02- 3.91) 16.67 (0-81.82)	Gladding *et al* (2003)*
RDF Worker Personal Exposure: 1995 2000 Static 1995 2000	US	 20.7-38.4 22.5-34.5 25.1-60.6 24.0-27.5		Mahar (2002)* (range across 2 plants)
RDF Plant (range across 2 plants)		21.4-38.7		Mahar *et al* (1999)*
MBT static samples Pre-treatment & crushing Bioreactor Hall Drying Hall	Finland	 210.5 (50-980) 194.3 (4.2-1100) 16.2 (8.4-31)		Tolvanen and Hänninen (2006)*
Incineration Combustion area (office level) (slag pool level) Bunker Crane room	Finland	 15.7 (1.7-46) 223.4 (1.8-1300) 39500 (16000-59000) 30.3 (2.4-120)		Tolvanen and Hänninen (2005)*

*full reference in Searl (2010)

Figure 5.1: Relationship between concentrations of endotoxin and inhalable dust in a study of UK composting sites (Sykes et al, 2011).



Exposure control

Bioaerosol has been recognised to be a major issue for the composting sector. The HSE (2006) have produced guidance for farmers that are employed in composting that provides detailed specification of appropriate controls. The recommended measures include the use of:

Vehicles with sealed cabs with air filtration and doors and windows which must be closed during operations with compost or appropriate RPE employed.

Elevators, conveyors and screens should be enclosed or fitted with extraction.

RPE should be used where exposure to airborne dust is unavoidable.

It is clear from published exposure data that the effectiveness of exposure control measures at different sites is highly variable. The output of the dust exposure modelling discussed in chapter 4, indicates that the use of sealed cabs with air filtration could reduce dust exposure by a factor of 8 and the enclosure of dust sources combined with extraction could reduce exposures by a further factor of more than 10. Similar reductions in exposure to bioaerosol would be anticipated following the implementation of these control measures.

5.6 HEALTH RISK ASSESSMENT

Bacteria

Relatively few studies have described the exposure of waste workers to airborne bacteria. The available data suggest that it is likely that workers at a substantial proportion of composting plants and MRFs are likely to be exposed to concentrations that exceed 10^6 total bacteria m^{-3} or 10^5 $cfum^{-3}$. Similar exposures may arise wherever MSW or MSW fractions are handled such as within the reception and waste storage areas of MBT and incineration plants. These levels of exposure to airborne bacteria would be anticipated to lead to adverse effects on respiratory and more general health (excessive tiredness) and workers may also be at increased risk of gastrointestinal symptoms, skin infections and systemic infection. The measurement data also suggest that it is likely that some workers in composting plants (and possibly in other plants treating organic wastes), are exposed to elevated levels of some Actinomycetes species that are sufficient to give rise to hypersensitivity pneumonitis (farmers' lung). This would be associated with a loss of lung function and efficiency and eventually serious damage to the lung. The use of sealed cabs and air filtration should be effective in minimising the risks for compost workers but it may be extremely difficult to control exposures below the threshold levels for adverse effects at MRFs, particularly on picking lines, and where composting is undertaken indoors, even when dust sources such as shredders are enclosed and fitted with extraction.

Fungi

Published measurement data indicate that concentrations of airborne fungi at many sites handling MSW or green waste are likely to exceed 10^4 cfu m^{-3} of 10^3-10^6 spores m^{-3}. Concentrations exceeding these levels have been reported at waste transfer stations, MRFs, MBT plants, composting sites, the waste storage area at incinerators. Notably elevated concentrations of airborne fungi have been reported even where waste handling is automated and equipment is operated remotely. Elevated exposures to airborne fungi at waste handling sites are likely to give rise to an increased risk of respiratory symptoms including irritation of the eyes, nose and throat. A significant proportion of workers may have pre-existing allergies to common moulds as a result of exposure at home or other workplaces. These workers are particularly likely to develop symptoms such as rhinitis and cough. Longer term exposure is likely to be associated with increased risks of asthma or hypersensitivity pneumonitis resulting from sensitisation to specific moulds as well of increased risks of other chronic respiratory conditions such as bronchitis. As with bacteria, the use of sealed cabs and air filtration should be effective in minimising the risks for compost workers but it may be extremely difficult to control exposures below the threshold levels for adverse effects at MRFs, particularly on picking lines, and where composting is undertaken indoors, even when dust sources such as shredders are enclosed and fitted with extraction.

Endotoxin and beta (1->3) glucan

Published measurement data suggest endotoxin concentrations may exceed the DECOS OEL where municipal waste is handled or stored including processes at MRFs and MBT and at composting operations. Not all studies of composting and operations involving municipal waste have reported elevated endotoxin concentrations indicating that the effectiveness of control measures is highly variable. Where exposure is poorly controlled, endotoxin in workplace air could give rise to cough, breathlessness, fever, bronchoconstriction, headache, aching joints and general malaise. People with asthma may experience increased respiratory symptoms. Long term exposure to endotoxins may lead to chronic bronchitis and diminished lung function. Endotoxin may play an important role in increasing the risk of chronic respiratory illness associated with dust exposure where wastes containing an organic component are handled.

The importance of inhaled beta (1→3) glucan as a cause of ill health is highly uncertain. Reported exposures to beta (1→3) glucan in the waste industry are highly variable and it possible that a significant component of the variability is due to measurement uncertainty as it is not a widely measured analyte in occupational hygiene studies. Where data are available, typical exposure levels associated with the manual handling of waste and with composting exceed 10 ngm^{-3} and may be sufficient to contribute to the development of respiratory symptoms and symptoms such as headache and fatigue. The importance of beta (1→3) glucan as a risk factor for chronic respiratory illness is highly uncertain.

Vulnerable groups

A significant proportion of the population have pre-existing respiratory conditions and would be particularly vulnerable to the adverse effects of bioaerosol. In addition about 1 in 20 people are sensitised to common moulds that are likely to be present in air at any plant where organic rich wastes or MSW is handled. Some individuals would develop respiratory symptoms as a result of exposure to bioaerosol at background concentrations in ambient or indoor air that are orders of magnitude lower than the concentrations that may arise in workplace air (Searl, 2010). It is likely that somebody with asthma or allergic rhinitis would develop respiratory symptoms if employed at a site where organic rich wastes or MSW are handled. It is probable that these individuals and others with pre-existing respiratory illness that might be exacerbated on exposure to bioaerosol would find the discomfort associated with bioaerosol exposure at a waste plant intolerable. It is therefore possible that a strong healthy worker effect is prevalent in the waste industry as those who develop respiratory symptoms within a few days to weeks of starting work do not remain in post. This would be consistent with the reported high levels of turnover of labour in the waste industry. The employment of workers through agencies and the large number of workers whose first language is not English means that the impact of respiratory health on worker retention may be difficult to track. Similarly, those who become sensitised to bioaerosol components and develop asthmatic symptoms or allergic rhinitis over a longer time period, may also leave the industry. The mobile nature of the waste industry work force means that it is likely that the full impact of bioaerosol exposure on the respiratory health of waste workers would be under-estimated in any epidemiological study because of a strong healthy worker effect.

In addition to increased vulnerability to bioaerosol resulting from pre-existing respiratory conditions or sensitisation to bioaerosol components, the health risks associated with exposure to bioaerosol are considerably greater for those with compromised immune function. These individuals may develop serious illness as a result of opportunistic infection by aspergillus or other organisms as a result of exposure to bioaerosol at the concentrations typically present in UK air. Immunosuppression can have a number of causes and it is possible that an immunosuppressed individual who is otherwise fit would seek employment at a waste handling site. Such individuals would need a very high level of protection from bioaerosol.

Evidence for increased respiratory illness associated with bioaerosol exposure in the UK waste industry

None of the six respondents to our online survey identified respiratory health as of major concern, although bioaerosol were identified as an exposure of concern. The HSL (2009) sickness absence study did not identify respiratory health as a major issue but this could have been due to the limited information available to the study rather than the absence of excessive absence arising from respiratory causes. Measurement data suggest that there are a number of sites where bioaerosol exposures are likely to exceed thresholds for adverse effects, particularly at some compost sites and MRFs. The lack of awareness of respiratory health problems may reflect a strong healthy worker effect as described above and/or the highly mobile workforce such that few remain in the industry long enough to develop chronic respiratory conditions while still within the industry. In addition factors such as smoking may conceal work-related respiratory illness.

5.7 CONCLUSIONS

Levels of exposure to bioaerosol in the waste industry are highly variable, although it is possible that some of the reported variation may be partly due to measurement uncertainty. Other factors include differences in waste composition, process, season and control measures in place.

Exposures to airborne bacteria and fungi at composting sites, MRFs, associated with MBT and at any site where raw MSW or organic rich wastes are handled are likely to exceed the thresholds associated with adverse respiratory effects and increased risks of chronic respiratory illness. Processes that are particularly associated with elevated exposures to high concentrations of airborne microbes are the manual sorting of waste, shredding organic wastes, turning compost piles and sieving/screening. Handling stored wastes may also be associated with elevated levels of exposure to airborne bacteria and fungi. Even where exposure concentrations are relatively well controlled, it is likely that people with asthma and/or pre-existing sensitisation to moulds (about 5% of the population) working at composting sites or other sites handling organic rich wastes would experience adverse respiratory effects. Where indoor processes are not entirely enclosed and fitted with extraction or the operators of outdoor processes do not work within sealed cabs with air filtration, there is a risk that prolonged exposure to relatively high concentrations of Acetomycetes species in air could give rise to a condition similar to farmers' lung – hypersensitivity pneumonitis. Even at lower levels of exposure, it is likely that prolonged exposure to airborne microbes is likely to give rise to increased risks of sensitisation to common moulds with associated symptoms of rhinitis and cough, chronic bronchitis and other respiratory illness. Immunocompromised individuals are particular risk of becoming seriously ill as a result of bioaerosol exposure with the possibility of fatal infection by aspergillosis or other species. It is critically important that any immune-compromised individuals in the workforce are adequately protected.

Published measurement data suggest endotoxin concentrations may exceed the DECOS OEL where municipal waste is handled or stored including processes at MRFs and MBT and at composting operations. The measurement data for microbial concentrations and for endotoxin in air shown in Tables 5.2-4 are largely from different sites, but the overall impression given is that endotoxin may be an issue at a greater proportion of sites than the presence of viable micro-organisms in air. Where exposure to bioaerosol is poorly controlled, exposure to endotoxin in workplace air could give rise to cough, breathlessness, fever, bronchoconstriction, headache, aching joints and general malaise. People with asthma may experience increased respiratory symptoms. Long term exposure to endotoxins may lead to chronic bronchitis and diminished lung function. Endotoxin may play an important role in increasing the risk of chronic respiratory illness associated with dust exposure where wastes containing an organic component are handled.

Levels of beta(1->3) glucan measured at different types of waste site have been very variable and its importance as a cause of ill health is highly uncertain.

The measurement of exposure to bioaerosol is technically demanding and expensive. The measurement of dust concentrations is likely to give a good indication of where the highest exposures to bioaerosol may occur. Dust monitoring is likely to a be useful tool in managing exposure to bioaerosol provided that dust concentrations are controlled to much lower levels than the current UK exposure limits for dust. It would be appropriate to control exposure to organic dusts (inhalable fraction) to below 0.3 mgm^{-3} (see chapter 4), and even at these concentrations, bioaerosol concentrations may be significant in relation to the lowest levels reported to be associated with adverse effects.

6 Metals

6.1 INTRODUCTION

Waste workers may have elevated exposures to a wide range of metals, particularly during processes targeted at recycling metals and/or recovering metals from mixed wastes. Elevated exposures to metals may also arise in association with incineration residue.

Metals recycling is a long established industry and the reprocessing of segregated metal waste to form new metallic products often takes place in primary production plants or in highly specialised plants such as those specialising in reprocessing lead acid batteries. Nonferrous metals can also be recycled from captured particle emissions from metal primary or secondary production facilities and from industrial scrap such as aluminium left over when can lids are punched out of sheets, brass from lock manufacturing and copper from tubing manufacturing (OSHA, 2008). These manufacturing wastes are likely to be recycled at the production site.

This chapter specifically considers exposure to metals associated with working in the scrap metal industry, at materials recovery centres, WEEE processing plants and at incinerators. The recovery of metals from segregated metallic waste involves processes that are identical or similar to those occurring during primary production and workplace exposures are likely to be similar to those experienced during primary production. These processes would generally be classified as metals production rather than waste processing and the exposure and health issues would be largely indistinguishable from those associated with the production of metals from primary ore. This chapter therefore does not consider exposures to metals associated with the recovery of metals from segregated metallic wastes.

The first part of this chapter provides a brief description of the health effects associated with a wide range of metals that could be encountered in the waste industry. The second part of the chapter discusses likely exposure levels and the third part assesses the potential risks to health that may be associated with exposure to metals some sectors of the waste industry.

6.2 HEALTH EFFECTS

Metallic dusts

The health effects of exposure to metals are generally well understood, although there are no studies specific to the waste industry. The key health effects are summarised in Table 6.1. Most of the information about the effects of workplace exposure to individual metals is based on studies of workers that have been predominantly exposed to a single metal or a relatively small number of metals. In contrast waste workers would typically be exposed to a range of metals, often in combination with exposure to other hazardous substances. There is relatively little information about the effects of co-exposure to mixtures and the extent to which the risks to health may be additive, more than additive or less than additive. Many metals have similar modes of action arising from their similar chemistry. While this would be anticipated to lead to simple additive impacts, it is possible that competition between metals for key binding sites in biological molecules such as enzymes or haemoglobin, may give rise to less than additive effects.

Table 6.1: Summary of health effects associated with different metals to which waste workers may be exposed>

Metal	Effects
Aluminium (Al)	Limited evidence from workplace studies of impaired cognitive function, motor dysfunction, peripheral neuropathy and other neurological symptoms, respiratory impairment and work-related asthma – not clear whether effects due to Al or co-exposure to other hazardous substances (IPCS,1997).
Antimony (Sb)	High levels of workplace exposure over periods of weeks to years are associated with headache, vomiting, coughing, joint and muscular pain, sleeplessness, vertigo and loss of appetite. Metallic Sb is more toxic than trivalent Sb which is more toxic than pentavalent Sb. Long term exposure to concentrations of ≥ 0.5 mgm^{-3} in workplace air is associated with the development of chronic bronchitis and pneumoconiosis and may also be associated with increased risks of cardiovascular illness but the data are equivocal. Ulcerations and perforation of the nasal septum have been reported in Sb workers but are likely to have been due to co-exposure to arsenic. Contact eczema characterised by papular eruptions on the skin that may be preceded by intense itching has been reported in Sb exposed workers. Contact dermatitis has also been reported in ceramics workers exposed to Sb trioxide (NEG, 1998).
Arsenic (As)	Exposure to arsenic in workplace air at cumulative exposure levels ≥0.75 mgm^{-3}.years (ie 15 years exposure to 0.05 mgm^{-3}) is associated with increased lung cancer risks. Other reported effects include hypertension and cardiovascular disease, possible increased risks of diabetes, long term neurological effects and reproductive toxicity. Long term exposure to arsenic in drinking water is associated with increased risks of lung, bladder, skin and kidney cancer, skin changes and peripheral vascular disease leading to gangrene (black foot disease; IPCS, 2001a).
Barium (Ba)	The acute toxicity of Ba compounds appears to increase with increasing solubility. There is little information about the effects of workplace exposure to Ba. Long term exposure to Ba sulphate in workplace air is associated with reversible baritosis (a type of pneumoconiosis). One study reported an increased risk of hypertension but this could have been attributable to co-exposure to lead. The results of animal studies suggest that long term oral exposure is associated with kidney toxicity. No clear adverse effects have been observed in humans exposed to elevated levels of Ba in drinking water (estimated intake of 0.4 mg/day; IPCS, 2001b).
Beryllium (Be)	Workplace exposure to Be is associated with Be sensitisation leading to chronic Be disease (CBD) and increased lung cancer risks. The ICPS report cancer risk estimates ranging from $1.6x10^{-4}$ to 7.2×10^{-3} per μgm^{-3} Be for lifetime exposure in ambient air. This is approximately equivalent to risks of $1.6x10^{-2}$ to 7.2×10^{-1} per mgm^{-3} Be in workplace air (assuming exposure at work for 40 years of an 80 year lifetime for 1600 hours/year). CBD is an inflammatory lung disease developed as an immune response to Be, characterised by a characteristic form of lung fibrosis. It has been reported at concentrations in workplace air ≥0.002 mgm^{-3}. Workplace exposure to Be is also associated with irritation of the skin and eyes (IPCS, 2001c; EPAQS, 2008).
Cadmium (Cd)	Long term exposure to Cd in the workplace is associated with adverse effects on the kidney and lungs, including a possible lung cancer risk. The threshold for respiratory effects is believed to be equivalent to workplace exposure to 0.0125 mgm^{-3} for 40 years. An increased prevalence of proteinura (a marker of kidney damage) has been reported after 10-20 years exposure to 0.02-0.05 mgm^{-3}. There is evidence of an increased risk of osteoporosis associated with similar levels of exposure(IPCS, 1992; SCOEL, 2010). .

Metal	Effects
Chromium (Cr)	*Inorganic Cr (III) compounds* – rats exposed to concentrations ≥3 mgm^{-3} showed inflammatory changes in the lung; Finnish workers exposed to average concentrations of chromite ore (≤50% Cr_2O_3) of 1 mgm^{-3} showed some increase in respiratory symptoms and reduction in lung function. Chronic bronchitis was observed in Sudanese workers at much higher levels of exposure. No adverse respiratory effects reported in ferrochrome workers exposed to Cr (IIII) concentrations of 0.24-0.48 mgm^{-3}. *Cr(VI)* is a lung carcinogen in humans, it is also a respiratory and skin irritant. Workplace exposure to concentrations >0.002 mgm^{-3} are associated with perforation of the nasal septum. It is a respiratory and skin sensitiser and is also associated with damage to the liver, kidney and gastrointestinal tract. (IPCS, 1988, 2009; SCOEL, 1986, 2002; IARC, 1990).
Cobalt (Co)	Co is a skin and respiratory sensitiser and workplace exposure is associated with interstitial lung disease termed hard metal lung disease. Exposure to a mixture of hard metals including Co may be associated with an increased lung cancer risk. Adverse effects on lung function and an increased prevalence of mucous membrane irritation and cough was reported in workers exposed to average concentrations of 0.0151 mgm^{-3}. There was a nonsignificant increase in respiratory symptoms in workers exposed to average concentrations of 0.053 mgm^{-3} and no impact on lung function (IPCS, 2006). .
Copper (Cu)	High levels of workplace exposure have been reported to cause metal fume fever. Respiratory symptoms have been reported in workers exposed to a number of metals including Cu. Workers exposed to concentrations that gave an estimated intake of 200 mg Cu/day developed signs of copper toxicity (e.g. elevated serum copper levels, enlarged liver). Cu may be associated with allergic dermatitis in a small proportion of individuals (IPCS, 1998).
Iron (Fe)	Fe oxide - Benign pneumoconiosis with X-ray shadows indistinguishable from fibrotic pneumoconiosis (siderosis) Fe salts - irritation eyes, skin, mucous membrane; abdominal pain, diarrhoea, vomiting; possible liver damage (NIOSH Pocket guide to chemical hazards).
Indium (In)	Irritation eyes, skin, respiratory system; possible liver, kidney, heart, blood effects; pulmonary oedema (NIOSH Pocket guide to chemical hazards).
Lead (Pb)	The symptoms of lead poisoning include weakness, irritability, asthenia, nausea, abdominal pain with constipation and anaemia. Minor effects have been reported in adults at blood lead levels >20 $ugdL^{-1}$ with more obvious symptoms at blood lead levels >40 $ugdL^{-1}$. Lead is a neurotoxin and impacts on peripheral nerve function and neurological function have been found in adults at exposure levels well below those associated with overt toxicity (20 ug/dL). Long term low level exposure to lead is associated with kidney damage and proteinura. Higher levels of exposure lead to severe kidney damage and potentially kidney failure. Lead is a confirmed animal carcinogen but there are insufficient data to demonstrate carcinogenicity in humans (IARC 2006; SCOEL, (2002; WHO, 2000).
Manganese (Mn)	High levels of workplace exposure are associated with irritation and inflammation of the lungs leading to cough, bronchitis, pneumonitis and reduced lung function. Long term exposure at much lower concentrations adversely affects neurobehavioural function leading to symptoms similar to Parkinson's Disease including tremor and impaired cognitive abilities. Mn also adversely affects libido and fertility in male workers. Neurobehavioural effects have been reported in workers exposed to mean concentrations of 0.032 mgm^{-3} as respirable Mn (0.151 mgm^{-3} as total inhalable Mn) (IPCS, 1999).

Metal	Effects
Mercury (Hg)	Inhalation exposure of Hg vapour or exposure to inorganic Hg salts is associated with tremors, emotional instability, insomnia, memory loss, neuromuscular changes, headaches, polyneuropathy, and performance deficits in tests of cognitive and motor function. Some effects may be reversible on cessation of exposure. Neurotoxicity has been reported in workers exposure to elemental Hg at a concentration of 0.02 mgm^{-3}. Inorganic Hg is also toxic to the kidneys. Proteinura, a marker of impaired kidney function, has been observed in workers with urinary Hg levels consistent with exposure to concentrations of Hg in workplace air of about 0.02 mgm^{-3} (IPCS, 2003; SCOEL, 2007).
Molybdenum (Mo)	High levels of dietary exposure to Mo are associated with a gout-like condition characterized by pain, swelling, inflammation and deformities of the joints, and an increase in the uric acid content of the blood. Effects on the gastrointestinal tract, liver, and kidneys have also been reported. A Mo intake of 0.14 mg/kg/day is associated with elevated serum uric acid levels (US EPA, 1993.
Nickel (Ni)	Ni is a respiratory carcinogen. Other effects reported in Ni-exposed workers include rhinitis, sinusitis, nasal septum perforation, lung fibrosis, allergic contact dermatitis. Ni and its soluble salts are potent skin sensitisers. In animal experiments, the concentration of soluble Ni salts associated with adverse respiratory effects is 0.06 mgm^{-3} although no adverse effects were observed following repeated exposure to 0.11 mgm^{-3} of an insoluble Ni salt (IPCS, 1991a; EPAQS, 2008).
Palladium (Pd)	Pd is a potent skin sensitiser. There is little information about the effects of occupational exposure. There is limited evidence that it may be a respiratory sensitiser. Skin and eye irritation has been reported in animals and limited experimental data indicate that medium to long term exposure to Pd compounds is associated with damage to the liver and kidney leading to changes in blood and urine parameters (IPCS, 2002).
Platinum (Pt)	Pt compounds are potent skin and respiratory sensitisers associated with contact dermatitis, rashes, sneezing, shortness of breath and severe asthma. Adverse effects have been reported at exposure levels <0.1 mgm^{-3} (IPCS, 1991b).
Rhodium (Rh)	Rh metal - possible respirable sensitization Soluble Rh salts - In animals: irritation eyes; central nervous system damage (NIOSH Pocket guide to chemical hazards).
Selenium (Se)	Systemic effects of Se dioxide exposure include garlicky-smelling breath, metallic taste on the tongue, and effects such as fatigue and irritability. Populations exposed to high levels of dietary Se show hair loss and nail changes. Clinical signs include garlicky-smelling breath and urine, thickened and brittle nails, hair and nail loss, lowered haemoglobin levels, mottled teeth, skin lesions and CNS abnormalities (peripheral loss of sensation, pins and needles and pain in the extremities). Alterations in the measured biochemical parameters occurred at dietary intake levels of 750-850 ug/day. Long term exposure to Se in workplace air is associated with irritation of the nose, respiratory tract, and lungs, bronchial spasms, and coughing following exposure to Se dioxide or elemental Se as dust. Liver toxicity has been reported in animal experiments (IPCS, 1986; ATSDR, 2003).
Silver (Ag)	Workplace exposure to silver and silver compounds is associated with agria - grey-blue discolouration of the eyes, skin, nails, mucous membranes and internal organs. Symptoms have been observed in workers exposed to Ag compounds concentrations of 0.005-0.38 mgm^{-3} although no effects were reported in workers reported to metallic Ag at concentrations of 0.003-0.54 mgm^{-3}, higher levels of exposure may give rise to irritation and ulceration of the skin and gastrointestinal disturbance (SCOEL, 1993; NIOSH Pocket guide to chemical hazards).
Tantalum (Ta)	Ta and oxide dust - irritation eyes, skin; in animals: pulmonary irritation (IPCS – International Chemical Safety Card).

Metal	Effects
Tellurium (Te)	Garlic breath, sweating; dry mouth, metallic taste; drowsiness; anorexia, nausea, no sweating; dermatitis; in animals: central nervous system, red blood cell changes (NIOSH Pocket guide to chemical hazards).
Tin (Sn)	There is little information about the adverse effects of workplace exposure to Sn. Long term exposure to Sn(VI) oxide dust was reported to give rise to lung changes that were detectable in chest X-rays but were not associated with fibrosis or effects on respiratory health. There is limited evidence of adverse effects on the kidney. There have been rare cases of allergic contact dermatitis in humans exposed to Sn and a number of Sn (II) compounds have been identified as skin irritants. Studies in animals have shown that ingestion of Sn (II) compounds is associated with effects on body's handling of copper, iron and zinc that may adversely impact on health (IPCS, 2005; SCOEL,2003).
Tungsten (W)	Irritation of eyes, skin, respiratory system; diffuse pulmonary fibrosis; loss of appetite, nausea, cough; blood changes Exposure to dusts containing W in the hard metals industry is associated with pulmonary fibrosis, memory and sensory deficits, and increased mortality due to lung cancer but these effects have been primary attributed to co-exposure to Co. There are limited animal data that suggest W may be a reproductive and developmental toxin (NIOSH Pocket guide to chemical hazards; ATSDR, 2005).
Vanadium (V)	Repeated inhalation exposure to V pentoxide dust or fume in workplace air is associated with irritation of the eyes, nose and throat, wheeze and dyspnoea. Other symptoms include the development of "green tongue". Adverse effects on the lung were reported in human volunteers after a single 8 hour exposure to 0.1 mgm^{-3}. Workplace studies have reported lung function changes in boilermakers exposed to concentrations of V ranging from 0.0016 to 0.032 mgm^{-3} but effects may have been caused to co-exposure to other agents. Green tongue was reported in one worker exposed to 0.1 mgm^{-3} for 30 minutes/day (equivalent to an 8 hour time weighted average of 0.0125 mgm^{-3}. Both tri- and pentavalent V are genotoxic in experimental systems. No carcinogenicity data are available (IPCS, 2001; SCOEL, 2004).
Zinc (Zn)	Workplace exposure to fine metallic particulate matter including Zn oxide fume is associated with metal fume fever, a reversible 'flu like syndrome that can be fatal in severe cases. In a volunteer experiment exposure to concentrations of zinc of 0.077 to 0.15 mgm^{-3} for 15-30 minutes gave rise to evidence of lung inflammation. Zn is an essential element. Over-exposure to Zn adversely effects copper metabolism and can cause effects such as anaemia or lowered white blood cell count (IPCS, 2001).

The UK has set workplace exposure limits (WELs) for most of the metals that workers in the waste industry may be exposed to (Table 6.2).

Table 6.2: UK WELs for metals (8 hour TWA)

Metal	**UK WEL mgm^{-3}**
Aluminium	4 – respirable dust 10 – inhalable dust 0.2 – soluble salts
Antimony	0.5
Arsenic	0.1
Barium	0.5 – soluble compounds 4 – respirable barium sulphate 10 – inhalable respirable Ba sulphate
Beryllium	0.002
Cadmium	0.025 – except oxide, sulphide 0.025 – Cd oxide (0.05*) 0.03 – Cd sulphide
Chromium	0.5 - Cr(0), Cr (III) as Cr 0.05 – Cr(VI) as Cr
Cobalt	0.1
Copper	0.2 – fume 1 – dusts and mists as Cu (2*)
Iron	5 – Fe oxide fume (10*) 1 – Fe salts as Fe (2*)
Indium	0.1 – In and compounds as In (0.3)
Lead	0.15
Manganese	0.5 – Mn and inorganic compounds as Mn
Mercury	0.02 – Hg and divalent inorganic compounds as Hg
Molybdenum	5 – soluble compounds as Mo (10*) 10 – insoluble compounds as Mo (20*)
Nickel	0.1 – water soluble compounds as Ni 0.5 – Ni and water insoluble compounds as Ni
Palladium	
Platinum	0.002 - Soluble compounds as Pt 5 – Pt metals
Rhodium	0.1 – metal fume and dust (0.3*) 0.001 – soluble salts as Rh (0.003*)
Selenium	0.1 – Se and compounds as Se
Silver	0.01 – soluble compounds as Ag 0.1 – metallic Ag
Tantalum	5 (10*)
Tellurium	0.1 – Te and compounds as Te
Tin	0.1 – inorganic compounds as Sn (0.2)
Tungsten	1 – soluble compounds (3*) 5 – insoluble compounds (10*)
Vanadium	0.05 – V pentoxide
Zinc	1 – Zn chloride fume (2*)

*15 minute short term exposure limit (STEL)

There is very little health information for metals recycling workers. OSHA (2008) indicates that private, nonferrous recycling industries reported approximately 3,000 injuries and illnesses in a workforce of 16,000 employees in the US in 2001. The most common causes of illness were poisoning (e.g., lead or cadmium poisoning), disorders associated with repeated trauma, skin diseases or disorders, and respiratory conditions due to inhalation of, or other contact with, toxic agents. The OSHA report lists a number of case studies where individuals become seriously ill and sometimes died as a result to acute over-exposure to metals including deaths resulting to exposure from cadmium fume arising from welding activities, smelting lead, serious illness following clearing a mercury spill. Two Italian studies describe the effects of over-exposure to metals during the processing of recyclate, although in both cases the activity would probably be classified as metals production rather than as a waste industry function.

Fonte et al (2007) reported the occurrence of symptoms of overt lead poisoning in a battery recycling worker who displayed chronic anaemia, recurrent abdominal colic, discoloration of gums, sensitive polyneuropathy to the four limbs and evidence of effects on electrolyte balance and liver function. Cristaudo et al (2005) reported platinium sensitisation in 22 of 153 subjects working in a catalyst manufacturing and recycling factory. There is a paucity of published information about the extent of illness in UK waste workers that can be attributed to metals exposure.

6.3 EXPOSURE

Overview

Within the waste industry, exposure to metals is likely during the recovery and segregation of metallic materials prior to reprocessing, for example in scrap yards, during segregation of mixed wastes, during the processing of WEEE and during activities involving incineration residues. Trace levels of metals are also present in dusts generated by other activities such as composting, landfill operations, waste shredding etc but the quantities of metals present in such dusts are small and these operations are not considered further within this chapter. There is a paucity of published exposure data for all the activities considered in this chapter.

Scrap yards

Some activities at scrap yards may create airborne dusts with a high metals content but generally processes such as crushing and baling are undertaken outdoors using remotely operated equipment and are unlikely to lead to a substantial level of dust exposure. Workers could be exposed to higher levels of airborne metals and metal fumes where materials are cut by hand held tools but there are no published exposure data. It is assumed that appropriate protective equipment would be used during cutting operations to prevent burns and damage to the eyes. It is not certain whether effective RPE would also be employed. In addition to the potential for inhalation exposure, exposure may also occur as a result of dermal contact with dust and more importantly through accidental ingestion. Scrap yards are not “clean” environments and it is likely that high levels of settled dust would be present in the working environment. Dust may be transferred from hands onto cigarettes, food, mugs etc and from work wear into areas where food is eaten or home giving rise to the potential for food contamination and significant intakes of ingested metallic dust. There is a paucity of information about rates of dust ingestion in the workplace, but typical adults are believed to ingest about 50 mg of soil and house dust per day (Environment Agency, 2009). Given that most household environments would be considerably less dusty than a scrap yard or other waste handling facilities, it seems likely that an individual with poor personal hygiene could ingest a significantly greater quantity of dust originating in the workplace. Inadvertent ingestion of 100-200 mg dust/day originating from work could be a significantly more important source of exposure to metals for scrap metal workers than inhalation.

The scrap industry encompasses a wide range of metallic materials giving the potential for exposure to a diverse range of metals, many of which are present at relatively low concentrations in scrap but may still give rise to exposures that are potentially damaging to health. Scrap metals can be divided into ferrous and nonferrous metals. Ferrous scrap includes scrap from primary processing which may not enter the general waste stream, end of life vehicles, boats and rail rolling stock, construction beams, plates, pipes, tubes, wiring, and shot and railtrack. Aluminium is the most widely recycled nonferrous metal. The major sources of nonferrous scrap include copper cables, copper household products, copper and zinc pipes and radiators, zinc from die-cast alloys in cars, aluminium from used drinks cans, aluminium building products, platinum from automobile catalytic converters, gold from electronic applications, silver from used photographic film, nickel from stainless steel and lead from battery plates (OSHA, 2008). Some of these wastes are more likely to be handled at MRFs (e.g. aluminium cans) or specialist recovery plants (silver recovery) than at scrap yards.

There is a small quantity of published information describing the exposure of scrap metal workers to lead but no information was identified about exposures to other metals.

The HSE publish information about blood lead levels in scrap metal workers in the UK (Table 6.3). During 2009-10, blood lead levels were measured in 515 men and 22 women in the scrap industry. The data suggest that exposure to lead in the scrap metal industry is less well controlled than exposure to lead in other industries. Of the men, 70 individuals (14%) reported blood lead levels in excess of 50 $ugdL^{-1}$ (the action level in men) compared with only 2.4% of individuals across all industries. The number of males under surveillance with the highest blood-lead levels increased between 2008-9 and 2009-10 in the scrap industry (from 18 [6.0%] to 70 [13.6%]), but the 2010-11 figures show a marked reduction relative to earlier levels (20 [3.5%]).

Table 6.3: Blood lead levels in the scrap industry measured during routine monitoring 2009-10 – numbers of individuals by blood lead level.
http://www.hse.gov.uk/statistics/causdis/lead/index.htm

Blood Pb $ugdL^{-1}$	<10	10-19	20-24	25-29	30-34	35-39	40-49	50-59	60-69	70-79	>80	All
Scrap industry	259	79	24	21	14	17	31	34	25	4	7	515
All industries	2562	1676	767	602	465	320	360	112	37	7	8	6916

The source of lead exposure at scrap yards is uncertain but presumably includes the presence of lead in solder in the articles handled at scrap yards and also the presence of lead in metal alloys and in leaded paints. It is also not certain what proportion of lead-exposed workers in scrap yards are participating in biological monitoring programmes and included in the 515 workers for which data were available to the HSE. Given that some workers appear to experience relatively high levels of exposure to lead, it is likely that some workers also experience significant exposures to other metals such as aluminium, chromium, cobalt, copper, molybdenum, manganese, nickel, tungsten or vanadium that are present in steel or widely used alloys. Generally the concentrations of these metals in steel (eg <2% for manganese) are such that if the 10 mgm^{-3} inhalable dust limit is met, the WELs for individual metals would also be met. The handling of alloy materials with significantly higher concentrations of some of these metals could potentially lead to exposure levels that exceed the WELs for individual metals.

A study of scrap metal workers undertaken by the New York State Department (2007) investigated worker exposure to lead at 101 metal recyclers throughout New York State. The companies were engaged in a variety of activities: torch cutting (59), shearing (48), stripping and cutting communication cables (28), melting metal (6) and dismantling batteries (5). Personal exposure concentrations for lead were measured for 6 torch cutters at 5 facilities cutting materials that included painted machine parts, unpainted highway guard rails, unpainted new plate steel, aluminium and copper. The time-weighted average of lead concentrations during the sample time ranged from below the limit of detection to 0.32 mgm^{-3}. The majority (85%) of the metal recycling companies did not undertake biological monitoring for lead. Where blood lead testing was undertaken it was because OSHA required it or, workers or their family members had developed overt signs of lead toxicity. The mean blood lead level for 2 torch cutters at one facility was 64 $ugdL^{-1}$ with measured values ranging from 27-161 $ugdL^{-1}$. Wipe samples demonstrated that there was extensive lead contamination of surfaces in welfare facilities and on workers hands (tested prior to eating) and few of the operations provided facilities to enable workers to change out of work clothes and shower before going home. Of the 101 companies that responded to the survey, 45% did not provide their workers with any respiratory protection and 28% provided only disposable dust masks. Of the 60 companies that performed torch cutting, 40% provided their workers with half-face or full-face air purifying respirators. Most (93%) of the 101 survey respondents provided their employees with gloves and goggles (83%) but only half the companies provided uniforms. The study concluded that metal recycling companies did not recognize potential sources of lead exposure (such as new steel) and underestimated the degree of exposure. It is not known how representative this US study would be of conditions in the UK.

Materials recovery facilities and MBT

Processes at MRFs and during MBT may include the crushing and shredding of mixed waste prior to segregation, the separation of ferrous and nonferrous materials from organic materials destined for processes such as composting and the sorting or grading of the crushed/shredded product prior to onward transport for specialist processing. At MRFs, metallic materials may be handpicked from mixed wastes giving rise to a much lower potential for exposure.

The necessity to pre-treat wastes before they are consigned to landfill is relatively new. The treatment process is likely to be dusty, particularly if the treated waste stream is composed of "dry mixed waste" rather than MSW, which would be anticipated to have a higher moisture content. The various forms of mechanical treatment that are available have been designed to optimise the processing of waste and segregation of usable materials such as metallic waste that is suitable for further processing. Equipment design has not necessarily been optimised to minimise workplace exposure and levels of containment are likely to be variable. In principle processes could be highly automated, enclosed and fitted with appropriate extraction to prevent the escape of dust to workplace air. Illustrations of various systems designed for the mechanical treatment of waste suggest that levels of containment are variable.

The dust generated during any initial crushing and shredding operations of mixed wastes is unlikely to have a particularly elevated metals content whereas dust generated from the segregated metallic fractions will be largely composed of metals. Exposure to metallic dust could occur during operation of the segregation process and the handling of the segregated wastes. It is presumed that the dominant components of dust generated during these operations would reflect the general usage of metals in consumer goods and include iron and aluminium as major components and a wide range of minor components including other metals used in steel such as manganese and nickel, and lead and copper which are widely used in electronic goods. There are no published exposure data. In principle, equipment used in the handling of metal recyclate could be remotely operated, fully enclosed and fitted with appropriate extraction and filtration. If, however, workers spent a significant proportion of their working day in close proximity to poorly enclosed equipment handling shredded/crushed metallic wastes, they could experience relatively high levels of exposure to airborne dust containing elevated levels of a range of metals. It is likely, however, that metals recyclate would typically have a relatively low dust content and the dust that is present is likely to be relatively coarse. The outcome of exposure modelling using ART suggests that typical levels of exposure to inhalable dust are likely to be less than 1 mgm^{-3} and that it is relatively unlikely that inhalation exposure to metals would exceed UK WELs during routine operations. Exposures are likely to be highest where there are operational difficulties such that frequent manual intervention is required to clear jams such that any containment that is present is frequently breached. Exposure to metallic dusts is also likely during cleaning and maintenance operations. Where workers are frequently clearing blockages through the working shift, this could give rise to potentially significant exposures to iron, copper, aluminium, lead, nickel, manganese and possibly other metals in relation to the UK WELs, although the outcome of the exposure modelling suggests that the WELs are likely to be normally met (Table 6.4).

Table 6.4: Potential inhalation exposure (predicted 75th percentile concentration) to metals that could arise in associated with the handling of metal rich recyclate assumed to be dry with a 5% coarse dust component

		Dust	Steel				Aluminium
			<1% Mn	<1% Cr	<1% Ni	<1% Pb	90% Al
WEL		10	0.5	0.5	0.5	0.15	10
Transfer of segregated recyclate by conveyor 1000 m^2 room no special ventilation characteristics	No containment	0.29	<0.003	<0.003	<0.003	<0.003	0.26
	Segregated from workplace but no extraction	0.086	<0.001	<0.001	<0.001	<0.001	0.08
	Segregation with ventilation	0.029	<0.001	<0.001	<0.001	<0.001	0.03
Transfer to hopper, partially contained process 1000 m^2 room no special ventilation characteristics	No segregation	0.087	<0.001	<0.001	<0.001	<0.001	0.08
	Segregated from workplace but no extraction	0.026	<0.001	<0.001	<0.001	<0.001	0.02
	Segregation with ventilation	0.0086	<0.001	<0.001	<0.001	<0.001	0.01
Clearing blockage using compressed air: no special ventilation characteristics	1000 m^2 room	1.7	<0.017	<0.017	<0.017	<0.017	1.53
	30 m^2 space	8.2	<0.082	<0.082	<0.082	<0.082	7.38
Sweeping/shovelling spilt product	1000 m^2 room no special ventilation characteristics	1.5	<0.015	<0.015	<0.015	<0.015	1.35

As discussed above in relation to scrap yards, significant additional exposure to metals might arise at MRFs and MBT facilities as a result of inadvertent ingestion of settled dust. Accidental ingestion of 100 mg dust/day containing manganese, chromium, nickel and/or lead would give rise to ingested intakes of these metals that are significant in but less than those associated with 8 hours exposure to the relevant WEL (assuming than 10 m^3 of air is inhaled over a typical working shift). Where a worker is spending a significant proportion of the shift undertaking dusty tasks such as clearing blockages, it is conceivable that their combined exposure to some metals through inhalation and ingestion would be substantially greater that the intake associated with the WEL.

WEEE

WEEE contains a wide range of hazardous metals (and other substances). The quantities present vary by the type of e-waste and some example information on WEEE composition is shown below in Tables 6.5 to 6.8. It seems probable that the metals content of WEEE will change through time as different materials are used in new products.

Table 6.5: percentage of metals (total) in different categories of WEEE (Defra & CIWMEB, 2007)

Category	Description	% metals
1	Fridges	69.5
1	Small white goods	76.7
2	Small household appliances	38.2
3	IT and telecommunications equipment	59.9
4	Consumer equipment	53.5
5	Lighting	80.2
6	Electric and electronic goods	55.3
7	Toys, leisure and sports	28.3
9	Monitoring and control	60.0

Table 6.6: Metals content (percent) of different types of WEEE (e-waste guide: http://ewasteguide.info/node/4074)

	large household	Small household	ICT and consumer
Aluminium	43	29	36
Ferrous metal	14	9.3	5
Copper	12	17	4
Lead	1.6	0.57	0.29
Cadmium	0.0014	0.0068	0.018
Mercury	0.000038	0.000018	0.00007
Gold	0.00000067	0.00000061	0.00024
Silver	0.0000077	0.000007	0.0012
Palladium	0.0000003	0.00000024	0.00006
Indium	0	0	0.0005
Lead glass	0	0	19

Table 6.7: Metals content (mg/kg) of different categories of WEEE (as disposed of) based on tonnages reported by the EU (2006)

	Cat 1A	Cat 1B	Cat 1C	2, 5a, 8	3a	3b	3c	4a	4b	4c	5b	6	7
Ag	0	0	0	0	172	50	0	18	20	132	204	41	34
Au	0	0	1	0	28	7	0	2	1	8	78	10	0
Be	0	0	0	0	2	0	0	0	0	0	0	0	0
Cd	0	0	22	90	75	46	2330	59	0	0	0	0	0
Co	0	0	23	116	97	58	351	74	17	10	0	0	0
Cr	0	0	28	1	226	18	2	0	359	185	32	56	34
Cu	53769	35679	116314	311557	57005	176460	292310	6554	68727	48107	121780	74062	328688
Hg	0	0	0	0	0	0	0	0	0	0	2	7	758
Mn	0	0	1	6	5	3	20	4	0	0	0	0	0
Ni	1	0	77	296	1129	371	3671	313	847	569	731	288	170
Pb	23	0	61	45	380	914	57	20	1454	1223	919	1088	10954
Pd	0	0	0	0	11	1	0	0	0	4	16	3	0
Sb	1	0	4	3	68	100	2	0	287	286	63	64	85
Sn	790	0	34	592	1420	688	560	192	77	644	208	1645	13101

Table 6.8: Metals content (mg/kg) of other WEEE (AEAT, 2006; Umicore, 2008)

	Nine circuit boards - AEAT		Mobile phones – Umicore
	Min	Max	
Ag	-	-	3512
Au	-	-	341
As	11	34	-
Cd	4	173	-
Cr	57	154	-
Cu	74200	191000	130000
Fe	-	-	70000
Pb	2500	90800	6000
Hg	0.5	5	-
Ni	279	10200	14000
Pd	-	-	144
Pt	-	-	4
Sn	-	-	10000
Zn	2760	12900	11000

The treatment of WEEE may include some hand sorting and de-assembly that would not be expected to give rise to high inhalation exposures to metals. Some e-wastes such as mobile phones may be separated collected and transported directly to a smelter site for treatment. Following dismantling, if undertaken, WEEE waste streams are typically crushed and an automated process used to separate the constituent components – plastics, ferrous and non-ferrous metals based on differences in their physical and magnetic properties. Some materials such as the leaded glass used in Cathode Ray Tubes (CRTs) are removed prior to crushing and treated separately. Equipment is designed to optimise materials recovery and may incorporate safeguards to minimise the risk of immediate injury to workers, but may not be designed to minimise dust emissions and worker exposure to airborne dust.

In principle, the processing of WEEE prior to the recovery of metals and materials could be undertaken using highly automated and enclosed processes giving rise to little potential for worker exposure to metals. In practice the extent to which processes and materials are contained and the effectiveness of control measures may be very variable. The waste industry is a “dirty” industry and the standard of housekeeping at different sites is mixed. Dusty surfaces can give rise to exposure through disturbance of the dust leading to the material becoming airborne but significant exposure through dermal contact and inadvertent ingestion may also occur. These routes of exposure may be particularly important if washing facilities are inadequate and if workers are not required to change out of contaminated work clothing before taking a break or at the end of shift. The UK HSE is recently completed a targeted programme of inspection of WEEE recycling processes initiated because of an increasing awareness of poor control of hazardous substances at some WEEE sites. The intervention has focused on exposure to mercury and lead, as experience indicates that if these exposures are properly controlled then exposure to other hazardous substances is adequately controlled (SIM 03/2011/01, HSE, 2011). Based on earlier experience inspectors were asked to focus on enterprises employing less than 50 operatives and sites where more manual/labour intensive processes are undertaken and exposure control may be poor, rather than sites operating more sophisticated/mechanised processes. Although for the latter, excessive exposures may still occur during maintenance type activities (e.g. changing of filters on machines). Inspectors were also asked to examine a large number of safety related rather than exposure and health related hazards.

Published exposure measurements

There are few published measurements of exposures to metals during the processing of WEEE in the UK. The HSE have prosecuted one employer where gross over-exposure to lead and mercury had occurred during the recycling of WEEE (lead from CRTs and mercury from fluorescent lamps). The workers showed overt signs of mercury poisoning. In response to concern about potential levels of exposure to mercury, the HSE (2010) undertook a survey of exposures to mercury during the crushing and recycling of fluorescent lamps at seven plants. Only one of 32 measured full shift exposure concentrations of mercury exceeded the WEL and the urinary Health Guidance Value (HGV) for mercury was not exceeded at any of the sites indicating that adequate control of exposure to mercury from all routes. For short-term task specific activities, however, measured mercury vapour exposures at one site were 0.1874 and 0.2085 mgm^{-3} (associated with loading trays with phosphor powders) and inhalable dust exposure was up to 60.2 mgm^{-3}. Real time mercury vapour readings varied from 0 to > 2 mgm^{-3}. Significant direct readings (≥0.02 mgm^{-3}) were measured mainly in the storage areas, near sorted glass and near lamp crusher doors. Surface sampling indicated widespread contamination with mercury and associated metals at all sites (including low level contamination in the eating and drinking areas). Regular biological monitoring for urinary mercury was carried out at 6 of the 7 sites visited. At all sites except one, the RPE used including filters e.g. HgP3 were of the correct type and the employees had been face fit tested. However, there was evidence of poor RPE maintenance at most sites such as heavy contamination on the insides of masks and the use of inappropriate home-made alterations. All sites except one had LEV to control exposure to mercury dust and vapour. However, one of the LEV systems was remote from the source of the contaminant and the hood was inadequately designed to capture the airborne dust. Most of the sites visited had not had a suitable thorough examination and testing of the LEV systems. Personal exposures to other metals (including lead) were well below their appropriate WELs at all the plants and urinary cadmium levels were all below the reference range for an unexposed population group (i.e. <0.7 µmol/mol creatinine). Overall the survey findings demonstrate that although exposure to mercury appeared to be adequately controlled on the shifts on which measurements were made, there is significant potential for elevated exposures to occur. In addition poor housekeeping and poor personal hygiene (or inadequate provision of washing and welfare facilities) could lead to a significant potential for exposure through dermal contact and inadvertent ingestion.

Modelled inhalation exposure

Given that airborne dust is a relatively widely measured parameter in the waste industry, it seems probable that the 10 mgm^{-3} limit is met at most operations where WEEE is handled. An indication of the potential risks to health associated with the presence of metals in airborne dust during the crushing or shredding of e-waste and handling of the crushed/scheduled product can be derived by determining the likely concentrations of individual metals in air that would be associated with a total inhalable dust concentration of 10 mgm^{-3} based on average WEEE compositions(Tables 6.9-6.11). Due to poor hazard awareness and inadequate process design, it is possible that airborne dust levels greatly exceed 10 mgm^{-3} at a small number of plants. It is also likely that the separated fractions of crushed WEEE handled in some plants has a much higher hazardous metals content than assumed in Tables 6.9-6.11 which would give rise to greatly increased risks of exposure levels than exceed the WELs for individual metals. The output of modelling undertaken with ART indicates that if operations such as crushing glass, grading product and transferring the product to big bags or similar for transport are undertaken in the absence of any containment, the likely personal exposures to inhalable dust could exceed 20 mgm^{-3} if operations are undertaken in a relatively small room (300 m^2). Even in a much larger space (3000m2), the median and 75th percentile predicted dust concentrations are 7.3 mgm^{-3} and 15.5 mgm^{-3}. Actual shift mean concentrations may be lower, depending on the proportion of the shift that workers spend in the close vicinity to the process. Where processes are enclosed with ventilation and sited within a large space (3000 m^2), the predicted median and 75th percentile dust concentrations are 0.074 mgm^{-3} and 1.5 mgm^{-3}. Cleaning and maintenance operations are highly likely to be associated with much higher dust concentrations. For example, if workers spent 30 minutes conducting clearing blockages with a compressed airline, the median predicted 8 hour TWA ≤3 mgm^{-3} depending on material and activity, much higher exposures would arise in more confined spaces.

The estimated concentrations shown in Table 6.9-6.11 indicate that it is likely that the WELs for a number of different metals might be exceeded at dust concentrations equivalent to 10 mgm^{-3} total dust where it is assumed that the dust is comprised entirely of mixed metals. The metals for which over-exposure seems most likely are copper, lead, cadmium, nickel, chromium and mercury. If the waste sorting process separated aluminium and/or iron from the other metals, then an exposure to a total dust concentration of 10 mgm^{-3} excluding aluminium and/or iron would give rise to an increased likelihood of exposure to other metals at concentrations that exceed the WEL. It is likely that consideration of each individual metal in isolation would give an under-estimation of risk as many metals have similar toxic effects. Where substances have similar effects (eg kidney damage or neurotoxicity), HSE guidance (EH40) advises that the sum of the ratios of concentration to WEL for each individual metal (sometimes described as a hazard ratio) should be less than 1. If the sum of the ratios of concentration to WEL is calculated for the various WEEE streams considered in Tables 6.9-6.11, it is apparent that this sum exceeds 1 for a number of waste streams suggesting that the exposure to mixed metals in dust are likely to represent a health risk.

Table 6.9: Predicted concentrations of metals in air for different types of WEEE (e-waste guide) associated with a total concentration of metallic dust of 10 mgm^{-3}. Proportion of total metals in each waste stream assumed to be as shown in Table 6.6.

	WEL	**Large household**	**Small household**	**ICT and consumer**
Aluminium	10	6.187	7.592	6.050
Iron	5	2.014	2.435	0.840
Copper	1	1.727	4.450	0.672
Lead	0.15	0.230	0.149	0.049
Cadmium	0.025	0.000	0.002	0.003
Mercury	0.02	0.000	0.000	0.000
Gold	-	0.000	0.000	0.000
Silver	0.1	0.000	0.000	0.000
Palladium	-	0.000	0.000	0.000
Indium	0.1	0.000	0.000	0.000
HI*		3.66	6.01	1.29

*Hazard Index = sum of ratio of concentration/OEL for each metal

Table 6.10: Table: Predicted concentrations of metals in air (mgm^{-3}) for different types of WEEE associated with a total concentration of metallic dust of 10 mgm^{-3} based on metals content of nine circuit boards and mobile phones shown in Table 6.8.

	WEL	Nine circuit boards - AEAT		Mobile phones – Umicore
		Min	Max	
Ag	0.1	-	-	0.035
Au	-	-	-	0.003
As	0.1	0.0001	0.0003	-
Cd	0.025	0.00004	0.0017	-
Cr	0.05	0.0006	0.0015	-
Cu	1	0.742	1.91	1.300
Fe	5	-	-	0.700
Pb	0.15	0.025	0.908	0.060
Hg	0.02	<0.0001	<0.0001	-
Ni	0.1	0.0028	0.102	0.140
Pd	-	-	-	0.001
Pt	0.002	-	-	0.000
Sn	0.1	-	-	0.100
Zn	1	0.0276	0.129	0.110

Table 6.11: Predicted concentrations of metals in air for different types of WEEE associated with a total concentration of metallic dust of 10 mgm^{-3} based on EU (2006) composition data. Proportion of total metals in each waste stream assumed to be as shown in Table 6.7.

	WEL	Cat 1A	Cat 1B	Cat 1C	2, 5a, 8	3a	3b	3c	4a	4b	4c	5b	6	7
Ag	0.1	0.000	0.000	0.000	0.000	0.003	0.001	0.000	0.000	0.000	0.002	0.003	0.001	0.001
Au		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000
Be	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cd	0.025	0.000	0.000	0.000	0.002	0.001	0.001	0.039	0.001	0.000	0.000	0.000	0.000	0.000
Co	0.1	0.000	0.000	0.000	0.003	0.002	0.001	0.006	0.001	0.000	0.000	0.000	0.000	0.000
Cr	0.05	0.000	0.000	0.000	0.000	0.004	0.000	0.000	0.000	0.007	0.003	0.000	0.001	0.001
Cu	1	0.774	0.465	1.516	8.156	0.952	2.946	4.880	0.123	1.285	0.899	1.518	1.334	11.614
Hg	0.02	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.027
Mn	0.5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Ni	0.1	0.000	0.000	0.001	0.008	0.019	0.006	0.061	0.006	0.016	0.011	0.009	0.005	0.006
Pb	0.15	0.000	0.000	0.001	0.001	0.006	0.015	0.001	0.000	0.027	0.023	0.011	0.020	0.387
Pd	-	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sb	0.5	0.000	0.000	0.000	0.000	0.001	0.002	0.000	0.000	0.005	0.005	0.001	0.001	0.003
Sn	0.1	0.011	0.000	0.000	0.016	0.024	0.011	0.009	0.004	0.001	0.012	0.003	0.030	0.463
HI		24.14	0.47	1.56	8.52	1.61	3.28	7.21	0.28	1.79	1.38	1.75	1.85	20.27

The processing of cathode ray tubes (CRTs) is associated with a particularly risk of over-exposure to lead. The lead oxide content of the funnel glass can be as high as 60% equating to a lead content of 52.0%. Exposure to dust created during crushing funnel glass or subsequent handling could therefore have a lead content of up to 52% implying that the WEL for lead would be exceeded at dust concentrations of only 0.28 mgm^{-3}. The output of the exposure modelling described in chapter 4, indicates that even if processes involving dry granules derived from CRTs are enclosed, fitted with ventilation (not re-circulated to the workplace) and sited within a large space (floor area = 3000 m^2). The predicted 75th percentile dust concentration crushing and/or grading granules or moving the crushed product on a conveyer would be 1.5 mgm^{-3} or 0.6 mgm^{-3} respectively. These processes could be associated with an exceedance of the exposure limit by more than a factor of two, if workers spent a significant proportion of their working day, within close proximity to these processes. Considerably higher concentrations would arise if processes were not contained, there was no ventilation and the processes were undertaken in a smaller space or associated with cleaning and maintenance activities, particularly if a compressed airline is used to clear blockages. It seems likely that unless processes are highly automated, enclosed and workers are remote from dust sources (and/or use appropriate RPE), the recycling of CRTs could give rise to significant over-exposures to airborne lead. Exposures to lead are likely to be further enhanced by inadvertent ingestion (below).

Exposure by dermal contact and accidental ingestion

Exposure to metals by inadvertent ingestion could be significant where there are substantial quantities of settled dust in the work environment due to poor housekeeping, washing facilities are poor and individuals do not exercise good personal hygiene. Ingestion of 100 mg dust/day could give metal intakes equivalent to those associated with shift mean exposure to a dust concentration of 10 mgm^{-3} in air.

Incineration and other high temperature thermal processes

Overview

It is anticipated that during normal operation, incinerator ash and residues from other thermal treatments would be removed and transferred to containers for transport prior to final disposal by enclosed automated processes with no potential for significant exposure to airborne dust. Exposure to dust is likely during cleaning and maintenance and relatively high levels of exposure could arise as a result of repeated entry into areas where ash is present.

Reported exposures to metals in incinerators

Maitre et al (2003) measured exposures to metals in two French incinerators (Table 6.12). Measured exposure levels were well below the French OELs, even for the most highly exposed workers. The highest arsenic, cadmium, and lead levels were found in the residue transfer and disposal area, whereas most of the manganese was found near the refuse bunker. In contrast, chromium levels were of the same order in the various workstations, except in the flue gas cleaning area where the reading was lower. The highest exposures to airborne metals were associated with the transfer and loading of solid residues into trucks.

Table 6.12: Maitre et al (2003) Metals concentrations in the air at two incinerators and the control site (µgm^{-3}) (includes both personal and static samples)

	Incinerator 1	Incinerator 2	Control site
Number of samples	16	20	6
Arsenic	-	0.14 (0.06-0.43)	ND
Cadmium	0.22 (0.03-0.98)	0.34 (0.02-3.56)	0.001 (0.0004-0.003)
Chromium	0.74 (0.09-1.81)	0.64 (0.10-2.64)	0.015 (ND-0.044)
Lead	7.98 (0.29-28.0)	2.29 (0.09-25.47)	0.078 (0.027-0.134)
Manganese	-	2.67 (0.26-13.02)	0.033 (0.006-0.065)
Nickel	0.17 (0.01-1.60)	0.05 (0.01-0.49)	0.09 (ND-0.39)

Mari et al (2009) measured blood concentrations of manganese and mercury, and urinary levels of nickel in workers at a hazardous waste incinerator in Catalonia, Spain, 8 years after regular operations started at the facility. The levels found were no higher than those in the general population and there was no evidence of elevated exposure to metals resulting from employment at the incinerator. Similarly, Wultsch et al (2011) found no difference in the urinary concentrations of selected metals (chromium, manganese, nickel and arsenic) in Austrian incinerator workers compared with unexposed controls. Hours et al (2003), however, reported that blood lead levels in French incinerator workers were slightly higher than in unexposed controls.

Wribitzky et al (1995) reported that blood levels of lead and cadmium and urinary arsenic concentrations were slightly higher in some of 122 persons employed in a German industrial waste incineration plant than background levels in the German population. There were no exceedances of the biological exposure limits for these substances. It is probable that exposure levels in a modern plant would be lower than those prevalent 20 years ago.

Modelled exposures

Worker exposure to metals at incinerators can be estimated on the basis of published data describing ash composition. The air pollution residues from other thermal treatments may be similar to those associated with incineration whereas bottom residues are more typically slags with a lower potential to give rise to airborne dust. Defra (2004) present some information about ash composition (Table 6.13). It is anticipated that ash handling processes at modern incinerators will be highly automated and enclosed such that exposure to dust and metals during routine operation would be negligible. Exposure could occur during cleaning and maintenance operations and exposure levels will be dependent on the frequency of these operations, the methods employed, the size of the space in which they are undertaken and the control measures in place. Ash handling processes may be less enclosed at older plants and may be associated with higher levels of exposure to dust and metals than in a modern plant. Table 6.14 shows predicted metal concentrations associated with the inhalable dust limit of 10 mgm^{-3}. These predicted exposure levels are considerably higher than the exposure levels reported for workers at two French incinerator plants (Maitre et al, 2003). Based on the exposure modelling described in chapter 4, it is anticipated that typical levels of dust exposure are well below 10 mgm^{-3}. Provided that the 10 mgm^{-3} inhalable dust limit is met, exposures to most metals should be controlled to a small fraction of the relevant WEL. The greatest likelihood of metals exposure exceeding the WEL is for cadmium, lead and tin in flyash, with the greatest likelihood of over-exposure being for lead. If exposures are not controlled to 10 mgm^{-3}, for example, as a result of frequent breakdowns in the ash feed requiring operators to enter and clean equipment, then shift mean exposures could be ten or more times greater than shown in Table 6.14. This is particularly likely if compressed air is used to clear blockages within a relatively confined space (see chapter 4). Under these conditions, there is a significant likelihood of excessive exposure to chrome VI, lead and tin associated with bottom ash and cadmium, cobalt, chrome VI, mercury, lead, antimony and tin associated with flyash. Exposures associated with cleaning and maintenance operations may be controlled through the use of RPE, but this will only be effective if correctly specified, fitted and maintained and there is good compliance with its use. Exposure by skin contact and, more importantly, inadvertent ingestion may occur if workers have poor personal hygiene and/or wear contaminated work wear in areas where food is consumed at work or wear/take contaminated work wear home.

Table 6.13: Estimated metals content (mg/kg) of incinerator ash based on data summaries presented by Defra (2004)

	Bottom ash		**Flyash**	
	Best estimate	Upper bound estimate	Best estimate	Upper bound estimate
Aluminium	0.030	0.136	-	-
Arsenic	<0.001	<0.001	36.67	80.00
Barium	0.001	0.006	-	-
Cadmium	<0.001	<0.001	93.33	195.00
Cobalt	<0.001	<0.001	22.67	110.00
Chromium	<0.001	0.001	73.33	150.00
Copper	0.002	0.010	400.00	850.00
Iron	0.033	0.145	-	-
Mercury	0.000	0.000	8.33	17.50
Manganese	0.001	0.005	393.33	850.00
Nickel	<0.001	<0.001	20.33	55.00
Lead	0.003	0.012	2166.67	4650.00
Antimony	0.000	0.001	333.33	600.00
Tin	0.002	0.008	633.33	1750.00
Vanadium	<0.001	<0.001	10.33	25.00
Thallium	-	-	53.33	315.00
Zinc	0.005	0.021	-	-

Table 6.14: Predicted concentrations of metals in air associated with exposures to incineration ash equivalent to a total inhalable dust concentration of 10 mgm^{-3}

Metal	WEL	Bottom ash		Flyash	
		Best estimate	Upper bound estimate	Best estimate	Upper bound estimate
Aluminium	0.2 (soluble) 10 (dust)	0.300	0.833		
Arsenic	0.1	0.000	0.001	0.004	0.008
Barium	0.5 (soluble) 10 (insoluble)	0.013	0.036	-	-
Cadmium	0.025	0.000	0.001	0.009	0.020
Cobalt	0.1	0.000	0.001	0.002	0.011
Chromium	0.5 (Cr0, CrIII) 0.05 (CrVI)	0.003	0.008	0.007	0.015
Copper	1	0.022	0.061	0.040	0.085
Iron	5 – Fe oxide 1 – Fe salts	0.328	0.889	-	-
Mercury	0.02	0.000	0.000	0.001	0.002
Manganese	0.5	0.012	0.033	0.039	0.085
Nickel	0.1 – soluble 0.5 - insoluble	0.001	0.002	0.002	0.006
Lead	0.15	0.027	0.072	0.217	0.465
Antimony	0.5	0.002	0.004	0.033	0.060
Tin	0.1	0.018	0.047	0.063	0.175
Vanadium	0.05	0.001	0.002	0.001	0.003
Thallium				0.005	0.032
Zinc	1	0.047	0.128	-	-

Conclusions

The inhalation exposure to metals associated with the handling of incinerator ash would not be expected to give rise to significant levels of metal exposure provided that airborne dust concentrations were controlled well below 10 mgm^{-3}. Exposure by dermal contact and accidental ingestion can be controlled to low levels through use of appropriate gloves, protective clothing and good personal hygiene.

6.4 RISK ASSESSMENT

Scrap yards

Both UK and US data indicate that scrap yard workers may have relatively high exposures to lead. The UK data suggest that blood lead levels in about 20% of workers under surveillance are sufficient to give rise to symptoms of weakness, irritability, asthenia, nausea, abdominal pain with constipation and anaemia. Long term exposure to lead at these levels is associated with kidney damage and proteinura. About 30% of workers under surveillance have blood lead levels that reflect exposures that could damage peripheral nerve function and neurological function and an even greater proportion of workers are exposed to lead at levels that would damage an unborn child (if a woman was exposed). It is not known how many other scrap yard workers are similarly over-exposed to lead, but are not under medical surveillance. Inadvertent ingestion may make an important contribution to overall exposure levels and where there is settled dust in the workplace, poor washing facilities and poor personal hygiene practice, it is possible that exposures to ingested metals would exceed the inhalation intakes associated with the WEL, particularly in relation to lead. It seems plausible that over-exposure to other metals may also occur, but there are no data. Substances such as aluminium and copper are less toxic than lead such that a higher exposure (as mg/day) could be tolerated whereas other toxic metals such as nickel and manganese are likely to be present in much lower quantities than lead in metallic waste. Co-exposure to other metals could increase the risks of kidney toxicity (e.g. nickel, mercury, cadmium), neurobehavioural effects including impacts on mood and well being (e.g. mercury, manganese), lung cancer (nickel) and adverse effects on an unborn child. The interactions between individual metals may be additive, less than additive or more than additive depending on the exact mechanism of toxicity.

Processing of waste metals at MRFs and MBTs

Workers are likely to be exposed to mixed dust arising from all of the segregated waste streams. It is therefore assumed that exposures to metals as a proportion of airborne dust will be lower than those that might arise during the processing of scrap metal or shredding of WEEE and handling of shredded WEEE materials. It is anticipated that the dust content of the metallic wastes handled at these plants will be typically quite low and that inhalation exposures to airborne dust will generally be well below 1 mgm^{-3} as an 8 hour TWA, although higher inhalation exposures might arise if equipment needs frequent cleaning and unblocking using an airline. It is relatively unlikely that the WEL for any individual metal would be exceeded.

Inadvertent ingestion may make an important contribution to overall exposure levels and where there is settled dust in the workplace, poor washing facilities and poor personal hygiene practice, it is possible that exposures to ingested metals would exceed the inhalation intakes associated with the WEL, particularly in relation to lead. In addition workers are likely to be exposed to a mixture of metals that have similar individual effects. It is possible that metals exposure at materials recovery centres could contribute to increased risks of kidney disease, neurobehavioural effects or other adverse effects as described for scrap metal workers. In addition, the presence of elevated levels of metals in airborne dust might give rise to an increased risk of respiratory illness (see chapter 4).

WEEE

There is potential for significant exposure to metals to occur during the re-processing of WEEE, particularly at sites where both management and workers have a poor awareness of the hazards associated with the materials being handled. In addition to the potential for high levels of exposure to metals by inhalation, exposure may occur through dermal contact and, probably more significantly via the inadvertent ingestion of dust, particularly where standards of personal hygiene are low or there is poor provision of appropriate facilities for washing. Direct dermal contact is likely to be of greatest concern where metallic mercury is handled and significant dermal absorption could occur. Other metals are less readily absorbed through the skin.

The possible adverse effects of inhalation exposure to metallic dust include greatly increased risks of chronic respiratory illness in comparison to equivalent exposure to an inert dust. Other effects or exposure by any route include increased risks of kidney damage, heart disease, anaemia, gastrointestinal discomfort, lung cancer, neurotoxicity and possible adverse effects on an unborn child, particularly in relation to neurobehavioural development. The health effects of greatest concern will vary by waste type and process and the consequent potential for exposure.

The metals of greatest concern in terms of potential exposure levels and the associated risk of adverse effects are lead, mercury, cadmium, nickel and copper. Other metals may also be important for particular WEEE waste streams.

Although there are data that indicate that over-exposure to hazardous metals has occurred at some UK WEEE processing plants, there is no readily available information about typical exposure levels or the control measures that are typically in place during WEEE processing. It is not known whether over-exposure to hazardous metals during WEEE processing is widespread in the UK. In principle, it should be possible to design and operate highly automated WEEE treatment processes that are entirely enclosed with extraction. During the routine operation of such a plant, levels of metals exposure would be anticipated to be very low provided that all parts of the process were fully enclosed, the workplace was maintained in a clean condition and both incoming WEEE and the processed recyclate were appropriately stored. The HSE report on WEEE plants suggests that standards of housekeeping and process control at many plants may be insufficient to prevent significant exposure to toxic metals and associated adverse health effects. Long term employment in WEEE reprocessing at a plant where processes are not entirely contained, LEV is not optimally maintained, housekeeping and hygiene are poor and the RPE inadequately specified, fitted or maintained, is likely to be associated with greatly increased risks of adverse impacts on kidney and/or neurobehavorial function. This is a result of elevated exposures to mercury, cadmium and or lead. These effects could arise after periods, months or years in the absence of any short symptoms of illness.

Incineration and other high temperature thermal treatments

Levels of exposure to hazardous metals at incineration plants should remain well below relevant WELs and no adverse health effects arising from metal toxicity would be expected. If exposures to airborne dust generated from ash were greatly elevated above the 10 mgm^{-3} inhalable dust limit (as an 8 hour TWA) on a substantial proportion of shifts, there would be a significant likelihood of excessive exposure to chrome VI, lead and tin associated with bottom ash and cadmium, cobalt, chrome VI, mercury, lead, antimony and tin associated with flyash. This could lead to increased risks of adverse health effects associated with these metals including increased lung cancer risks, impacts on neurobehavioural function including impact on mood and mental well being, kidney dysfunction and adverse effects on an unborn child. Residues from other thermal treatments, other than air pollution residues, are anticipated to be less dusty than those arising from incineration and associated with lower levels of metals exposure.

6.5 CONCLUSIONS

Elevated exposures to metals are possible in several sectors of the waste industry with significant risks of over-exposure to metals in some scrap metal handling facilities and during the recycling of WEEE. Raised levels of exposure may also arise during the handling or recyclate at materials recovery operations including materials produced at MBT plants and in association with the handling of ash at incineration plants. Generally, levels of metal exposure at materials recovery operations or at incineration plants should be well below relevant WELs and well below the levels associated with toxicity. Increased levels of exposure could arise at materials recovery plants or at incinerators if frequent equipment failures mean that operators spend a significant proportion of their working shift entering equipment and clearing blockages.

Both inhalation and inadvertent ingestion may be important in determining total levels of metal exposure. Waste handling is perceived as a “dirty” industry and standards of housekeeping at different sites are very variable. Similarly, the provision of washing and changing facilities, the segregation of work wear and home wear and personal hygiene is very variable. Where high levels of settled dust are present in the workplace, there is an increased risk of inadvertent ingestion with intakes likely to be greatest where washing and changing arrangements are inadequate and individuals have a low standard of personal hygiene. Inadvertent ingestion may make a much greater contribution to metals exposure and the associated risk to health than inhalation.

Elevated levels of exposure to metals may be associated with various adverse health effects such as increased risks of dementia, kidney dysfunction, lung cancer and effects on cardiovascular health. These effects overlap with those associated with aging and/or smoking and the link with workplace exposure may go unrecognised. The workforce is highly fragmented with relatively small numbers of operatives at individual sites. This may reduce the likelihood of site managers or employers noticing unusually elevated incidences of individual common health conditions such as kidney dysfunction as one or two cases in a small workforce would not be exceptional.

Both UK and US data indicate that scrap yard workers may have relatively high exposures to lead and that blood lead levels may exceed levels associated with mild adverse effects including anaemia, effects on mood and stomach cramp. Long term exposure may give rise to increased risks of kidney disease and adverse effects on nerve function. Over-exposure to other metals may also occur at scrap yards, but are less likely.

There is potential for significant exposure to metals to occur during the re-processing of WEEE, particularly at sites where there is a low level of containment of dusty processes and products. The metals of greatest concern in terms of potential exposure levels and the associated risk of adverse effects are lead, mercury, cadmium, nickel and copper. Other metals may also be important for particular WEEE waste streams. Although there are data that indicate that over-exposure to hazardous metals has occurred at some UK WEEE processing plants, the extent of over-exposure to hazardous metals during WEEE processing in the UK is unknown. The HSE have reported that inadequate house-keeping and maintenance of exposure controls are common at WEEE processing facilities suggesting that low level over-exposure to hazardous metals may be relatively common among workers. Long term employment at these plants may be associated with significantly elevated risks of adverse effects on kidney and/or neurobehavioural function.

7 Landfill gas and other volatile substances

7.1 INTRODUCTION

The potential toxicity of landfill gas has been recognised for many years but waste workers are also exposed to volatile substances released from other wastes and as a result of the use of a wide range of chemicals in waste treatment processes. This chapter primarily focuses on landfill gas, the Volatile Organic Compounds (VOCs) and other trace gases such as hydrogen sulphide that are released during composting, anaerobic digestion and waste storage, Chlorofluorocarbons (CFCs) and Hydrochlorofluorocarbons (HCFCs) contained in obsolete refrigeration equipment and the recovery of fuel and oils from end of life vehicles. There is also potential for exposure to VOCs during the collection and recovery of solvents or the collection and incineration of other hazardous chemicals. For each of these scenarios, a brief description is provided of the substances present, their health effects, probable exposure levels and the potential risk to worker health.

7.2 LANDFILL GAS, ANAEROBIC DIGESTION

Introduction

The major components of landfill gas are methane and carbon dioxide. Landfill gas can contain a very wide range of trace gases and vapours at variable concentrations. The Environment Agency (2004) provide a summary of the typical trace gases found in landfill gas which include some known carcinogens and other toxic substances (Table 7.1). The main concern associated with landfill gas, however, is the explosion hazard. All landfill sites that accept biodegradable waste have to have a gas management plan in place to protect their workforce and the local community. Gas is typically collected and then burnt in an engine to generate power or, if insufficient gas is available for power generation, it will be flared. Landfill sites must also have leachate management plans in place in order to protect local surface and groundwater quality.

The gases produced during anaerobic digestion are very similar to those in landfill gas but biogas typically has a higher content of methane, hydrogen sulphide and ammonia and a lower content of aromatic hydrocarbons and other VOCs.

Health effects

A high proportion of the volatile organic compounds present in landfill gas are associated with neurotoxic effects that can lead to conditions including dementia and some are also associated with liver and kidney toxicity following long term exposure (Table 7.1). Studies of painters who were traditionally exposed to a mix of VOCs in air (prior to the introduction of low solvent paints) have demonstrated increased incidences of complaints of memory impairment, fatigue, impaired concentration, irritability, dizziness, headache, anxiety and apathy and dose-related impaired performance in neuropsychological tests (IPCS, 1996; dick 2006). At higher levels of exposure, dementia may develop. Some solvents including styrene are associated with sub-clinical changes in colour vision. Solvent exposure may also be associated with hearing loss, particularly if combined with exposure to noise (Dick, 2006). The VOCs that have been identified in landfill gas include known carcinogens such as vinyl chloride and benzene (HSL, 2011).

Exposure to hydrogen sulphide is associated with irritation of the respiratory system and neurotoxicity. There is also some evidence that exposure to H_2S may be associated with an increased rate of spontaneous abortion. Reported neurological effects include incoordination, poor memory, hallucinations, personality changes, and anosmia (loss of sense of smell); the respiratory effects include nasal symptoms, sore throat, cough, and dyspnoea. The lowest concentrations at which respiratory irritation have been reported are 1-5.6 mgm^{-3}, but it was unclear whether the effects were due to hydrogen sulphide or co-exposure to other agents (SCOEL, 2007).

Table 7.1: Typical concentrations of trace components in landfill gas (Environment Agency, 2004) and estimated concentrations at a dilution to 10% of the Lower Explosion Limit (LEL;0.5% methane) based on an assumed methane content of landfill gas of 63.8%; health effects from ICSCs (www.inchem.org)

	WEL mgm^{-3}		Concentration in landfill gas mgm^{-3}		Concentration at 10% LEL mgm^{-3}		Average concentration as %WEL	Health effects	
	8 hour	**15 min**	**Median**	**Average**	**Median**	**Average**		**Short term**	**Long term**
1,1-Dichloroethane	420		13.26	476.22	0.104	3.732	0.9%	Dizziness. Drowsiness. Dullness. Nausea. Unconsciousness.	May affect liver and kidneys
Chlorobenzene	4.7	14	11.88	246.59	0.093	1.933	41.1%	Drowsiness. Headache. Nausea. Unconsciousness.	May affect liver and kidneys
1,1,1-Trichloroethane	555	1110	12.91	189.83	0.101	1.488	0.3%	Cough. Sore throat. Headache. Dizziness. Drowsiness. Nausea. Ataxia. Unconsciousness	
Chlorodifluoromethane	3590		11.57	167.40	0.091	1.312	0.0%	Cardiac arrhythmia. Confusion. Drowsiness. Unconsciousness.	
Hydrogen sulphide	7	14	2.83	134.23	0.022	1.052	15.0%	Headache. Dizziness. Cough. Sore throat. Nausea. Laboured breathing. Unconsciousness. Symptoms may be delayed	
Tetrachloroethene	345	689	16.64	112.75	0.130	0.884	0.3%	Dizziness. Drowsiness. Headache. Nausea. Weakness. Unconsciousness.	Effects on liver and kidney
Toluene	191	384	12.00	86.22	0.094	0.676	0.4%	Cough. Sore throat. Dizziness. Drowsiness. Headache. Nausea. Unconsciousness	CNS possible reproductive toxin
Chloroethane	134		5.19	77.87	0.041	0.610	0.5%	Dizziness. Dullness. Headache. Abdominal cramps.	
n-butane	1450	1810	13.62	67.41	0.107	0.528	0.0%	Drowsiness. Unconsciousness	
Chloroethene	134		5.60	64.68	0.044	0.507	0.4%	Dizziness. Drowsiness. Headache. Unconsciousness.	Effects on the liver, spleen, blood and peripheral blood vessels, and tissue and bones of the fingers, carcinogenic
Carbon monoxide	35	232	5.82	62.95	0.046	0.493	1.4%	Dizziness. Dullness. Headache. Abdominal cramps	

	WEL mgm^{-3}		Concentration in landfill gas mgm^{-3}		Concentration at 10% LEL mgm^{-3}		Average concentration as %WEL	Health effects	
	8 hour	15 min	Median	Average	Median	Average		Short term	Long term
Ethylbenzene	441	552	6.48	37.79	0.051	0.296	0.1%	Headache. Confusion. Dizziness. Nausea. Weakness. Unconsciousness.	
1,2-Dichlorotetrafluoro-ethane			3.20	34.05	0.025	0.267		Suffocation	
α-pinene			29.30	3.32	0.230	0.026			
cis-1,2-Dichloroethene	806	1010	7.70	33.13	0.060	0.260	0.1%	Cough. Sore throat. Dizziness. Nausea. Drowsiness. Weakness. Unconsciousness. Vomiting.	Possible effects on liver
Xylene	200	441	4.70	23.90	0.037	0.187	0.4%	Dizziness. Drowsiness. Headache. Nausea.	CNS possible reproductive toxin
Dichlorofluoromethane	43		3.50	20.13	0.027	0.158	0.2%		
n-hexane	72		5.00	19.85	0.039	0.156	0.0%	Dizziness. Drowsiness. Dullness. Headache. Nausea. Weakness. Unconsciousness.	CNS possible reproductive toxin
Dichloromethane	350	1060	1.24	19.05	0.010	0.149		Dizziness. Drowsiness. Headache. Nausea. Weakness. Unconsciousness. Death	CNS liver
n-nonane			8.12	19.02	0.064	0.149	0.0%	Cough. Sore throat. Drowsiness. Dizziness. Ataxia. Convulsions. Unconsciousness.	
Butan-2-ol	308	462	5.40	18.70	0.042	0.147	0.6%	Headache. Dizziness. Drowsiness.	
1,2-Dichloroethane	21		1.58	16.50	0.012	0.129	0.1%	Abdominal pain. Cough. Dizziness. Drowsiness. Headache. Nausea. Sore throat. Unconsciousness. Vomiting. Symptoms may be delayed	
3-Methyl-2-butanone			1.98	13.61	0.016	0.107		Burning sensation. Cough. Laboured breathing, narcosis	

Exposure

Workers are most likely to be exposed to landfill gas during the installation and maintenance of the pipework required for leachate and gas collection. In order to protect against explosion hazard, workers use personal alarmed gas monitors set at a trigger level of 10% of the lower explosion limit (LEL) which is equivalent to a methane concentration of 0.5%. Typically the methane content of landfill gas is at least 10 times greater than the LEL implying that the alarm will trigger at levels of gas dilution of less than 1 in 100 (HSL, 2011). Workers are therefore normally exposed to less than 1% of the concentration of individual gases in landfill gas. Table 7.1 shows the estimated concentrations of other substances in landfill gas that would be associated with a dilution sufficient to reduce methane concentrations to less than 0.5%, based on the typical landfill gas composition reported by the Environment Agency (2004). The HSL (2011) measured worker exposure to benzene, hydrogen sulphide and vinyl chloride during bore hole drilling at 6 landfill sites and reported that the concentrations found were well below the levels of concern. The maximum personal exposure concentrations of these substances were 0.0002 ppm, 0.97 ppm and 0.0001 ppm respectively compared with the WELs of 1, 5 and 3 ppm as 8 hour TWAs. Higher exposures to hydrogen sulphide may occur at some sites where historically there has been co-disposal of calcium sulphate with MSW, giving rise to unusually high rates of hydrogen sulphide generation. Our experience from undertaking consultancy work suggests that there are a small number of sites where concentrations of hydrogen sulphide in landfill gas are more than 100 times the short term WEL implying that additional protective measures would be required at these sites. It is our belief, however, that the sites involved are aware of the issue and do use gas monitors in order to protect their workforce.

Anaerobic digestion is performed within sealed vessels and no exposures to biogas would be anticipated. If biogas were to leak from the digester or associated infrastructure, the main hazard for workers would be the explosion hazard associated with methane. Provided that exposures to methane do not exceed the LEL, it seems likely that exposures to other components of biogas would be similar to or lower than shown in Table 7.1. It is likely that emissions from partially digested waste would be highly malodorous but of similar or lower toxicity than landfill gas. If process problems lead to aerobic conditions within the decomposing waste and an aerobic microflora is able to establish itself, the associated volatile emissions would be similar to those associated with composting.

Odour

Landfill gases are typically malodorous and odour management is an important issue for landfill sites. Off-site odour nuisance may be a significant issue for many sites. Most research into the health effects of odour have investigated community exposures to odour arising from sources such as waste handling, intensive livestock farming, waste water works and petroleum refining (Schiffman and Williams, 2005, Horton et al, 2009, Heaney et al, 2011, Aatamila et al, 2011 Luginaah *et al*, 2000, 2002; Steinheider, 1999). Typical effects include respiratory symptoms, headache, fatigue and negative mood. Experimental studies undertaken with volunteers have demonstrated that adverse effects are more strongly associated with unpleasant than pleasant odours (Sucker et al, 2008). Odours have adverse effects on health at concentrations well below those at which adverse effects would be expected on the basis of the toxicological properties of component substances (Bulsing et al, 2009). The relationship between odour exposure and adverse reactions is poorly understood. It may partly relate to individuals' beliefs about the harmfulness of the odour and also to an innate response linking malodours with health hazards such as those associated with decomposing food (Bulsing et al, 2009). Many processes associated with odour emissions, however, would also be associated with bioaerosol emissions that would be expected to have similar adverse effects on health (Chapter 5). Individuals vary greatly in their susceptibility to odour. Some individuals, for example those of an anxious disposition, are considerably more sensitive to the effects of odour than others (Carlson *et al*, 2005; Bell *et al*, 1996).

There has been little investigation of the impacts of odour exposure at work and most studies have investigated odour as a component of indoor air quality in office or healthcare environments, rather than odour exposure in industrial environments such as the waste industry. In a review of studies of indoor air quality, Dalton and Jaén (2010) reported that poor indoor air quality, coupled with psychosocial factors such as the work environment, personality and stress, can lead to the development of building-related complaints and exacerbate chemical intolerance and symptoms.

They highlighted the importance of risk communication and worker education to minimise any misperception of risk from odours leading to illness and loss of well-being.

Risk assessment

Assuming that worker exposure to methane is normally controlled to less than 10% of the LEL, the calculated concentrations in Table 7.1 indicate that typical exposures to individual substances would be well below the WELs. Most of the substances, however, are associated with similar health effects and might be anticipated to have an additive impact on health. If the ratio of the concentrations of individual substances to their WEL is summed as described in EH40, the total is 62%. Given that there will be considerable variation between sites in the composition of landfill gas and that there will be other substances present, not considered in Table 7.1, it seems plausible that at the maximum levels of exposure that workers may experience on some landfill sites would be sufficient to give rise to adverse effects. Workers may experience irritation of the eyes and noise, which may be further enhanced by concurrent exposure to airborne dust. Repeated respiratory irritation may lead to increased risks of chronic respiratory illness. The relative importance of landfill gas and dust in contributing to adverse effects is likely to vary between sites and between individuals. Repeated exposure to VOCs may lead to increased risks of neurodegenerative diseases such as seen in painters. Exposures to VOCs in outdoor air at a landfill site are likely to be less than those historically experienced by painters working in indoor environments with solvent based paints and it is anticipated that the associated risk to health would be smaller. Similarly, the risks of other diseases related to long term solvent exposure would be expected to be relatively small. It is unlikely that exposure to volatile substances at landfill sites is sufficient to cause damage to the liver or kidney. Although landfill gases may contain a range of carcinogens, exposures to individual carcinogens are likely to be small (as demonstrated by HSL for benzene and vinyl chloride) and no increased cancer risk would be anticipated. Landfill gases are typically highly malodorous but there is no evidence that landfill workers experience serious adverse health effects resulting from long term exposure to malodour. It is possible that workers habituate to the smell and/or sensitive individuals leave the workforce. It is also possible that the exposure to malodour has a hidden impact on health that would not normally result in sickness absence through its negative impact on well-being and contribution to symptoms such as fatigue and headache. Exposures to gas generated by anaerobic digestion processes are likely to be negligible and would not be anticipated to give rise to adverse health effects, other than possible adverse effects on well-being that could arise if workers were repeatedly exposed to malodours.

7.3 VOCs AND RELATED SUBSTANCES ASSOCIATED WITH COMPOSTING AND OTHER PROCESSES INVOLVING ORGANIC WASTES

Overview

Many of the VOCs and other vapours generated during composting or other waste treatment processes are malodorous and may be the cause of significant complaint in the local community.

Health effects

Domingo and Nadal (2009) highlight the potential risks to health that may be associated with VOCs emissions from the composting of domestic waste. These authors noted that workplace exposure to a range of VOCs (in other industries) may be associated with irritation of the mucous membranes, neurotoxicity, adverse effects on the liver, kidneys and blood and some VOCs are carcinogens (e.g. benzene). Benzene, can cause disorders of the blood, dichloromethane is associated with the production of carboxyhaemoglobin, reducing the ability of blood to carry oxygen, dichloromethane, toluene, styrene, trichloroethylene and tetrachloroethylene are neurotoxic and naphthalene and styrene are irritating to the mucous membranes. It is unlikely that these example substances would be produced in substantial quantities by microbial processes. It is likely, however, that the types of health effects associated with VOCs from composting would be similar to those described.

The types of compounds that are most likely to be emitted from composting processes include short chain organic acids and ketones. These substances may make a substantial contribution to malodour. The individual substances are not particularly toxic at low levels of exposure, although it is likely that co-exposure to a mixture of these substances would give rise to additive effects. Proprionic acid and butyric acid are irritating to the eyes, nose, and throat. The WELs for proprionic acid are 31 and 46 mgm^{-3} as an 8 hour TWA and 15 minute maximum and exposure to a mixture of organic acids at higher concentrations would be anticipated to cause adverse effects. Relatively high levels of exposure to ketones are associated with adverse effects on the central nervous system (CNS). Exposure to acetone has been shown to alter performance in neurobehavioural tests in human volunteers at 595 mg/m^3 (250 ppm). In other experiments irritation of the eyes nose and throat was reported following 6 hours exposure to 1190 mgm^{-3} with some individuals experiencing adverse effects at a concentration of 240 mgm^{-3}. In experiments with methyl isobutyl ketone volunteers exposed to 410 mgm^{-3} for 15 minutes experienced eye irritation, headaches, nausea and dizziness. A two hour exposure to 200 mgm^{-3} induced CNS symptoms (headache and/or vertigo and/or nausea) but there were few complaints following exposure to 82 mgm^{-3} (ICPS, 1998).

Terpenes contribute to the odour associated with composting and other waste handling processes with organic rich materials and are associated with irritation of the mucous membranes with α-pinene having less irritative potency than n-butanol, 3-carene, and limonene (Jensen et al, 2004).

Mercaptans also contribute to the malodours associated with some organic waste processes. Accidental exposure to methyl mercaptan at a concentration of 8 mgm^{-3} for several hours in a group of students caused nausea and headache. Occupational exposure to methyl mercaptan may induce headache, nausea, vomiting, eye irritation, chest tightness and wheezing, dizziness, double vision and a productive cough (ATSDR, 2006).

Some composting operations may generate significant amounts of ammonia, for example, where certain food wastes or animal waste are treated. Exposure to ammonia is associated with upper respiratory and eye irritation at concentrations of >20 mgm^{-3}. Workplace studies have reported definite irritation at 88 mgm^{-3} and slight irritation at 3 mgm^{-3}. Long term workplace exposure to low levels of ammonia (<17 mgm^{-3}) has been reported to have little effect on workers' lung function. Although studies of farmers suggest that exposure to ammonia may contribute to the development of a range of respiratory symptoms, the specific role of ammonia was unclear (ATSDR, 2004).

Exposure

There are limited data on workplace exposure to VOCs at composting sites. Nadal et al (2009) reported that median concentrations of total VOCs at a large composting facility handling MSW were 14.4, 4.61, 1.06 and 2.91 mgm^{-3} at sorting cabins, reception, aerobic digestion plant and composting tunnels respectively. Concentrations of BTEX (the sum of benzene, toluene, ethylbenzene and xylene) were 8.41, 1.80, 0.12 and 1.08 mgm^{-3} respectively. The high concentrations of BTEX measured at the sorting cabins were associated with the incoming waste rather than being a product of decomposition. Domingo and Nadal (2009) cite a study of 8 US facilities that was undertaken in the early 1990s. This study found that exposure to VOCs was similar regardless of the operating characteristics of each facility and that the highest concentrations of VOCs were associated with the deposits of fresh material, the crushing machines, and the initial zone of the composting process. The total concentrations of VOCs (sum of all identified compounds) oscillated between <10 and >150 mgm^{-3}. None of the individual compounds identified exceeded the workplace threshold limit values (TLVs) set by the American Conference of Governmental Industrial Hygienists (ACGIH), although it would seem likely that many of the substances could have additive effects. A study undertaken by Tolvanen et al (2005) at a Finnish composting plant detected carboxylic acids and their esters, alcohols, ketones, aldehydes, and terpenes in workplace air. Concentrations of VOCs were much lower than the Finnish workplace exposure limits although many of the compounds were present in concentrations that exceeded their threshold odour concentrations. The authors noted that unpleasant odours may cause secondary symptoms such as nausea and hypersensitivity reactions. Muller et al (2004) reported that the mean concentrations of VOCs at the compost piles in 3 composting plants ranged from 0.04-0.51 mgm^{-3}, concentrations in the sieving area ranged from 0.007-0.22 mgm^{-3}. A wide range of different compounds were detected but alpha-pinene. limonene and camphor, camphene and (+)-3-carene were all relatively important in the mix. Mao et al (2005) reported the presence of 29 compounds, including ammonia, amines, acetic acid, and VOCs including hydrocarbons, ketones, esters, terpenes and sulphur-compounds in emissions from food waste at composting plants in Tawain. Concentrations of ammonia, amines, dimethyl sulphide, acetic acid, ethyl benzene and p-cymene were reported to exceed odour thresholds. More recently, Delgado-Rodríguez (2011) reported that the VOCs emitted from a pilot scale composting plant for vegetable trimmings includied limonene, β-pinene, 2-butanone, undecane, phenol, toluene, and dimethyl disulfide. In a study of a French composting site, Persoons et al (2010) reported that VOC concentration profiles were highly variable. Terpenoids and alcohols were the most predominant compounds, and total microbial VOC levels reached up to 40 mgm^{-3}. Geometric mean levels of terpenoids, alcohols, ketones and esters in the summer were 0.643, 0.177, 0.032 and 0.009 mgm^{-3} respectively. Concentrations were lower in the winter. The highest concentrations of microbial VOCs were associated with waste loading/shredding, fermentation and turning piles, which were associated with geometric mean concentrations of terpenoids of 1.958, 3.092 and 1.222 mgm^{-3} respectively. There was little or no correlation found between concentrations of microorganisms and VOCs. In an experimental study of VOC emissions during the microbial degradation of household waste, Mayrhofer et al (2006) reported that the most important compounds generated by microbial activity that give rise to malodour are dimethylamine, acetaldehyde, methanethiol, trimethylamine, acetic acid, dimethylsulfide, butyric acid and dimethyldisulphide.

Risk assessment

The presence of VOCs in air at composting plants and other plants where organic wastes are handled may be associated with substantial malodour and are likely to be associated with an increased risk of respiratory irritation and irritation of the eyes. Long term exposure may contribute to increased risks of chronic respiratory illness, although workers are also likely to be exposed to organic dusts and bioaerosol that are likely to represent much greater risk factors for long term respiratory illness. It seems highly unlikely that exposures to VOCs of microbial origin at plants handling organic wastes would be of significant magnitude to be associated with significant risks of neurotoxicity, liver or kidney toxicity or cancer. The health effects of exposure to odour in the workplace are not well established. Exposure to odour can make individuals feel nauseous and may contribute to symptoms such as headache and fatigue. Workers who are persistently exposed to malodour in the workplace may develop tolerance or it is possible that individuals with a low tolerance of malodour find alternative employment in other industries such that workers who remain in the waste industry are innately less odour-sensitive.

7.4 CHLOROFLUOROCARBONS, HYDROCHLOROFLUOROCABONS

Introduction

These substances were widely used as refrigerants in the past and are likely to present in older waste refrigerant equipment, although they have been banned from use in new equipment since 2000 (Table 7.2). Substances that were particularly important in the past include Dichlorodifluoromethane (R12), difluoromonochloromethane (R22), Trichlorofluoromethane (R11), 1,1,1,2-Tetrafluoroethane (R-134a) and Trichlorofluoromethane. Exposure to these substances may arise during the recycling of fridges and other refrigerating devices.

Table 7.2: Refrigerant gases

Chlorofluorocarbons (CFCs)	
Trichlorofluoromethane	CFC-11
Dichlorodiofluoromethane	CFC-12
Chlorotrifluoromethane	CFC-13
1,2-difluoro-1,1,2,2-tetrachloroethane	CFC-112
1,1-difluoro-1,2,2,2-tetrachloroethane	CFC-112a
1,1,2-trichloro-1,2,2-trifluorethane	CFC-113
1,1,1-trichloro-2,2,2-trifluoroethane	CFC-113a
1,2-dichloro-1,1,2,2-tetrafluroethane	CFC-114
1,1-dichloro-1,2,2,2-tetrafluoroethane	CFC-114a
1-chloro-1,1,2,2,2-pentafluoroethane	CFC-115
Hydrochlorofluorocarbons (HCFCs)	
Dichlorofluoromethane	HCFC 21
Chlorodifluoromethane	HCFC 22
Dichlorofluorethane	HCFC 141b
Chlorodifluoethane	HCFC 142b
Dichlorodifluoethane	HCFC 132b
Chlorotrifluorethane	HCFC 133a
Dichlorotrifluoroethane	HCFC 123
Chlorotetrafluorethane	HCFC 124

Health effects

The IPCS (1991) has reviewed the health effects of both CFCs and HCFCs

Short-term inhalation and oral studies with CFC-11, CFC-12, CFC-112, CFC-113, CFC-114 and CFC-115 in animals have shown low toxicity with effects observed on the CNS, respiratory tract and the liver. Dermal exposure to high doses of CFC-112, CFC-112a, and CFC-113 cause various degrees of irritation. In a long-term inhalation study, there was a reduction in body weight gain but no other adverse effects in rats that were exposed to CFC-113 at 1, or 2% (76.6, or 183 gm^{-3}) for 6 hours/day, 5 days/week for up to 2 years. The no effects level was15.3 gm^{-3}. Experiments in rats and mice with CFC-11 and CFC-12 showed no evidence for carcinogenicity. Developmental toxicity studies with CFC- 11, CFC-12, and CFC-113 found no evidence of embryotoxicity, foetotoxicity, or teratogenicity.

In studies in human volunteers with CFC-11and CFC-12 were observed at concentrations up to 0.1% (CFC-11, 5.6 gm^{-3}; CFC-12, 5 gm^{-3}) for periods of up to 8 hours. Adverse effects on neurobehavioural performance were observed at higher levels of exposure and adverse respiratory and cardiac effects at much higher levels of exposure. No adverse effects were associated with workplace exposure to CFC-113 at concentrations of 0.47% (36.7 gm^{-3}) or an average level of 0.07% (5.4 gm^{-3}).

Animal experiments have demonstrated a low level of toxicity following inhalation exposure to HCFC 21 or HCFC 22. Acute effects include loss of coordination and narcosis. Cardiac arrhythmias and pulmonary effects may occur at high concentrations (106.7 gm^{-3} or more). Longer term exposure is associated with liver damage, HCFC 21 and HCFC 22 may cause skin and eye irritation. Liver lesions were observed in rats exposed to HCFC 21 at 0.213 gm^{-3} of 6 hours/day, 5 days/week, for 90 days. Effects on the pancreas and kidney were also observed. Similar effects were not observed following exposure to HCFC 22 at exposure levels between 17.5 gm^{-3} (for 13 weeks) and l75 gm^{-3} (for 4 or 8 weeks). Lifetime exposure to HCFC 22 at 175 gm^{-3}, 5 hours/day, 5 days/week gave rise to hyperactivity in mice. No teratogenic effects were observed in rats exposed to HCFC21 but some reproductive toxicity was reported for HCFC 22 with a no effects level of 3.5 gm^{-3}.

There is no evidence that human exposure to HCFC 21 or HCFC 22 leads to ill health effects.

WELS have been set for Chlorodifluoromethane, Dichlorofluoromethane and 1,1,1,2-tetrafluoroethane of 3590, 43 and 4220 mgm^{-3} (as an 8 hour TWA) respectively.

Exposure

Exposure to CFCs and HCFCs could arise during the dismantling of fridges, freezers and other WEEE containing refrigerant gases. There are tight restrictions on the emission of these substances to the wider environment and the equipment used to extract these gases from WEEE is therefore designed to minimise the risk of release of these gases to the workplace or wider environment. Although it is likely that occasional leaks occur, the potential for significant worker exposure to these substances is extremely small.

Risk assessment

Worker exposure to CFCs and HCFCs during the dismantling of WEEE containing refrigerant under normal operating conditions would be negligible. Given the low levels of exposure and the low toxicity of these substances, there would be no associated risk to health.

7.5 RECOVERY OF FUEL AND LUBRICANTS FROM END OF LIFE VEHICLES

Overview

Workers dismantling end of life vehicles and some other types of equipment may be exposed to petrol, diesel or other fuels present in the fuel tank and fuel lines or other hydrocarbons present as lubricating oils, coolants etc.

Health effects

The main acute effects associated with inhalation exposure to a mixture of hydrocarbons such as those present in fuels are respiratory irritation, nausea, headache, dizziness and potentially loss of consciousness at very high concentrations (HPA, 2006, 2007). Long term exposure to hydrocarbon vapours is associated with risks of toxicity to both the central and peripheral nervous systems as is well documented in painters and may be associated with increased risks of dementia and other neurological conditions (IPCS, 1996; Dick, 2006). Some hydrocarbons are associated with increased risks of liver and/or kidney damage. In addition, petrol contains benzene which is carcinogenic and there is limited evidence that suggests diesel also may also be carcinogenic. Skin contact with mixed hydrocarbons is likely to cause skin irritation and longer term skin contact may defat the skin and lead to an increased risk of dermatitis. Prolonged dermal exposure to some oil formulations including diesel may be associated with increased cancer risks (HPA, 2006). Prolonged skin contact with engine oil may be associated with increased risks of skin cancer (HSE, 2011). In addition hydrocarbons may be readily absorbed through the skin, for example, experimental data suggest that about 10-15% of a dose of kerosene applied to the skin is absorbed giving rise to risks of systemic toxicity. The practice of using diesel for cleaning skin, for example, is associated with greatly increased risks of serious kidney disease (HPA, 2006).

Exposure

The working methods employed during the dismantling of end of life vehicles are designed to prevent spillages in order to protect the environment and prevent explosions and fires as outlined in the HSE (2004) guidance. These working methods will limit but not prevent exposure to petrol, diesel and other hydrocarbons. Provided the measures required to prevent environmental release of fuel and other hydrocarbons are being followed and appropriate protective clothing and gloves are used to prevent skin contact, there should be no significant exposure to fuel and other hydrocarbons where operations are performed outside and/or there are measures in place to control vapour levels in indoor air. Significant inhalation exposures to volatile hydrocarbons could occur if fuel is spilt in an indoor environment where the ventilation is insufficient to maintain vapour concentrations below relevant WELs.

Skin contact with hydrocarbons may be a particular issue in scrap yards as workers may not be aware of the importance of using suitable protective clothing and gloves. Hydrocarbons may be readily absorbed through the skin and workers could experience significant exposures to benzene and other carcinogens present in petrol and oils. In the absence of protective clothing and gloves, there could be significant skin contact with fuel and oils during the dismantling of end of life vehicles leading to a significant level of systemic exposure to carcinogens and other toxic substances. There are likely to be significant differences in the standards of personal hygiene typical of different sites and between individuals working at a single site. Where standards of personal hygiene are poor, there may also be a significant risk of exposure through inadvertent ingestion to the less volatile hydrocarbons that may accumulate during the working day. In other types of workplace environment, dermal exposure has been demonstrated to make a substantial contribution to overall exposure levels (e.g. Chang et al, 2007).

Risk assessment

Where exposure to hydrocarbons is appropriately controlled during the dismantling of vehicles and other equipment containing waste oils, there should be no associated risk to health. It is likely that inhalation exposures will normally be reasonably well controlled in order to prevent fire and explosion, although workers may experience above background exposures to some hydrocarbons by inhalation. The greatest potential for exposure is associated with skin contact. Failure to use appropriate protective clothing and gloves could lead to significant exposures to hydrocarbons, particularly if individuals were careless about personal hygiene. Repeated exposure over days to weeks is likely to be associated with increased risks of dermatitis. Repeated exposure over periods of months to years is likely to be associated with increased risks of neurodegenerative diseases and kidney toxicity and may also be associated with a small increased cancer risk.

7.6 SOLVENT COLLECTION AND RECOVERY

Solvent waste must be properly packaged prior to transport and the potential for exposure during collection, transport and in the delivery area of specialist recovery facilities should be small. Some exposure to solvent vapour may occur during the opening of containers to introduce waste solvent into a recovery process and if containers of the recycled product are manually filled and/or capped. Exposure can be minimised by the containment of solvent transfer processes and elimination of any stages involving the free fall of liquid combined with the use of effective LEV. The solvent recovery process should be fully enclosed and fitted with extraction with no untreated emissions reaching general workplace air. It may be difficult to eliminate exposure to VOCs, particularly at smaller plants, and some low level exposure to VOCs is likely.

The short term effects of elevated exposure to VOCs emitted from solvent wastes are likely to include respiratory irritation and irritation of the eyes. Other effects could include headache, dizziness and nausea. High levels of exposure following an accidental spillage within a relatively confined workspace could include serious respiratory and cardiac difficulties and potentially loss of consciousness (see above). Long term effects are likely to include liver and kidney toxicity, neurobehavioural effects and, potentially a small increased cancer risk associated with exposure to substances such as benzene which is associated with leukaemia (see above). Dermal contact with solvents or solvent vapour could cause irritation of the skin and prolonged exposure could give rise to dermatitis. Many organic solvents are readily absorbed through skin. Dermal contact with waste solvents should be readily preventable but dermal contact with solvent vapours may contribute to total systemic exposure and increase the potential for toxicity. Workplace health and safety culture is likely to play a key role in minimising exposure and risk

7.7 COLLECTION AND INCINERATION OF CHEMICAL WASTE

Chemical wastes must be properly packaged prior to transport and the potential for exposure during collection, transport and in the delivery area of specialist disposal facilities should be extremely small. The use of specialist disposal facilities means that processes are designed specifically for the handling of these wastes and intended to minimise worker exposure. Exposures are most likely to occur if processing problems such as jams in the waste feed occur upstream of the incineration process or in the waste reception area, if wastes are inadequately contained. Workers could be exposed to a wide range of hazardous substances including carcinogens and reproductive toxins but, unless the facility is very poorly managed, significant exposures to individual chemicals are likely to be infrequent (i.e. levels exceeding the WEL if applicable or threshold of effect). The risk of exposure may be greater in older facilities that may be more prone to process problems or where familiarity with the hazard has blunted the safety culture.

The health issues associated with exposures to VOCs released from chemical waste are likely to be similar to those described for solvent recovery processes. Workplace health and safety culture is likely to play a key role in minimising exposure and risk and no significant exposures should occur at a well managed disposal plant. Exposures during waste collection should be readily preventable provided that staff are trained not to accept inadequately packaged waste.

7.8 SOLVENTS AND OTHER CHEMICALS USED IN MATERIALS RECYCLING PROCESSES

A wide variety of chemicals are used in the treatment of different types of wastes such as plastics or paper. These are associated with a range of health hazards and the extent of risk will depend on the effectiveness of the exposure control measures in place. It is not possible to provide a succinct summary of all the chemicals, associated hazards and likely exposure levels. In general, exposures should be readily controlled if equipment has been designed with an appropriate level of enclosure, the appropriate ventilation is in place and the equipment is correctly operated and reliable. There may be increased risks of exposure to solvent vapours and associated risks to health in the waste industry compared with a modern chemical plant because of the lack of familiarity of managers and workers with the relevant regulation, the potential health risks and control measures required in order to prevent exposure.

7.9 CONCLUSIONS

Waste workers are exposed to a wide range of volatile substances and some of these exposures may be associated with adverse effects on health that may not be currently recognised. Exposure to VOCs and other trace gases released from decomposing waste at landfill sites, during composting and associated with other waste handling processes involving organic-rich wastes are likely to be well below the levels associated with toxicity for individual components. Exposure to the mixture may contribute to mucous membrane irritation and the development of symptoms such as cough and runny nose, particularly where exposures are combined with exposure to dust and bioaerosol. Exposure to the malodour associated with these substances may contribute to symptoms such as headache, fatigue and nausea and have a small overall negative impact on well-being. In contrast, exposure to refrigerant gases during fridge recycling is highly unlikely to adversely affect health. Exposure to fuels and other hydrocarbons at scrapyards could give rise to increased risks of respiratory and eye irritation but dermal contact and inadvertent ingestion may represent much more significant routes of exposure. Where exposures are poorly controlled, long term exposure may lead to kidney disease, adverse effects on liver function and the CNS and increased cancer risks. Similar risks may be associated with solvent recycling or handling other chemical wastes if insufficient measures are in place to control exposures by all routes. The use of solvents in waste treatment processes may be associated with exposures to a wide range of substances and hazards. Although it should be possible to control exposures to safe levels through appropriate equipment design and operating procedures, managers and workers and workers at waste sites may be unfamiliar with working with chemicals and the control measures required in order to prevent exposure. This may lead to higher levels of exposure and associated risks to health than might arise where these substances are handled in other sectors.

8 Semi-volatile organic chemicals

8.1 INTRODUCTION

Waste workers in a small number of specific sectors may be exposed to toxic organic compounds of relatively low volatility that are widely perceived to represent a significant hazard to human health. This chapter assesses the potential risks to health associated with exposure to dioxins and furans, polyaromatic hydrocarbons, brominated fire retardants and polychlorinated biphenyls in the waste industry. For each group of substances a description is provided of the potential health effects, where exposure is most likely in the waste industry, exposure levels and the overall risk to worker health.

8.2 DIOXIN

Overview

The name dioxin is used for the family of structurally and chemically related Polychlorinated Dibenzo-Para-dioxins (PCDDs) and is also sometimes applied to polychlorinated dibenzofurans (PCDFs), and certain polychlorinated biphenyls (PCBs). PCDDs, PCDFs and PCBs all comprise large families of chemicals with similar molecular structures. The individual members of these chemical groups are referred to as congeners. The most toxic of these compounds is 2,3,7,8- Tetrachlorodibenzo-para-dioxin (TCDD). Only about 30 of a total of 419 types of dioxin-related compounds are considered to have significant toxicity (WHO, 1999). These substances form during combustion over specific temperature ranges and where chlorine is present. Historically waste incineration was a major source of dioxin in the general environment but since the Waste Incineration Directive came into force, dioxin emissions from incinerators have been very small and the main source of dioxins in ambient air is from uncontrolled domestic fires (e.g. burning of garden waste).

Exposures to dioxin and dioxin like compounds are usually expressed in terms of Toxic Equivalency (TEQ) to a dose of TCDD. This has required the development of Toxic Equivalent Factors (TEF). Each dioxin-like compound has been assigned a TEF that describes the magnitude of its toxicity in relation to TCDD. The TEFs used for different dioxin compounds were substantially revised in the late 1990s so that exposure estimates in earlier studies expressed as I-TEQ are not directly comparable with those in recent studies expressed as TEQ(WHO).

Dioxins are very stable chemicals. The main route of exposure to dioxins is usually through diet. Dioxins are lipid soluble and accumulate in fatty and oily foods such as fish, meat, eggs and milk. In the UK, normal dietary intakes of dioxins are 0.9 pgTEQ $kg^{-1}day^{-1}$ for a typical adult and 0.7 to 1.8 pgTEQ $kg^{-1}day^{-1}$in children with the relative greatest intake being in younger children (Food Standards Agency, 2003). An important route of exposure for young children is through breast milk. Current levels of exposure to dioxins are less than 20% of those in the early 1980s. Once absorbed by the human body, dioxins may be stored within fatty tissues for extremely long periods. Their half-life in the body is, on average, seven years. There is some evidence that clearance rates are related to total body burden such that higher body burdens may be associated with relatively greater rates of clearance. The WHO (1998) calculated that body burdens of between 28 and 73 ng/kg would be associated with a human intake of between 14 and 37 pg of TCDD $kg^{-1}day^{-1}$.

Health effects

Systemic toxicity

Human exposure to 2,3,7,8-TCDD or other PCDD congeners due to industrial or accidental exposure has been associated with chloracne, a persistent skin condition, and alterations in liver enzyme levels in both children and adults. Changes in the immune system and glucose metabolism, and increased risk of cardiovascular disease have also been observed in adults. Infants exposed to PCDDs and PCDFs through breast milk exhibit alterations in thyroid hormone levels and possible neurobehavioural and neurological deficits. Signs of TCDD toxicity in animals include thymic atrophy, hypertrophy/hyperplasia of hepatic, gastrointestinal, urogenital and cutaneous epithelia, atrophy of the gonads, subcutaneous oedema and systemic haemorrhage. Dioxins cause suppression of both cell-mediated and humoral immunity in several species at low doses and have the potential to suppress resistance to bacterial, viral and parasitic challenges in mice (USEPA, 2001).

Workplace studies provided limited evidence of the harmfulness of PCDD/Fs. One US study of pesticide production workers and sprayers found an increased risk of circulatory disease, particularly ischemic heart disease in workers exposed to TCDD and other dioxins and a non-significant increased risk of diabetes (Vena et al, 1998). Risks were greatest in those exposed for over ten years. Another US study of pesticide production workers, however, did not find an association between TCDD exposure and cardiovascular illness despite serum concentrations of TCDD that were more than 20 times higher than in unexposed individuals (Calvert et al, 1998). Fierenes et al (2003) reported that a group of diabetic patients in Belgium had significantly increased serum levels of dioxins relative to control subjects but these individuals are likely to have been exposed to other environmental pollutants. In addition factors such as diet which would influence diabetes risk would also have an influence on dioxin exposure. In a Czech study of 13 herbicide production workers exposed to high levels of TCDD 30 years earlier, evidence of abnormal electromyography, electroencephalography, and visual evoked potentials was observed in 23%, 54%, and 31 %, respectively, of former workers (Pelclova et al, 2001). The estimated mean plasma concentration at the time of exposure was 5,000 pg g^{-1} fat.

The American Agency for Toxic Substances and Disease Registry (ATSDR) have identified a No Observed Adverse Effect Level (NOAEL) for acute (short term) exposure to TCDD in oil of 5000 pg/kg for immuno-suppression in female mice and a NOEAL of 700 pg $kg^{-1}day^{-1}$ for atrophy of the thymus in guinea pigs (an immunological effect) and liver toxicity (Pohl et al, 1999).

Reproductive and developmental toxicity

TCDD is both a developmental and reproductive toxicant in experimental animals (IARC, 1997). Sensitive targets include the developing reproductive, nervous and immune systems. Effects on the developing organism occur at doses <1% of those associated with effects in the mother. The results of studies of reproductive and developmental toxicity in humans have been mixed. Lawson et al (2004) reported that babies born to the wives of male chemical workers with high exposures to TCDD did not appear to have increased risks of low birth weight or preterm delivery. In a Japanese study of 240 mothers, Tajima et al (2005) found a nonsignificant negative correlation between birth weight and the PCDD/Fs. Konishi et al (2009) found evidence linking material blood levels of dioxins and furans to reduced birth weight in male but not female infants in a study of 514 pregnant Japanese women. In a study of 510 Sevesco women (888 total pregnancies), Eskenazi et al (2003) found no significant association between TCDD exposure and a range of adverse reproductive outcomes.

The WHO (1998) identified a range of lowest observed effect levels in animal experiments associated with maternal body burdens between 28 and 73 ngkg. Effects included decreased sperm count, immune suppression, genital malformations and neurobehavioural effects in the offspring of exposed rats and monkeys and endiometriosis in female monkeys. The Japanese Environment Agency (1999) has suggested that the endiometriosis may have been the result of poor animal care as opposed to exposure to dioxins. The WHO (1998) calculated that body burdens of between 28 and 73 ng/kg would be associated with a human intake of between 14 and 37 pg of TCDD $kg^{-1}day^{-1}$. An uncertainty factor of 10 was applied to derive an upper range for the Tolerable Daily Intake (TDI) of 4 pg $kg^{-1}day^{-1}$ or 0.28 ng/day for an adult weighing 70 kg. The WHO stated that the ultimate goal should be to reduce human intake to less than 1 pg/kg/day, but also noted that short term exposures to dioxins that exceed the TDI would have no long term consequences. One pg is 0.001ng or 10-6 ug.

Cancer

The International Agency for Research on Cancer (IARC, 1997) categorised TCDD as a "known human carcinogen". IARC concluded that the strongest evidence for the carcinogenicity of 2,3,7,8-TCDD in exposed workers was for all cancers combined, rather than for any specific site. TCDD does not affect genetic material and it is generally believed that there is a threshold level of exposure below which cancer risk would be negligible. Bain et al (2009) reported that an IARC review of TCDD had confirmed its classification as a human carcinogen on the basis that it was associated with an increased risk of “all cancers combined” in humans. Boffeta et al (2011), however, reviewed the epidemiologic studies on exposure to TCDD and cancer risk, published since the IARC (1997) review and concluded that the epidemiological evidence fell far short of conclusively demonstrating a causal link between TCDD exposure and cancer risk in humans. Updates of studies that had previously reported excess cancer risks linked to TCDD exposure had failed to find significant relationships between TCDD and increased cancer risk. This included updates of studies undertaken in the US of pesticide production workers exposed to TCDD in the US, Netherlands and New Zealand. Although the updated surveillance of the Seveso population provided evidence of increased all-cancer mortality 15-20 years after exposure among those living in the most contaminated area, this is likely to have been due to random variation, as no overall excess risks have been observed in more recent follow-up studies. Similarly, updated results from cohort studies of Vietnam veterans potentially exposed to TCDD did not consistently suggest an increased risk of cancer. Results of additional, smaller studies of other occupational groups potentially exposed to TCDD, and of community-based case-control studies, did not provide consistent evidence of an increased cancer risk.

Ruder and Yin (2011) reported a small excess of cancer mortality 2122 US Pentachlorophenol (PCP) production workers from four plants in the US exposed to exposed to PCP and to polychlorinated dibenzo-p-dioxin and dibenzofuran contaminants of PCP production. Notably Cooper and Jones (2008) reported evidence linking hematopoietic cancer to exposure to pentachlorophenol exposure in a US cohort and attributed the risk to PCP rather than contaminants in PCP.

Studies in waste incineration workers

Studies in incinerator workers have provided evidence that exposure to PCDD/Fs may be associated with small effects on immune function, liver function, cholesterol and serum lipid levels and oestrogen activity.

In a study of 57 Japanese male waste incinerator workers, Yoshida et al (2005) reported evidence of endocrine disruption: mean oestriol concentrations, adjusted for confounding factors among 3 serum dioxin levels, showed a statistically significant increase with increasing serum dioxin level: 1.30, 1.41, and 2.02 nmol/mol creatinine at < 30.3, 30.3-39.7, and > 39.7 pg TEQ/g lipid, respectively.

Kitamura et al (2000) examined the health of 94 workers at an incinerator in Japan associated with particularly high emissions of dioxin. The median TEQ of dioxins was 39.7 pg I-TEQ/g lipid, and the range was 13.3 to 805.8. Although significant positive correlations between dioxin levels and GGT, total protein, uric acid and calcium, and a negative correlation with Fe, were found, these correlations disappeared once age, smoking status, and alcohol consumption were taken into account. In contrast, small effects on immune activity – increased NK activity and lower response to PHA stimulation remained significant even after adjusting for age. Serum dioxin levels were also significantly associated with hyperlipidemia and allergy.

Oh et al (2005) investigated the immunotoxic effects of exposure to TCDD in 31 Korean waste incineration workers and in 84 control subjects. They found no significant difference in T- and B-cell profiles in incineration workers and control subjects or differences in the ratio of T helper cells to T ytotoxic cells. However, T-cell activation (but not B-cell activation) was significantly higher in the incineration workers than in the controls. Immunoglobulin levels were lowered in incineration workers but not significantly. There was also a significant lowering in the level cytokine the IL-4 and a non-significant lowering INF-gamma in the waste incineration workers.

In a study of Taiwanese incinerator workers, Hu et al (2003) reported that total cholesterol levels in workers with blood dioxins/furans levels of 15.4-59.0 pg TEQ/g lipid (high-exposure workers) averaged 13.5 mg/dL higher than workers with 5.5-15.3 pg TEQ/g lipid (low-exposure workers). The adjusted odds ratio for total cholesterol abnormality (>220 mg/dL) was 2.8 (95% confidence interval = 1.0-7.9) between high and low-exposure workers. High-exposure workers showed consistently, although not statistically significantly, higher levels of three enzymes that may be indicative of liver damage - gamma-glutamyltransferase, alanine aminotransferase, and aspartate aminotransferase - than low-exposure workers.

Yoshida et al (2006) reported a negative correlation between the concentrations of serum dioxins and lymphocytic 8-hydroxydeoxyguanosine (8-OH-dG) in 57 male waste incinerator workers and no relationship with urinary 8-OH-dG or urinary mutagenicity. They concluded that dioxin was not directly associated with oxidative DNA damage, but may be linked to upregulation of cellular defence systems leading to oxidative damage and/or DNA repair system activity.

Exposure to dioxins and furans

Overview

Exposure to dioxin may occur in waste incineration plants, at landfill sites, particularly where there are uncontrolled underground fires and during metals recycling. The exposures associated with recycling metals occur during downstream processing and are therefore relevant to the metals industry rather than the waste industry.

Biomonitoring Data

Most studies of worker exposure to PCDD/Fs have reported the results of biomonitoring rather than measured concentrations in workplace air.

There is little evidence that plasma PCDD/F levels in workers at modern incineration plants are significantly elevated above background levels in the wider population during routine operations. Modern incinerators must meet very demanding emission standards for dioxin and conditions during combustion and in the post-combustion gas stream are carefully managed in order to minimise the formation of PCDD/Fs leading to a much reduced potential for worker exposure in comparison to historical levels. Mari et al (2009) reported that the levels of PCDD/Fs in plasma of workers at a hazardous waste incinerator in Spain decreased from 26.7 pg I-TEQ g^{-1} lipid in the baseline survey to 2.5 pg I-TEQ g^{-1} lipid after 8 years operation of the facility. Previously Mari et al (2007) had determined that the mean serum PCDD/F concentration of workers after four and six years of operation, 7.7 ng I-TEQ/kg lipid and 10.4 pg I-TEQ g^{-1} lipid, respectively. PCDD/F levels in plasma were similar or even lower than reported for various non-exposed populations. There is little readily available information about typical body burdens of dioxin in the UK population. Pless-Mulloli et al (2003) investigated 40 older women (mean 64 years, range 42-79 years) and reported that the mean body burden of PCDD/Fs was: 29.9 pg TEQ (WHO) g^{-1} lipid. The TCDD body burden increased with age with accelerated increments above age 70.

Studies in workers at modern incinerator plants in Japan and Tawain indicate similar dioxin blood levels to those observed by Mari et al in Spain. Kumagi et al (2004) reported that the mean of serum TEQ of PCDDs, that of PCDFs and that of total PCDDs and PCDFs in workers at 13 municipal waste incinerator workers were 16, 12 and 28 pg TEQ g^{-1} lipid, respectively. Serum concentrations of hexachlorodibenzofurans and heptachlorodibenzofurans were, however, significantly higher in the incinerator workers than the general population and positively correlated with those in dust except for three plants where large-scale remodelling of the equipment had occurred within the past seven years. In a similar, earlier study, Kumagai et al (2002) reported that the summed PCDDs and PCDFs in 20 municipal waste incinerator workers from 3 plants and controls were 22.8 and 16.4 pg TEQ g^{-1} lipid for area I, 29.4 and 19.3 pg TEQ g^{-1} lipid for area II, and 22.8 and 24.9 pg TEQ g^{-1} lipid for area III, which were almost the same as for the general population of Japan. Hu et al (2004) reported that the the geometric means of blood PCDD/Fs concentrations were 14.6, 15.8, 19.1 pg TEQ g^{-1} in workers at 3 incineration plants in Tawain. There were significant differences in the blood concentrations of several PCDD/Fs congeners between the three incineration plants that were not explained by the differences in job contents, duration of employment and time of activity in these plants.

Several studies provide some evidence that cleaning and maintenance operations may lead to slightly higher levels of exposure to dioxin than routine operations, although overall body burdens of dioxin may not be significantly raised above background levels. In a Flemish study, Raemdonck et al (2006) used a chemical-activated luciferase gene expression (CALUX) assay to determine serum dioxin-like activity in five workers before and after two different cleaning activities inside a municipal domestic solid-waste incinerator. The workers' mean serum concentration of dioxin-like substances before the first cleaning operation was 17.2 pg TEQ g^{-1} fat (range = 12-22), which was comparable with concentrations found in similarly aged men in a Flemish environmental health pilot study. After cleaning work, the workers' mean serum concentration was 28.5 pg TEQ g^{-1} fat (range = 18-31). At the second plant stoppage, the workers' mean dioxin-like activity was 15.4 pg TEQ g^{-1} fat (range = 12-21) before and 16.4 pg TEQ g^{-1} fat (range = < 10-32) after the cleaning operation. There was evidence of an association between elevated TEQ concentration serum and poor compliance with the requirement to use PPE. Kumagai et al (2000) investigated serum dioxin levels in waste incineration workers in Japan who had worn dust masks or airline masks during the periodic repair work inside the incinerators. The concentrations of PCDD/Fs in the deposited dust were 4.8, 1.0, and 6.4 ng TEQs/g, respectively, for plants A, B, and C. The mean serum TEQ of PCDDs and PCDFs in the incinerator workers and control workers were 19.2 and 22.9 pg TEQ g^{-1} lipid, respectively, for plant A, 28.8 and 24.5 pg TEQs/g lipid for plant B, and 23.4 and 23.6 pg TEQ g^{-1} lipid for plant C. No significant differences were found in TEQs between the incinerator workers and the controls but the concentration of specific congeners were significantly higher in the incinerator workers than in the controls for all the three plants and appeared to increase with increasing length of employment. Shih et al (2006) investigated the change in serum PCDD/F levels of 35 temporary employees between the beginning of periodic incinerator maintenance and one month after the work was completed. PCDD/F levels in blood were significantly increased after a month of maintenance work. The increase was greater in workers who had never done this type of maintenance than in those with previous experience, especially for one particular congener. Mean serum levels of total PCDD/Fs in workers with no previous experience rose from 15.7 to 19.6 pg TEQ(WHO) g^{-1} lipid compared with a rise from 24.1 to 27.5 pg TEQ(WHO) g^{-1} lipid in workers with previous experience. Mean serum levels of PCDD/Fs in workers exposed to flyash were significantly higher than in those with no exposure to flyash (22.2 compared with 12.5 pg TEQ(WHO) g^{-1} lipid). There was no significant difference in the serum PCDD/F levels of the repair workers and those supervising the work.

Levels of PCDD/F emission and workplace exposures were greater in the past and may also be greater outside of the EU and older studies have reported blood dioxin levels in incineration workers that exceed those of the wider population. In a study of Japanese municipal waste incinerators, Kumagai et al (2003) reported that the mean blood dioxin concentration was 346 pg TEQ/g lipid in workers with the highest exposures in one particular plant compared with 11 to 40 pg TEQ/ g lipid in the other incineration plants. No significant differences in the TEQ of PCDDs and TEQ of PCDDs and PCDDs were found between the incinerator workers and the controls. When the occupational exposure index for each constituent of PCDDs and PCDFs was defined as the product of the duration of employment at the incineration plant and the concentration of the constituent in the deposited dust, multiple regression analysis showed that the concentrations some specific congeners and TEQ of PCDFs in serum samples increased with the occupational exposure index. Kumagai and Koda (2005) reported that one month after a Japanese infectious waste incineration plant ceased operation in 2000 because of emissions issues, workers had plasma dioxin levels of 49.1 pg TEQ g^{-1} lipid, 2.7 times as high as that for the controls. At 16 months, the mean TEQ for the workers had decreased to 29.4 pg TEQ g^{-1} lipid, which was 1.6 times that for the controls. In another Japanese study of a MSW incinerator that was associated with particularly high emissions of dioxin, Kitamura et al (2000). reported that the median blood dioxin level in 94 workers was 39.7 pg I-TEQ g^{-1} lipid, and the range was 13.3 to 805.8. In a Korean study, Park et al (2009) reported serum dioxin concentrations in 26 incinerator workers (10 industrial waste and 16 MSW) were 41.57 and 9.86 pg TEQ(WHO) g^{-1} lipid, respectively compared with 17.64 pg TEQ(WHO) g^{-1} lipid in the control subjects. In a US study, Schecter et al (1995) reported that total concentrations of PCDDs and PCDFs in the blood of 10 workers from an old municipal waste incinerator without adequate pollution controls were significantly higher than in 11 workers from a newer incinerator with (then) modern pollution controls. Workers at the new incinerator had blood concentrations that were indistinguishable from those of 25 controls from the general population matched for age, sex, and race. The mean and range of total PCDD/F concentrations in lipid were 930 (578-2105) pg g^{-1} lipid and 1395 (794-2470) pg g^{-1} lipid for the two groups of workers compared with 918 (279-2131) pg g^{-1} lipid for the controls. When concentrations were expressed as TEQ, however, the three groups had very similiar blood PCDD/F levels with mean levels of 42.9, 34.3 and 39.7 pg g^{-1} lipid respectively for the controls, workers at the new incinerator and workers at the old incinerator.

Overall, it seems unlikely that blood concentrations of dioxins and furans in UK incinerator workers employed in modern plants are significantly different from those of the wider population. It is possible that workers with a heavy involvement in cleaning and maintenance operations have slightly higher blood dioxin levels than the wider population. Workers who have been employed for many years in older incinerators may have higher blood dioxin levels as a result of historical exposure, although their current blood dioxin levels are likely to be significantly lower than in the past as a result of the gradual clearance of dioxin from the body.

Reported concentrations of dioxin and furans in workplace air

There have been very few published investigations of the concentrations of dioxin in workplace air at incineration plants or associated with other waste processes. In a UK study, Sweetman et al (2004) reported concentrations of PCDD/F in personal samples collected in the tipping hall and residual hall of a municipal waste incinerator of 0.26 and 0.16 pg TEQ (WHO) m^{-3} and concentrations in static samples of 0.07 and 0.34 in the tipping hall and 0.06 and 0.08 pg TEQ (WHO) m^{-3} in the residue hall. Concentrations around an ash processing plant at a landfill site were 1.65 pg TEQ (WHO) m^{-3} in a personal sample for the plant manager and 0.13-0.16 pg TEQ (WHO) m^{-3} in the plant loading bay. Sweetman et al also reported concentrations of PCDD/Fs in settled dust at a municipal waste incinerator of 103 and 7 pg TEQ (WHO) kg^{-1} respectively. Settled dust at an ash processing plant at the landfill contained 36.67 pg TEQ (WHO) kg^{-1}. Hu et al (2004) reported that PCDD/Fs levels in 3 municipal waste incinerators in Tawain ranged from 0.08 to 3.01 pg TEQ-I m^{-3}. Kumagai et al (2003) estimated that dioxin exposure concentrations in Japanese municipal waste incinerators were 0.5 to 7.2 pg TEQ (WHO) m^{-3} during routine operation and 0.2 to 92,000 pg TEQ m^{-3} during periodic maintenance.

A number of studies have reported concentrations of dioxins and furans in incinerator ash (Table 8.1)

Table 8.1: reported concentrations of PCDD/Fs in incinerator residues

Study	Country	Waste type	Residue type	ng-TEQ g^{-1}
Yao et al (2011)	China	MSW	Fly ash	9 - 6177
Chung et al (2010)	Taiwan.	MSW	bottom residue fly ash pit fabric filter semi-dryer absorber economizer super heater	0.0329 1.1589 1.2807 0.1476 0.6868 0.0921
Cobo et al (2009),	Columbia	hazardous waste	Bag filter fly ash dioxins + dioxin like PCBs	> 185
Horii et al (2008)	US	Municipal hazardous and industrial waste	Fly ash Bottom ash	15.800 0.067
Lin et al (2008)	Taiwan	MSW	ash in the super heater economizer semi-dryer absorber fabric filter fly ash pit bottom residue	0.102 0.788 0.210 1.95 2.04 0.0218
Bie et al (2007)	China	MSW	fabric filter fly ash	798200
Matsui et al (2003)	Japan	Medical, domestic and MSW	Ash	2.23 and 12.29
Kumagai and Koda (2005)	Japan - plant ceased operation in November 2000	infectious waste	Ash remaining in the incinerator dust deposited around the conveyer and incinerator	44 10
Kumagai et al (2004)	Japan	MSW	deposited dust	0.54 to 33
Kumagai et al 2000	Japan	MSW	Deposited dust Plant A Plant B Plant C	 4.8 1.0 6.4

Defra (2004) reviewed the dioxin and furans content of incinerator residues. Based on the figures produced in this report, it would appear that the best estimate of the PCDD/F content of flyash is 1.23 x 10^{-4} ng TEQ mg^{-1} ash (range 3.53x10^{-6} – 4.46 x 10^{-5}). The PCDD/F content of bottom ash was lower. Dust exposures during normal operation of an incineration plant would be anticipated to be small but could readily exceed 10 mgm^{-3} during cleaning and maintenance operations such that significant exposures could occur if frequent breakdowns led to the repeated interaction of workers with ash. A shift mean exposure concentration of 10 mgm^{-3} derived from flyash would give an intake of 100 mg dust containing 0.0123 ng (0.00353– 0.446 ng). Improvements in combustion technology and the requirement to minimise PCDD/F formation in order to meet the requirements of the Waste Incineration Directive mean that it is likely that concentrations of PCDD/Fs in incineration residues and the associated potential for exposure have reduced since the DEFRA (2004) review was undertaken.

Landfill sites

Concentrations of dioxin in landfill gas are extremely small and any associated exposure of workers to dioxin would be extremely small.

Metals recycling

Sweetman et al (2004) reported concentrations of PCDD/Fs in workplace air at a number of metals recycling plants, although these processes would not be classified as being within the waste and recycling industry (Table 8.2).

Table 8.2: Concentrations of PCDD/Fs in workplace air at metals recycling plants

Metal recycling process	**Sample details**		**pg WHO-TEQ m^{-3}**
Aluminium	Personal	Site 1 induction burner	3.5, 54.9
		Site 2 warf drier	1.3
		Site 4 dross processing	25
	Static	Site 1 sloping hearth	4.1
		Site 4 dross processing	7.1
		Site 5 warf drier	68.3
		Site 5 sloping hearth	3.9
Steel	Personal		0.1, 1.6, 2.0, 9.0
	Static		2.4, 4.0, 4.7
Magnesium	Static		0.1, 0.1, 0.4, 1.7
Zinc	Static		2.4, 2.5 8.3

Risk assessment

The Tolerable Daily Intake (TDI) for the general population recommended by the independent Committee on Toxicity is 2 pg WHO-TEQ/kg of bodyweight per day. The equivalent intake for a 70 kg adult is 0.14 ng/day, equivalent to exposure to 0.014 ngm^{-3} as an 8 hour TWA. The results of the exposure assessment suggest that exposure levels are likely to be well below this level, even at incineration plants where there are repeated process problems. It is unlikely that waste workers are regularly exposed to more than 10% of the TDI and no significant impacts on health would be anticipated.

8.3 POLYAROMATIC HYDROCARBONS (PAHs)

Overview

PAHs are a large class of organic compounds containing two or more fused aromatic rings and are characterised by high melting- and boiling-points, low vapour pressure, very low water solubility and chemical inertness. They are soluble in many organic solvents and are highly lipophilic. They are formed by combustion process and have been detected in emissions from waste incineration. They are also present in diesel exhaust emissions. Diesel plant is employed at virtually all waste handling plants and additionally, waste is delivered to virtually all waste handling plants by heavy goods vehicles that emit diesel fume.

Health effects

IPCS (1998) and the HPA (2008) provide a summary of the health effects of PAHs.

The acute toxicity of PAH appears to be moderate to low. The results of short term experiments in animals suggest that some PAHs are associated with adverse haematological effects. PAHs have also been associated with immunosuppression and liver toxicity. In experiments where PAHs have been applied to the skin, some PAHs have caused hyperkeratosis. PAH vapours have caused mild eye irritation in animals and Benzo[a]pyrene (B(a)P) induced contact hypersensitivity in guinea-pigs and mice. Some PAHs have been demonstrated to exhibit phototoxicity.

Long term exposure to PAHs in the workplace are associated with a decrease in lung function, chest pain, respiratory irritation, cough, dermatitis and depressed immune function, although in most studies workers have been exposed to a mixture of agents and the contribution of PAHs to observed effects is uncertain.

Some PAHs are reproductive and developmental toxins in animals.

A large number of PAHs are proven genotoxins and some are carcinogenic. The results of animal experiments indicate that there is a substantial variation in the carcinogenic potency of different PAHs. Workplace exposure to PAHs at coke ovens during coal coking and coal gasification, at asphalt works, foundries, and aluminium smelters, and to diesel exhaust is associated with tumours of the lung, bladder and skin. B(a)P makes a substantial contribution to the carcinogenicity of the mixed PAHs that are typically found in workplace environments. The index dose for inhalation for B(a)P derived by the Environment Agency is 0.07 x ng $kg^{-1}day^{-1}$. For a 70 kg individual this would equate to an intake of 4.9 ug/ day, the intake associated with 8 hours exposure to 0.49 μgm^{-3} in workplace air. Assuming a 40 year working lifetime, 80 year total lifetime and a total of 200 working days/year, the equivalent workplace exposure concentration would be 1.8 ngm^{-3}.

A number of studies have found markers of DNA toxicity in PAH exposed workers but the results of studies in incinerator workers have not found evidence that exposure to PAHs is associated with significant effects on DNA. In a recent Austrian study, Wutltsch et al (2011) found no evidence of DNA damage as assessed by single-cell gel electrophoresis and micronucleus assays in lymphocytes in workers who had spent 11 months undertaking maintenance work at an incinerator. A Korean study (Sul et al, 2003) provided some weak evidence linking exposure to PAHs at incinerators to increased levels of DNA damage. In T-lymphocytes. In another Korean study, Lee et al (2002) assessed PAH exposure in 29 incinerator workers though the measurement of urinary 1-hydroxypyrene glucuronide (1-OHPG) and aromatic DNA adducts in peripheral white blood cells (WBCs). They found a significant correlation between 1-OHPG and aromatic DNA adducts but exposure to PAHs was more strongly associated with smoking than with working at an incinerator.

PAHs are likely to make a small contribution to the overall harmfulness of airborne dust in incineration plants. In a Korean study, Kim et al (2004) reported that there was evidence that genes associated with oxidative stress were up-regulated in waste incineration workers which have been related to exposure to PAHs as similar effects were reported in vehicles emission inspectors.

Exposure

Exposure to PAHs is possible wherever combustion processes are undertaken including the use of diesel powered plants. The general population is exposed to PAHs in vehicle exhaust, tobacco smoke, smoke from domestic solid fuel or oil combustion, industrial emissions and other sources. There has been little investigation of the PAH exposure of waste workers. Two studies have reported evidence that workers in incineration plants may be exposed to higher levels of PAHs than the wider population.

Maitre et al (2003) reported that the mean concentration of total PAHs at a French incinerator was 18.84 ngm^{-3} (range: 0.02-1.47). The mean concentration of B(a)P was 1.09 ngm^{-3} (maximum 11.64). In a Japanese study, Ichiba et al (2007) measured concentrations of urinary 1-hydroxypyrene (1OHP), a metabolite of pyrene, and 2-naphthol (2NP), a metabolite of naphthalene, in 100 workers in 4 different types of incinerators: two old types, one modern type and one outdoors. The medians of urinary 1OHP before and after the work shifts obtained from all workers were 0.067 and 0.044 ug g^{-1} creatinine, respectively; and the medians of urinary 2NP were 7.5 and 10.0 ug g^{-1} creatinine, respectively. A significant increase of 2NP after the work shift at one old incinerator. A significant decrease of metabolites was found at the other old incinerator. The urinary metabolites levels were significantly associated with the number of cigarettes smoked per day and multiple regression analysis indicated that both a smoking habit and incinerator type were significantly associated with PAH exposure.

Other high temperature waste treatment processes such as pyrolysis or gasification involve the combustion of methane or syngas rather than direct combustion of waste materials and the extent of PAH formation is likely to be much less than for incineration.

Waste workers may be exposed to elevated levels of PAHs where diesel exhaust fumes are emitted from vehicles and/or plant, particularly where emissions are within an indoor space. The results of two studies conducted in Finland suggest that waste collection workers may have slightly higher, but not consistently higher, exposures to PAHs than the general population (Kuusimaki et al, 2002, 2004; Harri et al, 2005). It is plausible that exposure to diesel fume emitted by plant and/or delivery vehicles at some waste handling sites could give rise to significantly raised exposures to PAHs in the absence of appropriate ventilation.

Risk assessment

Workers at incineration plants may have slightly higher exposures to PAHs than the general population but the exposures are likely to be insignificant compared with those associated with smoking. There is no evidence that the exposure of incineration workers to PAHs is sufficient to give rise to a significant risk to health and no evidence of a significantly increased cancer risk in incinerator workers. It is plausible that exposure to diesel fume emitted by plant and/or delivery vehicles at some waste handling sites could give rise to increased cancer risks in the absence of appropriate ventilation. Overall, although some workers in the waste industry may experience slightly raised exposures to PAHs, it is highly unlikely that exposure to PAHs is associated with a substantially increased cancer risk in a large number of workers.

8.4 POLYCHORINATED BIPHENYLS (PCBs)

PCBs were widely used as dielectric and coolant fluids, for example in transformers, capacitors, and electric motors but their production was banned by the Stockholm Convention on Persistent Organic Pollutants in 2001 and they have not been widely used since the 1970s.

The health effects that have been reported to be associated with exposure to PCBs in animals include effects on the liver, thyroid, skin, eyes and immune system, reduced birth weight, reproductive toxicity, effects on neurobehavioural development and cancer. There is some evidence of similar effects in human populations with exceedingly high exposures to PCBs following the consumption of PCB-contaminated rice oil but the role of PCBs in giving rise to the observed effects is unclear as these populations were also exposed to dioxins (IPCS 1992, ATSDR 2000, 2011). Studies of PCB-exposed workers have not shown clear cut evidence of adverse effects, except at extremely high levels of exposure sufficient to cause chloracne. There have been no reports of chloracne in waste workers with potential exposure to PCBs.

Exposure to PCBs is possible where certain types of electronic equipment (capacitors and transformers) are recycled and where ultimate disposal of PCBs is undertaken. These procedures are undertaken in specialist facilities and it is anticipated that appropriate exposure control measures would be in place. Accidental exposure to PCBs might occur if PCB containing wastes were accepted by and then handled in facilities that are not dedicated to the waste streams where PCBs would be expected. The main potential route of exposure would be through skin contact. Such events would be expected to be infrequent and long term levels of exposure would be anticipated to be very small.

Overall, it is highly unlikely that workers in the waste industry have significant exposures to PCBs or are likely to develop adverse health effects as a result of exposure to PCBs while working in the waste industry. The health effects of PCBs are related to long term exposure and one off accidental exposures to PCBs are unlikely to have a significant impact on health. In the absence of proper handling procedures, however, significant exposure to PCBs could arise that might give rise to adverse health effects.

8.5 BROMINATED FIRE RETARDANTS

Overview

Commercially used Brominated Fire Retardants (BFRs) that may be present in mixed wastes and WEEE include Tetrabromobisphenol A (TBBPA), Hexabromocyclododecane (HBCD), and three commercial mixtures of Polybrominated Diphenyl Ethers (PBDEs): Decabromodiphenyl Ether (DecaBDE), Octabromodiphenyl Ether (OctaBDE), and Pentabromodiphenyl Ether (PentaBDE). These substances have been widely used in plastics and foams for specific applications and to treat textiles. All of these compounds are extremely persistent in the environment and potentially damaging to plants, wildlife and ecosystems. Most of these substances are now banned for use (PentaBDE, OctaBDE) or have restrictions on their use in Europe (DecaBDE, HBCD). These substances are likely to be present in articles entering the waste chain for many years into the future.

Deca-BDE and TBBPA have mainly been used in electrical and electronic equipment. DecaBDE is also used in plastics that are used in vehicles and in building products such as wires and cables and pipes. Deca-BDE and HBCD are used in curtains, carpets, wall coverings and upholstered furniture in public buildings, public transport and in domestic households. HBCD's main use has been in polystyrene foam insulation boards which are widely used by the construction sector.

Waste workers involved in the recycling of WEEE are most likely to be exposed to BFRs although incidental exposure to BRFs could also occur where MSW is handled.

Health effects

Overview

Wikoff and Birnbaum (2011) have recently reviewed the toxicity of BFRs and this section is a brief summary of their book chapter. The main health effects of concern are related to endocrine disruption. Other potential effects include liver toxicity and adverse effects on neurobehavioural development. Many studies have focussed on the potential of PBDEs to cause disruption to thyroid hormones because of their structural similarity to triidothyronine (T3) and thyroxin (T4).

Effects in animals

Oral or inhalation exposure of animals to PBDEs is associated with toxic effects whereas no toxicity has been observed following dermal exposure. Exposure of rats and mice to PentaBDE or OctaBDE congeners is associated with liver toxicity and associated changes in thyroid hormone levels. Long term oral exposure to very high doses of decBDE has been reported to give rise to liver tumours in rodents and slightly increased incidence of thyroid gland follicular tumours in mice. Neurobehavioral effects have been reported in mice following exposure to several PentaBDE congeners. PentaBDE, octaBDE and decaBDE are not mutagenic.

A number of studies in mice provide suggestive evidence linking PBDEs to developmental neurotoxicity associated with thyroid hormone disruption. Neonatal exposure of mice to decaBDE, for example, was associated with impaired performance in behavioural tests in adult mice.

TBBPA demonstrates low acute toxicity by all routes of exposure in a range of species and is not considered to be irritating to the eye, skin, or respiratory tract.

No adverse effects were observed following oral exposure of rodents to 0.05–1000 mg TBBPA kg^{-1} day^{-1} for 30 or 90 days. No adverse effects on fertility, reproductive performance, development, or neurobehavioral effects were reported in rats in a two-generational study. Some more recent studies, however, have shown that prenatal and postnatal exposure can result in lipid metabolic disorders, hepatic or kidney lesions and changes in behaviour, locomotion, and hearing, although another recent study found no evidence of developmental neurotoxicity The neurodevelopmental effects of TBBPA toxicity is thought to be through disruption of thyroid activity.

TBBPA has produced negative results in several assays of genotoxicity.

HBCD has very low acute toxicity following oral, inhalation, or dermal exposures. It caused mild irritation when applied to the skin of experimental animals but effects were not sufficient for HBCD to be classified as an irritant, corrosive or as a skin sensitiser.

Rats exposed to an oral dose of 940 mg kg^{-1} $day^{-1}$for 28 days developed thyroid hyperplasia. In another 28 day study, rats showed an increase in liver weight and, in females, an increase in thyroid weight at 300 mg kg^{-1} day^{-1}. Both sexes showed changes in serum levels of the thyroid hormones T4 and TSH at a dose of 100 mg/kg-day or higher. A similar 28-day study found that female rats exhibited significant increased absolute liver and thyroid weight and decreased serum T4 levels, with no effects levels of 23, 2, and 55 mg/kg/day, respectively. Exposure of mice to oral doses up to 1,300 mg/kg/day HBCD for 18 months was associated with the spontaneous development of a small number of tumours that were not believed to be linked to the exposure.

A two-generation, reproductive toxicity study on rats suggested a NOAEL of 10 mg/kg/day for HBCD based on decreased fertility index and number of primordial follicles but found no evidence of foetotoxicity, teratogenicity, or adverse effects on pup development. More recent studies have reported effects on pup development including decreased bone density, testis weight, and fraction of nuclear granulocytes and a relationship between neonatal HBCD exposure and adverse effects on neurobehavioural development.

Overall, the animal data suggest that very high levels of exposure to BFRs may be associated with adverse effects on the thyroid or liver in adults and that the exposure of newborn babies to brominated fire retardants may be associated with developmental neurotoxicity. The developmental toxicity may be of concern for children born to mothers with occupational exposure to BFRs.

Humans

There have been a number of studies in humans of the relationship between serum PBDE levels and thyroid hormones. These studies have been conducted in populations with both workplace and with environmental exposure from different places and have not employed a consistent approach to the measurement of PBDE levels or thyroid hormones. There are marked inconsistencies in the findings of different studies, but Wikoff and Birnbaum (2011) concluded that overall the evidence suggests that serum concentrations of PBDEs, and some congeners in particular, are associated with altered levels of thyroid hormones. Many but not all studies have reported a negative correlation between PBDE levels and TSH whereas most studies found no relationship between PBDEs and T4.

One study has reported a weak relationship between serum PBDE levels and diabetes.

Two recent studies have reported an association between PBDEs (assessed in cord blood) and evidence of impaired neurodevelopment in young children, although reported effects were small, not statistically significant for all outcome measures, In addition, the children are likely to have been exposed to other environmental contaminants such as methylmercury that are associated with neurodevelopmental toxicity. Most studies of potential adverse reproductive effects in humans have failed to find a relationship between PBDEs and different measures of reproductive health. One study, however, did find suggestive evidence linking PBDEs with reduced sperm concentrations.

Studies in which volunteers have had skin contact with PBDEs have found no evidence for sensitisation but did report that these substances can cause skin irritation in some individuals.

There are few human data for TBBPA. A volunteer study established that it has a low potential to cause skin sensitisation.

The only human data for HBCD indicate that it is not a skin sensitiser.

Julander et al (2005) measured plasma levels of PBDEs and three thyroid hormones: T3, T4 and thyroid stimulating hormone (TSH) in 11 workers at an electronic recycling facility over a period of 1.5 years. At the start of employment plasma levels of PBDEs 47, 153 and PBDE 183 were 2.8, 1.7 and <0.19 pmol g^{-1} lipid respectively. After dismantling, the corresponding median concentrations were: 3.7, 1.7 and 1.2 pmol g^{-1}., respectively with no significant relationship between PBDE levels and thyroid hormone activity.

Most studies of the effects of BFRs in humans have failed to find significant associations with adverse health effects. Most studies, however, have focussed on populations that are exposed to BFRs in the general environment at much lower levels than may arise in the workplace. In addition, the individuals enrolled in studies are likely to have been exposed to a range of toxic substances and it is difficult to link specific effects to specific pollutants.

Reference Doses

The US EPA has developed oral reference doses (RfDs) for BDEs 47, 99, 153, and 209 that are defined as an estimate of a daily exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime.

BDE 47: RfD = 0.0001 mg $kg^{-1}day^{-1}$ based on decreased habituation in mice in a neurobehavioral study. For a 70 kg adult the daily dose equates to the intake associated with workplace exposure to 0.07 mgm^{-3} over an 8 hour shift, although the efficiency of absorption following inhalation and ingestion may be different.

BDE 99: RfD =0.0001 mg $kg^{-1}day^{-1}$ based on rearing habituation in a neurobehavioral study in mice. For a 70 kg adult the daily dose equates to the intake associated with workplace exposure to 0.07 mgm^{-3} over an 8 hour shift, although, the efficiency of absorption following inhalation and ingestion may be different.

BDE 153: RfD = 0.0002 mg $kg^{-1}day^{-1}$based on spontaneous motor behaviour and learning ability in mice which had a NOAEL of 0.45 mg $kg^{-1}day^{-1}$. For a 70 kg adult the daily dose equates to the intake associated with workplace exposure to 0.14 mgm^{-3} over an 8 hour shift, although the efficiency of absorption following inhalation and ingestion may be different.

BDE 209: RfD = 0.007 mg $kg^{-1}day^{-1}$ based neurobehavioral changes in mice based on no effects level of 2.22 mg $kg^{-1}day^{-1}$. For a 70 kg adult the daily dose equates to the intake associated with workplace exposure to 0.49 mgm^{-3} over an 8 hour shift, although the efficiency of absorption following inhalation and ingestion may be different. The EPA also estimated a cancer risk factor of 7×10^{-4}/(mg $kg^{-1}day^{-1}$) was based on neoplastic nodules or carcinomas (combined) in the liver of male rats in a 2-year experiment.

Exposure

Exposure to BFRs may occur during the processing of WEEE but no significant exposure to BFRs is likely in other sectors of the waste industry. Exposure to BFRs has been assessed through measurements of blood levels in WEEE workers and also through the measurement of BFRs in workplace air.

A number of studies have investigated plasma PBDEs in WEEE recycling workers in Sweden.

Thuresson et al (2006) compared the serum PBDE levels measured in 1997 and 2000 in 12 workers. Although the volume of process waste had doubled, there was a significant decrease in the serum levels of BDE-183 and BDE-209. For BDE-209 the levels observed in year 2000 were even lower than in referents with no occupational exposure. In contrast, there was no significant change in the concentrations of BDE-47. The reduction in serum PBDE levels was attributed to improved exposure control measures (Table 8.4).

Table 8.4: Serum PBDE levels in e-waste workers reported by Thuresson et al (2006)

Serum concentrations (pmol/g l.w.) of six PBDE-congeners in electronics dismantlers in year 2000

PBDE-congener	Laboratory A					Laboratory B				
	Blue collar ($n = 11$)		White collar ($n = 2$)		LOQ	Blue collar ($n = 8$)		White collar ($n = 6$)		LOQ
	Median	Range	Subject 1	Subject 2		Median	Range	Median	Range	
BDE-47	7.3	3.6–110	8.0	4.5	3	4[a]	<4-16	4[b]	–	4
BDE-99	3.0	1.1–23	2.1	1.0	1	3.1[c]	<0.7–6.6	0.7[d]	<0.7–1.2	0.7
BDE-100	2.7	1.1–18	2.2	1.5	1	1.9	0.57–4.6	1.0	0.60–2.3	0.6
BDE-153	7.9	4.6–19	4.3	12	4	5.5	3.0–17	2.1	0.90–5.6	0.9
BDE-183	4.4	1.0–9.6	0.5	2.0	1	7.3	2.4–12	1[e]	<1–1.7	1
BDE-209	2.0[f]	<1–5.4	1.9	5.4	1	3[b]	–	3[b,g]	–	3
l.w. (g)	0.034	0.021–0.047	0.024	0.026		0.041	0.016–0.048	0.034	0.024–0.057	
l.c. (%)	0.57	0.38–0.86	0.62	0.48		0.57	0.27–0.82	0.59	0.46–0.74	

Lipid weight (l.w.) and relative serum lipid content (l.c.), as well as limit of quantification (LOQ) are given. The samples were analyzed at two different laboratories.

[a] Four samples below LOQ.
[b] All samples below LOQ.
[c] Three samples below LOQ.
[d] Four samples below LOQ.
[e] Five samples below LOQ.
[f] One samples below LOQ.
[g] Four samples only.

Julander et al (2005) reported that plasma levels of total PBDEs in 11 workers at an electronic recycling facility at the start of their employment ranged from 2.2 to 60 pmol/g l.w.. The most common congener was PBDE 47 (median 2.8 pmol/g l.w.), followed by PBDE 153 (median 1.7 pmol/g l.w.), and PBDE183 (median value of <0.19 pmol/g l.w). After 1.5 years, the corresponding median concentrations were: 3.7, 1.7 and 1.2 pmol/g l.w., respectively and not statistically significant from the levels measured initially. There was, however, a statistically significant increase in PBDE 28 from 0.11 pmol/g l.w. to 0.26 pmol/g l.w over 1.5 years. Levels of total PBDEs in the most exposed group of workers at the facility (dismantling, 39 workers) ranged from 1.8 to 89 pmol/g l.w, and were not significantly different from levels in workers with no previous exposure,

Two studies of Swedish WEEE recycling facilities have reported air concentrations of PBDEs. Pettersson-Julander et al (2004) measured personal exposure concentrations in 17 samples. The most abundant congeners of PBDE were 209 (<0.7-61 ngm^{-3}) and 183 (<0.1-32 ngm^{-3}) followed by PBDE 99 and 47 (<1.3-25 and <0.9-16 ngm^{-3} respectively). The mean concentration of summed PBDEs was 77 ngm^{-3} (standard deviation 50 ngm^{-3}) for dismantlers compared with 26 ngm^{-3} for other workers at the facility (standard deviation 24 ngm^{-3}) and 2.6 ngm^{-3} (standard deviation 0.3 ngm^{-3}) for an unexposed control group (installing and removing white goods outside of the facilities). Sjodin et al (2001) analysed air samples from a WEEE recycling plant, a factory assembling printed circuit boards, a computer repair facility, offices equipped with computers, and outdoor air. PBDEs and TBBPA were detected in the indoor air samples, with the highest concentrations being detected in air from the recycling plant. In air from the dismantling hall at the recycling plant the average concentrations of decaBDE and TBBPA were 38 and 55 pmol/m^3, respectively. Significantly higher levels of all of these additives were present in air in the vicinity of the shredder at the dismantling plant.

Based on previously published information Schecter et al (2009) calculated that the exposure of US workers to PBDEs at electronics recycling facilities was approximately 6-33 times greater than that of the US general population.

Risk assessment

Workers involved in dismantling WEEE may have higher than background levels of exposure to BFRs but there are no data that suggest that current levels of exposure to BFRs are harmful. Based on the limited published measurement data, the likely exposures of WEEE recycling workers to BFRs would give intakes of PBDEs that are a small fraction of those associated with the oral reference doses developed by the US EPA. Exposures to TBBPA and HBCD are likely to be equally small and there is no evidence that suggests that these substances are significantly more toxic than the PBDEs. Overall, it is highly unlikely that current exposures represent a significant risk to health although there are insufficient data to eliminate the possibility that elevated levels of exposure to BFRs could have a small adverse effect on thyroid function.

8.6 CONCLUSIONS

There is no evidence that the exposure of waste workers to substances such as dioxin, PAHs, CFCs or brominated fire retardants are associated with significant adverse health effects.

9 Infections

9.1 INTRODUCTION

This chapter assess the risk of infectious illness in waste workers handling potentially infected materials. The focus is on workers handling typical mixed municipal wastes or dry recyclate. It is anticipated that clinical waste would be handled by specialist operators who would apply appropriate protective measures to minimise infection risk and that the risk of infection in workers handling clinical waste would be very low. The first part of the chapter assesses the potential health effects that might be associated with exposure to infectious agents in the waste industry. The second and third parts of the chapter assess the risk of exposure to infection and the associated risk to health.

9.2 HEALTH EFFECTS

There is very little information about the incidence of work-related infectious illness in waste and recycling workers. The risk of developing an infectious illness is governed by a combination of factors including the presence of an infectious organism, its virulence, its concentration, the susceptibility of the individual to infection, a route of entry to the body and a mode of transmission (WHO, 2004). It would be anticipated that the highest infection risks would be associated with healthcare waste but the WHO (2004) were only able to identify two reported incidences of the possible occupational acquisition of infectious diseases from healthcare waste. These included an outbreak of tuberculosis among workers at a commercial healthcare waste treatment site in the US that received waste from medical and dental clinics, commercial clinical laboratories and hospitals. The types of waste processed consisted of cultures and stocks of infectious agents, blood, blood products, body fluids, sharps and a small amount of pathological waste.

The WHO (2004) reviewed the infection risks associated with handling MSW. Compared with the general population, solid-waste workers in Denmark had a 6.0 times higher risk of infectious diseases that were associated with elevated levels of exposure to airborne pathogens. An Italian study conducted in 1990 concluded that solid-waste workers had reported a 1.2 times higher risk of hepatitis than found in the general population and the risk increased with duration of employment. More recent studies have also reported suggestive evidence of an increased risk of hepatitis in waste workers. Squeri et al (2006) reported that 32.41% of 327 municipal solid waste workers in Messina (Italy) showed previous exposure to hepatitis B virus (HBV). Dounias and Rachiotis (2006) reported that the prevalence of total antibodies against Hepatitis A virus (HAV) in 72 solid-waste workers was significantly higher than in 79 other municipal workers not exposed to waste. Previously Dounias et al (2005) had reported that the prevalence of biological markers of HBV infection was greater in waste workers than in other municipal workers. However, Tooher et al (2005) concluded on the basis of a literature review that there was no evidence of increased risks of HAV, HAB or tetanus in waste workers. The HSE (1998) reported that there is some evidence of an increased infection rate among sewage workers:

> Each year, some workers will suffer from at least one episode of work-related illness.
> The majority of illnesses are relatively mild cases of gastroenteritis, but potentially fatal diseases, such as leptospirosis (Weil's disease) and hepatitis, are also reported to the HSE. However, there could well be significant under-reporting of cases because there is often failure to recognise the link between illness and work.

It would be anticipated that workers handling MSW would be exposed to some of the same infectious agents and might therefore be anticipated to also have increased risks of infectious illness. Atenstaedt (2010), however, concluded that the potential infection risk that was associated with the presence of disposable nappies in waste, taking account of those from children who are suffering from gastroenteritis was negligible, based on a review of the published literature.

Needlestick injuries could arise in any sector of the waste industry as a consequence of the inappropriate disposal of needles, particularly by drug addicts. The HPA (2008) reported that the risk of infection following a percutaneous injury, especially deep penetrating injuries involving a hollowbore needle or a device visibly contaminated with blood has been estimated at 1 in 3 for Hepatitis B, 1 in 30 for Hepatitis C and 1 in 300 for HIV.

9.3 EXPOSURE

Infection hazards that may be encountered in the collection and sorting of waste and recyclables include:

- Faeces present in nappies, incontinence pads and stoma bags;
- Animal waste (including bedding) produced from litter trays, hutches, pens etc of domestic pets;
- Dead animal carcasses;
- Rodent infestations;
- Bloodborne infectious material within used needles/syringes and drug/sex litter; and
- Broken glass and other sharp items.

Exposure to infectious agents can arise as a result of skin contact, especially through cuts and abrasions including sharps injuries, inhalation, ingestion through hand to mouth contact (e.g. during eating, drinking or smoking) or through contact with the mucous membranes of the eye (HSE, 2007). Specific agents identified by the HSE (2009) include tetanus associated with sharp objects, leptospirosis associated with water, toxocarsis associated with pet faeces, HIV and hepatitis B associated with blood, hepatitis A associated with ingestion of faecal material and Salmonellosis associated with ingestion of faeces or contaminated foodstuffs. The WHO (2004) reported that the microbiological content of MSW and healthcare waste had shown similar concentrations of microorganisms in both types of wastes with 2% of blood-stained waste testing positive for hepatitis viruses and the identification of poliovirus and echovirus recovered from soiled diapers in domestic waste. However, although a variety of pathogens and non-pathogens had been found in solid wastes, the WHO (2004) noted that few of these organisms were likely to survive at the temperatures and pH prevalent in waste. This has been confirmed by later studies. Park et al (2009) studied the types, concentrations and survival of microbial agents in various medical wastes collected from 5 major hospitals in South Korea stored at three different temperatures (-20, 6, and 30 ^oC). A number of (opportunistic) pathogenic bacteria, including Pseudomonas spp., Lactobacillus spp., Staphylococcus spp., Micrococcus spp., Kocuria spp., Brevibacillus spp., Microbacterium oxydans, and Propionibacterium acnes, were identified in various medical wastes. Pathogenic viruses such as noroviruses and hepatitis B virus were detected in one of the human tissue wastes. The results of experimental studies indicated that viral agents such as respiratory syncytial virus showed poor survival in most environmental conditions, and demonstrated that various pathogens could be present in medical wastes but that the associated health risk appeared to be low. SNIFFER (2007) indicate that hygiene waste including sanitary towels and tampons, incontinence products and nappies, catheter and stoma bags, animal faeces and bedding would not normally be associated with a significant risk of infection. Although, where hygiene waste is generated from the care of people with infectious illnesses such as E Coli, it should be treated as clinical waste, implying that such material would be considered an infection hazard. By implication, the normal practice of disposing of nappies and other personal care items with other household waste could be associated with a small increased risk of gastrointestinal illness for waste workers, although in the vast majority of cases, the infection risk would be very low.

Where potentially infectious wastes are segregated at source (e.g. healthcare providers), it is relatively easy to control subsequent workplace exposure to potentially infectious material. Tudor et al (2010) reported that none of four microbial infections that are of particular concern in hospitals (meticillin resistant Staphylococcus aureus (MRSA), meticillin sensitive Staphylococcus aureus (MSSA), Clostridium difficile (C. difficile) and vancomycin-resistant enterococci (VRE)) were found in waste. They concluded that when the waste is properly managed, infection risks are minimal. The main potential for exposure to infectious material associated with clinical waste may be associated with process problems at specialist incinerators or other treatment facilities that could lead to workers entering areas or equipment where untreated wastes are contained. Given the specialist nature of such facilities and the offensive nature of the waste, it seems unlikely that workers would undertake such tasks without using appropriate PPE and the potential for exposure should be small.

Many waste materials that contain infection hazards enter the domestic waste chain and infection risk may be more difficult to control than during the collection and disposal of clinical wastes. Low levels of exposure to infectious material is possible during waste collection and transfer operations but more significant exposures could occur on picking lines at MRFs handling general household and commercial wastes. SNIFFER (2007) report that the average absorbent hygiene product content of MSW is 2.3% suggesting that a significant quantity of potentially infected material could be present in some of the wastes handled by MRFs and other waste sorting facilities. In addition, ineffective waste handling procedures in hospitals or other places where clinical waste is generated could lead to clinical waste entering nonclinical waste streams. The risk of infection is likely to be increased by the presence of sharps in the waste including needles, broken glass and other sharp materials.

The HSE (2008) recommend a number of control measures intended to minimise the risks for waste and recycling workers:

Adequate lighting, work rate and workplace design to enable pickers to safely remove materials;

The tracing of the source of unacceptable quantities of offensive/hygiene waste in order to resolve waste classification and disposal issues;

Systems in place to deal with unexpected material that appears on the picking line and spills, seepage or contaminants from offensive/hygiene waste;

Provision of appropriate equipment to prevent worker contact with waste;

Training and worker awareness including awareness of symptoms and procedures in event of accidental exposure;

Clearly defined personal hygiene regime and provision of adequate washing facilities;

Use of appropriate protective clothing, especially gloves and safety boots.

Reporting any cases of ill health to the organisation's occupational health department.

Where effective vaccines are available against microorganisms to which employees may be exposed (for example, tentanus), then employers are required to make them available, free of charge, to employees.

A clearly defined post-exposure procedure should be in place including seeking occupational health advice.

Needles and needle stick injuries present a particular hazard for waste and recycling workers as drug users may not dispose of needles in an appropriate manner and isolated needles can turn up in all types of waste. The HSE recommend a range of risk control measures including the use of suitably strong gloves, puncture-proof clothing, adequate first aid equipment to ensure wounds are promptly cleaned and good worker awareness of the hazard and how to manage the risks. Blenkham and Odd (2008) reported that sharps injuries among the waste handlers working for a single specialist waste disposal company occurred at a rate of approximately 1 per 29 000 man hours. Injuries were caused by hypodermic needles from improperly closed or overfilled sharps boxes (n = 6) or from sharps incorrectly discarded into thin-walled plastic sacks intended only for soft wastes (n = 34). Although, no seroconversions occurred, two individuals suffered anxiety/stress disorder necessitating prolonged leave of absence with professional counselling and support.

9.4 RISK ASSESSMENT

It is assumed that clinical and hygiene wastes would be appropriately handled by specialist workers such that no significant infection risks are associated with the handling of clinical waste. It is very difficult to determine the infection risks associated with handling other waste types. The risks of accidental exposure to infected faecal material or blood stains are relatively high for workers who are hand picking unsorted wastes that are likely to contain nappies, other waste hygiene products and other petcare wastes and may more rarely contain hazards such as infected needles. Accidental exposure to these potential infection hazards may also occur where workers are handpicking source segregated risks as some members of the public will place such items in any bin as opposed to the appropriate bin. A number of relatively simple control measures can be implemented to minimise the risk of exposure including the use of gloves and good personal hygiene practice. There is also a risk of exposure to airborne dust containing infectious agents at plants where these waste types are handled.

There is a small amount of evidence that suggests that waste workers are more likely to develop infectious illness than other members of the population but the increase in risk of infectious illness would be appear to be relatively small. Many pathogenic organisms have a limited survival under the conditions that are likely to be present in different waste types and the numbers that enter a waste worker's body may be too few to sustain an infection. Several reviews (SNIFFER, 2007; Atenstaedt, 2010) have concluded that the infection risks associated with hygiene waste are low and do not justify the treatment of these wastes as clinical (i.e. infectious wastes) or differently from other municipal waste.

9.5 CONCLUSIONS

Workers in the waste industry may be at slightly increased risk of developing infectious illness. The risks can be minimised through relatively simple control measures including good personal hygiene. It is likely that workers' attitudes towards personal hygiene will be variable, particularly if they are working in a "dirty" environment and habituate to a low standard of cleanliness. In addition, not all sites currently provide appropriate washing and changing facilities. Needlestick injuries are of particular concern as sharps may turn up in all types of waste as a result of inappropriate disposal. All workers should use appropriate gloves to prevent needlestick injuries when handling waste materials and procedures must be in place to minimise infection risks following any sharps injuries that do arise.

10 Risks from Heat Illness in the Waste Recycling Industry

10.1 INTRODUCTION

Those employed in the waste industry may be exposed to sources of heat or work factors that cause an increase in core body temperature. These include high ambient temperatures from sources such as incinerators, composters or anaerobic digesters but consideration must also be made of the potential for increased heat loading from protective clothing, RPE, high physically demanding jobs or a combination of all these factors. Before discussing the risk factors, the following section is an introduction to thermoregulation and the impact of increasing body temperature summarised from Rodahl (1989), Youle et al (1996) and Youle et al (2009), The potential risks in waste and recycling are discussed in the second part of the chapter.

10.2 THERMOREGULATION AND HEAT BALANCE

Human beings are generally in a state of thermal comfort when their core body temperature is between 36.6°C and 37.1°C. If an individual's temperature deviates by ±2°C this can have an impact on both physical and mental performance. The human body reacts to changes in ambient environmental temperature through a number of different physiological processes called thermoregulation.

The process of thermoregulation in the human body is controlled by the hypothalamus in the brain and the temperature of the blood flowing in this area. A number of thermosenors within the skin, deeper tissue and the central nervous system provide feedback to the hypothalamus. If the core temperature increases, this can result in the onset of increased blood supply to the skin to reduce temperature (vasodilation). The next step will be the onset of sweating which allows the body to cool more quickly as the sweat evaporates from the skin. The reverse is true for exposure to cold where the response will be for the blood to be pulled into deeper body areas and if the core temperature decreases for shivering to begin. Behaviour is also a factor in this system where either removing clothes or putting clothes on can either reduce or increase temperature.

The core temperature aims to maintain equilibrium through thermoregulation and this is described by the heat balance equation

$$M \pm W = \pm K \pm C \pm R - E \pm S$$

M is the metabolic rate
W is the external work
K is the heat lost or gained by conduction
C is the heat lost or gained by convection
R is the heat lost or gained by radiation
E is the heat lost by evaporation
S is the rate of change of heat stored by the body

The main method of heat loss in humans is through evaporation of body sweat. Although heat can be lost by conduction, convection and radiation; most is lost through evaporation. Sources of heat can include radiant sources such as the sun or other sources of flame, conduction from radiators or convection from fan heaters.

10.3 THE PHYSICAL AND MENTAL IMPACT OF INCREASING TEMPERATURES

Although increasing ambient temperature can increase the core temperature of an individual, core body temperature can also be increased by factors such as clothing, wearing RPE, working in confined spaces and high physically demanding work. When an individual's core temperature increases, the blood available has to both transport oxygen and transport heat from the body core. This results in a limitation on the level of oxygen available as temperature regulation appears to have priority over oxygen transport. To ensure adequate oxygen delivery, the heart rate increases to pump blood more quickly around the body. However, due to the increase in heart rate, fatigue comes on more quickly especially when carrying out highly physically demanding jobs in hot temperatures. There is also a reported increase in lactic acid in the muscles when working in hot conditions which is potentially as a result of reduced muscle blood flow in the heat.

The impact of increasing body temperature on mental performance has been difficult to assess. Youle *et al* (1996), report that as ambient temperature increases, people become comfortable and sleepy. However, with increasing temperature individuals become irritable, very aware of the conditions but concentration does improve. However, should the ambient temperature continue to increase, at high temperatures, levels of concentration reduce. Rodahl (1989) suggests that the upper limit for optimal mental performance is 25°C.

10.4 WHAT IS HEAT STRESS /HEAT ILLNESS?

As mentioned previously there is a narrow range of temperatures at which the human body has to be maintained. When the core temperature increases above this range the impact can be seen by a number of physiological responses. These can be less serious issues such as prickly heat; a skin rash which occurs when sweat cannot evaporate or heat syncope where fainting occurs due to standing for long periods and the associated drop in blood pressure. Off course if fainting occurs, the environment in which the individual faints may be a risk factor for injury.

Hyperventilation has also been seen in individuals wearing PPE in hot environments. It has been suggested that over breathing occurs due to anxiety in the individual and can result in muscle spasms and tingling feelings in the hands and feet. In this case the immediate solution is to remove the individual from the source of the heat and ask them to re-breathe into a paper bag.

More serious symptoms of heat illness occur as a result of water or electrolyte imbalance. Dehydration of fluid from the body can result in symptoms 24 hours following heat exposure. Dangerous levels of dehydration (more than 10% of body weight) can result from physically demanding work in hot conditions. Less serious dehydration of 5% of body weight will be accompanied by feelings of thirst irritability and fatigue. It is recommended for individuals in this situation that drinks are made available throughout and after periods of work.

The most serious form of heat illness is heat stroke. This is defined as when the core body temperature reaches 41°C and is associated with a number of serious health symptoms including convulsions, coma or a hot dry skin. This can be preceded by warning symptoms including confusion, irritation and feeling dizzy. In this situation treatment must start immediately to try and reduce core body temperature to 39°C within an hour.

10.5 RISK FACTORS FOR HEAT ILLNESS

A number of different factors increase the risk of heat illness occurring in the workplace. These are discussed below.

Age
As we age, our tolerance to heat reduces and this is thought to be due to the reduction in efficacy of the cardio respiratory system (Crawford *et al* 2010). As we age our cardiovascular system becomes less efficient and this is reflected in a reduction in our physical fitness. It is thought that this reduction in efficiency causes the reduction in heat tolerance rather than an increased risk due to age alone. Thus when employing workers over 50 years old to the exposures listed below, consideration should be made of the impact of exposure on health.

Weight and Physical Fitness
Body weight and physical capacity also have an impact on our ability to withstand exposure to heat. Individuals who are overweight and/or physically unfit are at an increased risk of heat illness when exposed to hot conditions or other risk factors including working in confined spaces and wearing protective clothing and PPE or RPE.

Ill Health
Ill health can also contribute to heat illness. These include symptoms such as vomiting and diarrhoea, colds and flu and heart disease. Furthermore, skin disorders such as eczema may also be

made worse through exposure to heat. Other diseases which may affect heat tolerance include thyroid disorders and type II diabetes. Wick *et al* (2006) carried out a case controlled study of 20 participants and measured vasodilation for individuals with Type II Diabetes versus those without diabetes. The results identified that the onset of vasodilation took significantly longer in individuals with Type II Diabetes with a significant increase in core temperature before the onset of vasodilation. Individuals with Type II Diabetes appeared to have altered thermoregulatory control that may increase the risk of heat illness within this particular group.

Medication

The use of medicines can also impact on the ability to maintain heat balance. These include prescribed medication such as some anti-depressants and barbiturates and non-prescribed drugs including alcohol and illegal drug use. Youle *et al* (1996) present a table of potential interactions between drugs and thermal tolerance (Table 10.1). Employers are unlikely to be aware that individuals have been prescribed medication or have used other substances which may impact on their ability to deal with exposure to heat.

Table 10.1: Potential interactions between drugs and heat tolerance (Youle *et al* 1996)

Drug	**Action on Thermoregulation**
Alcohol	Inhibition of central nervous function. Impairment of behavioural thermoregulation and judgement
Antidepressants e.g., tricyclic's	Hyperthermia with high doses especially in combination with other agents e.g. amphetamines
Hypnotics e.g., barbiturates	Central nervous depressant. Body temperature increases in hot environments. Effects augmented by alcohol.
Psychotropic e.g., phenothiazines	Hyperthermia in high ambient temperature. Central effect on thermoregulation with possible peripheral actions
Cannabis	Hyperthermia in hot environments
Morphine	Hyperthermia with low doses
Amphetamines	Central nervous stimulant. Vasoconstriction, increased peripheral heat production
Anaesthetics	Central nervous depression of thermoregulatory centres. Hyperthermia in hot environments.
Cocaine	Overdose may result in heat stroke
Anticholinergenics e.g. atropine	Atropine fever, effects on thermoregulatory centres. Inhibition of sweating
Organophosphates e.g., pesticides	Potential heat stroke via alteration of set point

Clothing

The type of clothing worn by individuals will impact on their ability to maintain thermal balance. Where there is a requirement to wear protective clothing, this can impede heat loss and cause core body temperature to increase due to the insulation qualities of the clothing. Thus careful monitoring is required of individuals working wearing insulated clothing as heat build-up can occur while carrying out physically demanding work without the additional exposure to heat. There are methods of measuring the insulative value of protective clothing using a measure called the Clo. A Clo unit is the level of thermal insulation that will keep a resting individual comfortable in an ambient temperature of 21°C; this approximates to wearing a business suit in an office environment.

PPE/RPE

The use of PPE or RPE again may be a requirement in certain working environments. Again, the wearing of protective equipment or the use of respiratory protective equipment can add further physiological loading to the individual worker. Thus core temperature can increase again while physically working and wearing protective equipment without additional heat exposure. In addition PPE can be cumbersome to wear and make movement difficult within the workplace.

10.6 EXPOSURE RISKS

Exposure to heat from in-door sources

Exposure to ambient temperature e.g., above >20 °C while carrying out physical work can result in an increase in core body temperature. It is unlikely that many waste plants have temperature controlled environments, so individuals will be working in an environment which will vary in temperature and relative humidity dependent on outside conditions and the levels of heating available. The amount of heat gain will also vary dependent on the levels of physical work and the requirement to wear protective clothing or respiratory protection.

Furthermore when employees are exposed to additional heat sources in the indoor environment from incinerators or anaerobic digesters this can add to the heat loading of the individual worker. Although it is appreciated that with the design of many modern plants, employees may be shielded from sources of heat, this cannot always be assumed. Thus in environments when the air temperature is higher than 20°C, risk assessment and control measures should be made to ensure that heat gain is controlled via risk assessment and if necessary control measures.

Exposure to heat from outdoor sources

Although temperatures in the UK rarely reach high levels, exposure to outdoor temperatures of above 2O°C are becoming quite common in some areas of the country. While individuals working with machinery may be in air-conditioned cabs, this may not always be the case for all individuals working outside. Again, the level of physical work, the use of protective clothing and/or the use of respiratory protection can result in heat gain by the employee. For example, an individual working in the outdoors in summer at an HWRC or transfer station may be exposed to high levels of radiant heat. While working in this environment, heat gain may occur due to both the physical requirements of the job and the requirement to wear protective clothing.

During maintenance work

A number of waste handling processes either involve thermal treatment and/or generate heat, e.g., incinerators, composters or anaerobic digesters. Maintenance (whether planned or unplanned) may be undertaken during the operation of the process, or if stoppages are unavoidable, there is likely to be a desire to minimise downtime. Workers may be exposed to heat while carrying out maintenance work, for example, dealing with a blockage or other process failure at an incinerator. The potential for exposure to heat will depend on whether adequate time can be allowed for the process to cool down. If a cooling period is not possible, individuals may be exposed to heat, while wearing PPE carrying out heavy physical work (for example, to remove a blockage) and/or in a confined space.

The impact of wearing PPE and working in confined spaces to carry out maintenance work may have an impact on heat gain without the addition of increased ambient temperature. The lack of ventilation within a confined space reduces the body's ability to lose heat through evaporation. Where maintenance work is undertaken at raised ambient temperatures, for example, near to an anaerobic digester, the potential for heat loading may be from two sources. The use of protective clothing and the need for physical work has the potential to increase core temperature quickly.

It is clear that there is the potential to increase core body temperature from a variety of sources in the waste and recycling industry. These include the ambient temperature, exposure to heat sources, wearing of protective clothing, wearing of respiratory protection and the work rates that individuals are required to work at.

Risk assessment and control measures

As shown previously, increasing core temperature can occur as a result of a number of different workplace factors including exposure to heat, wearing of PPE or RPE and levels of physical activity. The HSE have provided a checklist which is available at http://www.hse.gov.uk/temperature/thermal/measuringthermalcomfort.pdf

The checklist allows people to identify if there are potential risks in their workplace and if more than two boxes are ticked, then a more in-depth risk assessment should be carried out.

The use of the checklist will identify if there are problems within the working environment but further risk assessment is required using the HSE model which is available here http://www.hse.gov.uk/temperature/information/heatstress/riskassessment.pdf

As can be seen from the risk assessment the process of identifying risks is clear with the first stage of identifying potential hazards including accidents and sickness absence; is there a pattern in warm weather or after exposure to heat? Also reviewing the work process and identifying if there is exposure to heat from radiant sources, increased relative humidity from any sources of steam, the use of PPE and the use of impermeable protective clothing.

The second stage of the risk assessment is identifying the individuals who may be exposed to harm. In the case of heat this can include older workers, those with health problems or using medication or inexperienced workers who may require training. The frequency of heat exposure should also be assessed as workers may only be exposed infrequently but it is likely that training would still be required to ensure safe working.

Consideration should also be made at this point of procedures that are in place should something go wrong; such as someone collapsing with heat illness in a confined environment. What emergency procedures would be necessary to evacuate an individual quickly and safely from a confined space? Do the emergency procedures include access by emergency workers to the site?

The following stage of the risk assessment process is the evaluation of current procedures and work processes. Firstly the timing of the work and in relation to waste and recycling; can the working time be changed to a cooler part of the working day if the individual is exposed to high external temperatures. It is appreciated this consideration may not happen all year round in the UK and may only be for a few days in any one year.

Alternatively, if the task is related to maintenance work on a process, can cooling occur of the surrounding area to remove the risk of exposure to heat? Thus, when possible, the process is allowed to cool to remove the risk of ambient heat exposure. Again, this may not be possible depending on the process involved as cooling could stop the process being completed. In this case further risk reduction measures such as clothing or work rest scheduling can be considered.

The types and rate of work carried out should also be assessed to identify if the speed of working is too great for the environmental conditions. The fact that increased physical activity can increase core temperature should be a consideration when temperatures increase. If this occurs in the internal environment, further risk reduction measures can include; improving the ventilation and air-flow through the building.

In reducing the risks from increasing core temperature, it is appreciated that each site or type of process may have different requirements therefore, other work procedures may be more beneficial. These include the use of worker rotation into and out of hot environments ensuring that breaks between hot work periods are adequate to reduce core temperature and fluids are available rehydrate the individual.

The use of PPE such as insulated clothing can be seen as a control measure when individuals are exposed to heat. However, the use of such clothing can also be a potential hazard in relation to heat gain so the implementation of clothing as a control measure should be closely monitored.

Training needs for workers should also be identified whether this is in working procedures in hot environments, the use of PPE, the use of RPE or a combination of all factors. Although it is appreciated that not everyone will be exposed to risk factors to increase core temperature, awareness across the workforce should be achieved to ensure all employees know how to respond should a colleague be showing signs of heat illness.

The first-aid and emergency procedures should also be assessed to ensure that the measures set out are workable within the particular working environment. Again all employees should be made aware of the processes and facilities available.

Should exposure to heat be causing a problem to employees, a quantitative risk assessment can also be carried out. The Wet Bulb Globe Temperature Index (WBGT) is an accepted measure, which is used to evaluate the heat stress to which an individual is exposed. The measures include air temperature, black globe temperature and natural wet bulb temperature. Its use includes both indoor and outdoor heat exposures, which can be calculated using the formula provided. The WBGT is a tool that is used to identify if there is a problem within the working environment. Comparing the measures made to reference values including the metabolic load of the individual will give a quantitative measure of risk when exposed to higher temperatures.

Health assessment of individual workers may also be recommended depending on the frequency and duration of the exposure to heat. Bearing in mind the risk factors during heat exposure including age, ill-health such as diabetes or thyroid problems and the use of medication, employees may require screening and education in relation to heat exposure.

10.7 CONCLUSIONS

Exposure to hot environments may be a result of working in the outdoor environment or indoors where sources of heat exist such as incinerators, anaerobic digesters and composters or in confined spaces. In this context “hot” may refer to temperatures as low as 20^{o}C. The use of PPE and RPE to protect the worker from chemical and biological hazards increases the physiological load on waste workers. Workers undertaking even relatively gentle physical tasks such as sampling at compost sites or handpicking at MRFs may be at risk of heat related illness on a warm day because of the requirement to wear coveralls. The risks are considerably greater for those undertaking more active tasks such as shovelling or sweeping spilt materials. Similarly, workers are at a relatively high risk of experiencing heat related illness if required to undertake maintenance tasks on hot equipment, particularly if this requires entry into a confined space. Operational pressures may lead to workers undertaking maintenance tasks before equipment has completely cooled. Individual workers vary considerably in their susceptibility to heat. Relevant risk factors identified within waste and recycling include individual factors such as age, health status, physical fitness and use of medication. To control the risks from working where there is a physiological heat load, a risk assessment can be carried out and including a basic risk assessment to identify hazards, a qualitative observational risk assessment and a quantitative risk assessment. As with all risk assessments, the process should be documented and evaluated when there is a change in personnel or process. Heat related illness is a potential issue for most types of waste treatment process, particularly in the warmer ambient conditions of the southern part of the UK. There are no published reports that suggest heat related illness is a major problem in the waste industry or that serious cases of heat related illness are common. It is likely that the risks of heat related illness at ambient temperatures are underappreciated and possible that heat contributes to a significant burden of minor ill health and reduced well being associated with workers being uncomfortably warm for a significant proportion of the working day. It is also possible that heat is contributing to increased risks of more serious illness such as cardiovascular problems that are not attributed to the working environment.

11 Overall risk assessment and recommendations

11.1 INTRODUCTION

This chapter is based on the preceding chapters that address individual hazards and presents a risk assessment by process. The final part of this chapter includes a discussion of the factors that may lead to increased risks of ill-health in the waste industry, a summary of the conclusions of the study and some recommendations in relation to the substantial gaps in knowledge that this study has identified. The processes considered are:

Landfill;
Anaerobic digestion;
Composting – open windrow;
Composting –indoors;
High temperature incineration;
Pyrolysis, plasma, gasification;
Auto-clave;
Materials recovery facilities (MRFs) including trammel mills and screens;
Mechanical biological treatment (MBT);
Household waste recycling centres (HWRC) and transfer stations;
Glass, plastic and wood separation plants;
Waste electrical and electronic equipment (WEEE) recycling;
Fridge recycling;
Metal crushing and aluminium separation; and
Paper and cardboard baling.

11.2 RISK ASSESSMENT BY PROCESS

Landfill

The requirement to control environmental emissions of dust and explosion hazard at landfill gas means that workplace exposures to dust, bioaerosol and toxic components of landfill gas are generally well controlled with little associated risk to worker health. Elevated exposures to dust are possible, if workers spend a significant part of their working day doing activities such as processing construction waste and/or operate plant that does not have a sealed cab with air filtration. If elevated exposures to dust do occur, then there may be an associated increase in the risk of developing chronic respiratory illness. Where there are gas management problems leading to above background exposure to malodorous components of landfill gas, it is possible that exposure to malodour could contribute to negative well-being but exposures to individual components of landfill gas are likely to be extremely small in relation to thresholds for toxic effects, even allowing for the possibility of additive effects.

Anaerobic Digestion

The exposures of most concern associated with anaerobic digestion are dust and bioaerosol associated with handling waste prior to treatment. Given that dust levels may only be controlled to meet the general limits on respirable and inhalable dust, it is likely that current exposures to organic dust and bioaerosol where relatively dry organic wastes are handled exceed the threshold levels for the development of respiratory symptoms at some plants. These elevated exposures to organic dust will give rise to increased risks of chronic respiratory illness. Factors that are likely to lead to increased risks of respiratory illness would include waste handling procedures that are not entirely enclosed and workers being within the same space as the waste as opposed to working inside a sealed and ventilated cab. In the absence of adequate containment, significant bioaerosol exposures may also arise during the handling of wet wastes such as animal and food wastes. This is likely to lead to increased risks of chronic respiratory illness and potentially other effects such as fatigue and gastrointestinal disturbances. Exposure to microbial VOCs is likely to contribute to the development of respiratory symptoms. Where waste has been stored for a number of days as a result of process problems, it is likely that bioaerosol exposures would be higher than when fresh waste is handled rise to increased risks of respiratory symptoms and other effects including fatigue and nausea. Where workers are not working in an air conditioned cab or workplace, mild heat stress may be an issue during warm weather as a result of the requirement to use coveralls possibly combined with RPE.

Workers with pre-existing respiratory conditions such as asthma or who are previously sensitised to moulds are at particular risk and may experience an exacerbation of symptoms at very low exposure levels. It is probable that workers with increased susceptibility leave the industry because their symptoms become intolerable. Allergic illness is likely to be a significant issue for workers who remain in post for periods of months to years. About 5% of the population are sensitised to common moulds and a greater proportion of the population are atopic (have an increased likelihood of developing allergies) and are at increased risk of becoming sensitised. Any workers with compromised immune function (for example, due to medication) are also at risk of aspergillosis.

Workers are unlikely to experience high levels of exposure to process emissions (biogas). The requirement to control methane levels to well below the lower explosion limit is likely to result in exposures to other potentially hazardous substances to very low levels. No significant adverse effects would be expected to arise as a result of exposure to toxic process emissions, even in the event of process problems that could lead to aerobic conditions within the digestor.

Workers at anaerobic digestion plants are likely to be exposed to odour with very high levels of exposure possible if wastes are inadequately contained prior to processing or process problems arise. This may contribute to symptoms such as headache, fatigue and nausea and may have a negative impact on well-being. The potential harmfulness of exposure to malodour is often under-rated as the concentrations of individual substances in air are well below the levels that might cause toxicity.

In conclusion, if wastes, process and product are well contained and appropriate extraction and air treatment is in place, exposures to dust, bioaerosol and other substances should be controlled to levels at which no significant adverse effects would be anticipated. Where processes are only partially contained, bioaerosol exposure during initial waste handling activities would be associated with increased risks of chronic respiratory illness and a range of short term effects including respiratory symptoms, fatigue and gastrointestinal disturbances. Where relatively dry materials are handled dust exposures may be sufficient to cause chronic respiratory illness, even where concentrations are controlled to well below the UK exposure limits for “inert” dusts.

Composting (open windrow and in tunnels)

The exposures of most concern associated with composting are dust and bioaerosol. Based on our previous work for Defra (Searl, 2010), it seems likely that if dust levels are controlled below the lowest levels associated with adverse effects in workers exposed to organic dust (about 0.2-0.3 mgm^{-3}), it seems likely that the exposures to bioaerosol would also be reasonably well controlled. Where waste has been stored for a number of days, however, as a result of process problems, it is possible that elevated bioaerosol exposures could arise at even lower levels of dust exposure giving rise to increased risks of respiratory symptoms and other effects including fatigue and nausea. It is likely that current levels of exposure to dust and bioaerosol at many sites exceed the threshold levels for the development of respiratory symptoms and increased risks of chronic respiratory illness. Exposure to microbial VOCs is likely to contribute to the development of respiratory symptoms and the associated exposure to malodour could also be associated with negative effects on well-being.

Factors that are likely to lead to increased risks of respiratory illness and other adverse effects at outdoor sites would include; elevated exposures arising while workers are operating machinery such as excavators with the cab windows open or not employing cab filtration if the windows are closed, operatives working outdoors operating screening or other fixed equipment (e.g. bagging operations) that is not fully contained, shovelling or sweeping spilt material or taking samples of partially processed waste or product. Dust exposures are likely to be particularly high if the product is allowed to dry out. Although exposure to dust and bioaerosol may be reduced by the use of appropriate RPE, it is essential that this is face fit tested for the individual and the mask and that there is good compliance in its use, which may be difficult to achieve in hot summer weather. Where workers are not working in an air conditioned cab or workplace, mild heat related illness may be an issue during warm weather as a result of the requirement to use coveralls possibly combined with RPE.

Factors that are likely to lead to increased risks of respiratory illness and other adverse effects at where composting processes are conducted indoors are similar to those associated with outdoor operations, although it may be possible to largely eliminate exposure through process containment if appropriate extract ventilation is in place. Levels of exposure to dust and bioaerosol may be particularly high, if air is recirculated within the building without adequate treatment to remove bioaerosol and dust rather than extracted to the outdoor environment. Concerns about community exposure that have led to the enclosure of composting processes are likely to have led to much greater levels of worker exposure to dust and bioaerosol with an associated increased risk of serious respiratory illness. It seems likely that exposures to dust and bioaerosol at indoor composting plants could be substantially higher than those associated with outdoor operations, but there will be substantial site to site variability reflecting differences in processes and procedures, ventilation and air handling arrangements, housekeeping and the incoming waste.

Repeated exposure to bioaerosol at composting operations could lead to workers developing hypersensitivity pneumonitis similar to that traditionally known as farmers' lung. This is a disabling disease associated with serious damage to the lung and the development of severe respiratory symptoms in response to further exposure. It is likely that compost workers' lung will emerge as a new occupational illness within the next few years. At sites where exposures to dust and bioaerosol are particularly poorly controlled, it is possible that workers could develop organic dust toxic syndrome which is a short lived 'flu-like syndrome triggered by particularly high exposures to organic dust.

Workers with pre-existing respiratory conditions such as asthma or pre-existing sensitisation to moulds may experience an exacerbation of symptoms at very low exposure levels and allergic illness is likely to be a significant issue for workers who remain in post for periods of months to years. It is probable that workers with increased susceptibility leave the industry because their symptoms become intolerable. Any workers with compromised immune function are at risk of developing aspergillosis.

Where workers are not working in an air conditioned cab or workplace, mild heat related illness may be an issue during warm weather as a result of the requirement to use coveralls and RPE.

High temperature waste treatment processes

Municipal solid waste (MSW) and other wastes may be treated by incineration, pyrolysis, gasification and plasma treatment. Most of these processes are relatively new within the UK and are conducted in modern plants with a high level of automation and containment and minimal potential for worker exposure to waste, emissions from waste or emissions from the waste treatment process.

Exposure to organic dust and bioaerosol are possible in the waste reception and storage areas and any pre-combustion handling of waste. Particularly high levels of bioaerosol emission may result from the prolonged storage of waste prior to treatment. In a modern plant where processes are highly automated and contained, workers would not normally be in areas where dust and bioaerosol concentrations are raised. At older, less automated plants, workers may be exposed to dust and bioaerosol while moving waste using equipment such as a mechanical excavator or operating equipment such as conveyers or any shredding or grading processes undertaken prior to combustion. The results of exposure modelling suggest that exposures to dust should, however, generally be below levels associated with increased risks of respiratory illness in workers exposed to organic dust. As with anaerobic digestion and composting exposures to bioaerosol will depend on the nature of the waste and the time period over which it has been stored. Based on our previous work for Defra (Searl, 2010), it seems likely that if dust levels are controlled below the lowest levels associated with adverse effects in workers exposed to organic dust (about 0.2-0.3 mgm^{-3}), it is likely that the exposures to bioaerosol would also be reasonably well controlled. Where waste has been stored for a number of days, however, as a result of process problems, it is possible that elevated bioaerosol exposures could arise at relatively low levels of dust exposure giving rise to increased risks of respiratory symptoms and other effects including fatigue and nausea. Elevated exposures to dust and bioaerosol are likely to arise during cleaning and maintenance operations at both older and modern plants, although exposures can be controlled through the appropriate use of PPE. It is possible that frequent equipment failures could lead to repeated exposures and a lower level of compliance with PPE use, giving rise to shift mean exposures that would be sufficient to give rise to respiratory symptoms in some individuals and/or contribute towards increased risks of developing chronic respiratory illness.

Significant exposure to airborne dust could occur where workers are handling air pollution residues (flyash) or bottom ash from incinerators. Although exposure levels would be anticipated to be negligible during routine plant operation, significant exposure to airborne dust could occur during cleaning and maintenance operations. Where process problems lead to the frequent entry to confined spaces in order to clear blockages in the equipment handling ash, it is conceivable that shift mean exposures to dust could exceed the 10 mgm^{-3} inhalable dust limit and even where this limit is not exceeded, exposure levels could be sufficient to give rise to significantly increased risks of chronic respiratory illness. There is a small risk that elevated dust exposures could give rise to elevated exposures to hazardous metals, particularly lead, and other hazardous substances. Even where exposures to individual metals may be below the relevant WELs, there is a possibility that exposure to the mixture could give rise to additive adverse effects on liver or kidney function or the CNS. Limited published data confirms that cleaning and maintenance operations at incinerators are associated with elevated exposures to hazardous substances such as metals and PCDD/Fs but does not suggest that exposure levels are likely to be sufficient to cause adverse effects. Given the potentially toxic nature of the residue from thermal treatments, it is probable that workers undertaking cleaning and maintenance operations would be using appropriate PPE that would ensure an acceptable level of exposure control. The risks of over-exposure may be increased if frequent breakdowns lead to carelessness in PPE use.

The exposures to airborne dust associated with handling other residues from pyrolysis, gasification and plasma technologies are anticipated to be much lower than for incineration residues as these processes produce slag rather than ash.

Workers with pre-existing respiratory conditions such as asthma or a pre-disposition to develop allergies are at particular risk of developing respiratory symptoms as a result of exposure to airborne dust. They may experience an exacerbation of symptoms at very low exposures to dusts, and particularly in relation to bioaerosol as described above for composting/anaerobic digestion. These individuals are likely to experience an exacerbation of symptoms on exposure to any dust type including dusts generated by waste treatment residues as well as organic dusts.

Exposure to heat is likely to be well controlled during the normal operation of thermal treatment plants but frequent breakdowns may contribute to an increased risk of heat-related illness, if operational pressures lead to workers undertaking maintenance operations before equipment has cooled down.

In conclusion, the risk to health associated with working at a modern high temperature thermal waste treatment plant are small, provided that processes are appropriately contained and that appropriate PPE is used during cleaning and maintenance operations. There may be a significant risk of high levels of bioaerosol exposure at older plants associated with waste reception and storage if these areas are not entirely enclosed with remotely operated handling processes. These exposures are likely to be associated with increased risks of chronic respiratory illness and the development of allergic disease. There is a risk that workers at both older and modern plants will develop chronic respiratory illness, if they have frequent high dust exposures arising from the requirement to undertake unplanned cleaning and maintenance operations, if there are frequent equipment failures.

Auto-clave

Autoclave processes are contained and waste gases are subjected to treatment such that exposures during routine operation are negligible. The processed waste is sterile and unlikely to be particularly dusty. Process problems could lead to short term exposure to process emissions that could cause short term respiratory effects in some individuals, particularly in those with asthma or other pre-existing respiratory illness, but are unlikely to give rise to significant long term adverse effects.

The health risks associated with waste reception and handling prior to treatment would be similar to those associated with waste reception and pre-treatment of MSW associated with other waste treatment processes such as incineration or pyrolysis. Some workers may be at increased risk of heat related illness if they are required to handle warm materials or undertake maintenance operations on hot equipment.

Overall, the use of autoclave technology would not be expected to give rise to increased health risks that are significantly different from those associated with other waste treatment processes.

MRFs

The main issues associated with MRFs are the potential for exposure to dust and bioaerosol during primary waste reception, during manual or automated waste sorting operations, during any crushing or grading of separated recyclate fractions and during cleaning and maintenance operations. There is a high potential for dust exposure as the waste materials are typically dry. Processes such as the automated shredding of waste materials, the transfer of recyclate by conveyor, any grading or screening operations or crushing are likely to be significant sources of airborne dust, particularly where processes are not fully enclosed. Workers spending a substantial proportion of their working day in close proximity to these sources are likely to experience exposures to dust and bioaerosol that exceed the thresholds for respiratory symptoms and increased risk of longer term respiratory illness, even where LEV is in place. Even where processes are enclosed and fitted with extraction ventilation, workplace exposures to dust and bioaerosol may still exceed the thresholds for respiratory illness where workers are within a relatively enclosed space ($\leq$ 300 m^2 floor area) and there is a limited supply of fresh air. Elevated exposures are also likely to occur in the waste reception area if loads of mixed recyclate are dropped from collection vehicles and then transferred using excavators or other equipment not fitted with a sealed cab and air filtration. Any workers entering an area where wastes are being handled would experience elevated exposures to dust and bioaerosol that would be significant if that individual spent more than a few minutes within the area over a working shift. Predicted exposures for handpicking are also likely to exceed the threshold levels for the development of chronic respiratory illness, even where LEV is in place. The correct installation, operation and maintenance of LEV, however, would be expected to lead to a significant reduction in exposure levels for workers in MRFs.

At plants that receive unsorted MSW, workers may be at risk of exposure to infections associated with hygiene waste such as disposable nappies and items that have been inappropriately disposed of such as needles. In addition, they may have a small risk of being exposed to asbestos or other hazardous substances as a result of the inappropriate disposal of hazardous materials by householders. At plants that receive dry recyclate, there are risks of infection or exposure to hazardous substances as a result of poor compliance with required waste segregation procedures by householders. The potential risks to health may be relatively greater than where unsegregated MSW is processed as items such as disposable nappies may unexpectedly turn up on picking lines leading to the work environment becoming contaminated with faecal matter. In practice the infection risks associated with most hygiene waste are small because of the limited survival of most pathogens outside of the human body. The risk of infection associated with hygiene wastes is greatest for individuals with poor personal hygiene or who are immunocompromised and at facilities that do not provide adequate washing facilities and work wear. Needles present a particular risk as they may penetrate PPE and the inappropriate disposal of needles is likely to be associated with drug users who have an above average prevalence of blood borne infections. Any exposure to asbestos is likely to be small and infrequent and unlikely to be associated with a significant increase in lifetime cancer risk. Exposure to other chemicals may cause immediate respiratory and eye irritation and could cause burns but in the absence of immediate injury is relatively unlikely to lead to lasting adverse effects. It is relatively unlikely that a highly corrosive substance would be disposed of in household waste. Workers are likely to have occasional exposures to a variety of pesticides (as residues within plastic containers) but not at levels associated with immediate toxicity or at frequency likely to give rise to longer term effects.

Workers with pre-existing respiratory conditions such as asthma or pre-existing sensitisation to common moulds are at particular risk and may experience an exacerbation of symptoms at very low exposure levels. Allergic illness is likely to be a significant issue for workers who remain in post for periods of months to years, particularly for those who are atopic. It is probable that workers with increased susceptibility leave the industry because their symptoms become intolerable. Any workers with compromised immune function are at risk of developing aspergillosis and also at increased risk of other infections, particularly if they have contact with hygiene waste.

Workers at MRFs may be at risk of experiencing mild heat related illness during warm weather because of the necessity to wear coveralls.

MBT

The main issues associated with MBT are the potential for exposure to dust and bioaerosol during waste reception and during cleaning and maintenance operations. MBT plants are highly automated and provided the process is fully enclosed with extract ventilation (and doesn't return contaminated air to the workplace), worker exposures to dust and bioaerosol should remain well below the levels that are likely to be associated with increased risks of respiratory illness. Where process enclosure has been designed primarily to reduce the risk of large fragments of waste flying across the workplace rather than the release of dust, then significant release of dust and bioaerosol to general workplace air is likely. Workers spending much of their working day in close proximity to such equipment are likely to have exposures to dust and bioaerosol that exceed the thresholds for the development of respiratory symptoms. Repeated exposure would give rise to increased risks of chronic respiratory illness, although the risks of hypersensitivity pneumonitis and organic dust toxic syndrome should be substantially lower than those associated with some composting operations. Increased exposures to dust and bioaerosol could also arise during cleaning and maintenance operations unless appropriate PPE is employed.

Cleaning and maintenance operations could bring workers into close contact with untreated hygiene waste and other infection hazards including rat urine (Weils disease), pigeon faeces, animal wastes and contaminated food. The infection risks should be minimal provided that appropriate PPE is employed including disposable suits, strong waterproof gloves and a faceshield, adequate washing and changing facilities are provided, there is good separation of work and nonwork wear and strict standards of personal hygiene are imposed.

As described above for MRFs, workers with pre-existing respiratory conditions, mould sensitisation or compromised immune function are at increased risk of developing symptoms or infection.

Workers at MBT plants may be at risk of experiencing mild heat related illness during warm weather because of the necessity to wear coveralls.

HWRC's and Transfer Stations

No active processing of waste occurs at HWRCs and waste transfer stations which limits the potential for exposure to hazardous substances during normal operations. Exposure to dust with a variable organic content is likely to arise at waste transfer stations as waste is deposited from collection vehicles and transferred to other containers for onward transport. Similarly, some exposure to dust may occur at HWRT as materials are transferred from one container to another. Shift mean dust exposure concentrations may exceed threshold levels for the development of respiratory symptoms at some waste transfer stations where dry wastes are handled, particularly if plant operators work with their cab windows open. Similarly cleaning and maintenance operations that create airborne dust at both HWRCs and waste transfer stations could lead to shift mean exposures that are sufficient to give rise to respiratory symptoms, particularly in individuals with pre-existing respiratory illness. Repeated exposure could give rise to increased risks of chronic respiratory illness. Dust exposures are likely to be associated with exposure to bioaerosol particularly where garden waste, MSW, paper and cardboard or similar materials are handled. It would be anticipated that the relatively low level of dust exposure associated with most activities at HWRCs and transfer stations would also be associated with relatively low exposure to bioaerosol, Published measurement data suggest, however, that significant exposure to bioaerosol has arisen at waste transfer stations, even where waste is handled remotely. Prolonged storage of waste would increase the potential for bioaerosol emission when it is eventually moved.

Workers at HWRCs and transfer stations may experience occasional exposures to hazardous substances such as asbestos that householders have inappropriately put out for kerbside collection or dropped into an inappropriate skip at a HWRC. Exposures are likely to be infrequent and unlikely to give rise to a significantly increased risk of future illness including cancer.

Workers at HWRCs and transfer stations may be at risk of experiencing mild heat related illness during warm weather because of the necessity to wear coveralls, particularly if they are undertaking physical activity such as helping to load household waste into the appropriate skips while outside in hot sunshine.

Glass, plastic and wood separation plants

The exposures of concern are bioaerosol and dust. The dust liberated for glass and plastics may be associated with bioaerosol arising from residual food and paper wrappers. The dust liberated from wood will also be associated with bioaerosol and will have a high organic component giving rise to a risk of respiratory irritation and irritation to the eyes at exposure levels well below the current UK WELs for dust. Long term exposures at concentrations that are 3% of the current inhalable dust limit may be associated with increased risks of chronic bronchitis and other respiratory illness. Wood dust is also classified as a carcinogen, although it is highly unlikely that exposure levels associated with timber reclamation would be sufficient to give rise to a significant increase in cancer risk. The adverse effects of dust are likely to be enhanced by the presence of endotoxin and other biological components. The presence of airborne fungi in dust is likely to be associated with increased risks of the development of allergic illness, particularly in workers with atopy. Workers with pre-existing respiratory conditions such as asthma or pre-existing sensitisation to moulds are likely to develop respiratory symptoms at very low exposure levels.

The dust released from crushed glass will be relatively inert but long term exposure to dust at concentrations below the current workplace exposure limits is associated with an increased risk of chronic respiratory illness. Workers who spend a significant proportion of their day working in close proximity to processes involving the crushing of glass, grading crushed glass or transferring crushed glass that are not entirely enclosed and fitted with extraction, are at increased risk of developing chronic respiratory illness. Exposures and risks are likely to greatest where these processes are undertaken within a relatively enclosed space (≤300 m^2) with a limited supply of fresh air.

The reprocessing of plastic wastes using solvents may be associated with exposure to solvent vapours where processes are inadequately contained. The risks of exposure are probably greatest where such processes are performed at a waste handling site where there may be a relatively poor understanding of the potential risks to health associated with solvent exposure.

Workers may be at risk of mild heat related illness during warm weather because of the requirement to wear coveralls.

WEEE recycling

WEEE contains a wide range of hazardous metals and where processes are poorly designed and/or operated, there is a significant risk that workers may be exposed to toxic levels of lead, mercury or other metals. The HSE have identified issues of over-exposure to lead and mercury associated with some activities such as processing fluorescent light tubes, CRTs or LCDs. WEEE also contains other hazardous substances such as brominated fire retardants, but although there is evidence that WEEE re-processing workers may have higher exposures to these substances than the wider population, there is no evidence that these exposures are of sufficient magnitude to be harmful to health.

Exposures to metal rich dust are most likely where materials are shredded or crushed, graded and handled in shredded or crushed form with the risks potentially being increased once different materials such as plastics, ferrous and non-ferrous metals are segregated. Inefficient segregation of different materials may increase risks of over-exposure to hazardous substances, if materials such as shredded plastic are contaminated with hazardous metals. The potential for exposure is likely to be highly variable between operations. Processes involving equipment that contains mercury such as fluorescent light tubes may be associated with exposures to mercury vapour if they are not entirely contained with an effective collection system for recovered mercury. Exposure to dust generated during the processing of CRTs is associated with the risk of significant exposure to lead. Most processes are likely to be highly automated and in principle could be readily enclosed and fitted with extraction. Exposures could be further reduced if the operations hall is appropriately ventilated. Worker exposure will be determined by the tasks that they undertake and their proximity to dust sources in the work environment. Cleaning and maintenance may be associated with very high levels of dust exposure, particularly if compressed air is used to clear equipment blockages and to clean surfaces. Other workers may experience high exposures if process containment is designed only to prevent material flying out that could cause injury rather than to prevent dust emissions and no extraction is in place. Other factors that could lead to high levels of exposure would include the failure to appropriately filter recirculated air in the workplace and an insufficient supply of fresh air.

Dermal contact and inadvertent ingestion may be important routes of exposure to hazardous metals and other substances at some WEEE processing sites where housekeeping is poor, particularly if there is an inadequate provision of welfare facilities and poor segregation of work and nonwork clothing. Even where intakes of individual metals do not exceed the levels associated with WELs or other advisory limits, exposure to a mixture of metals may give rise to additive effects giving rise to toxicity.

Fridge recycling

The exposure of concern is to refrigerant gases, primarily CFCs and HCFCs. It is likely that some escape of refrigerant gases occurs at fridge recycling plants although the necessity to minimise emissions to the wider environment means that releases and exposures are likely to be small. Most refrigerant gases have a relatively low toxicity. It is highly unlikely that exposure to refrigerant gases associated with fridge recycling would give rise to a significant risk to worker health.

Subsequent to the extraction of the refrigerant gases, the exposures and health issues associated with processing waste fridges are similar to those associated with other types of WEEE.

Recovery of metal recyclate

There are few data describing exposures during metal recovery operations. Elevated exposure to metals may occur while cutting scrap metal, in association with crushing operations and during the separation of different types of metal waste.

There are data that indicate that elevated exposures to lead are relatively common among scrap metal workers in the UK. In 2009-2010, 6.0% of the male scrap workers under surveillance had blood lead levels that exceeded the level at which they had to be withdrawn from the workplace and 14% had blood lead levels above the action level. About 20% of workers had blood lead levels that were above 40 ug/dL and sufficient to give rise to effects such as anaemia, fatigue, stomach cramps and effects on mood and cognitive functioning. Adverse effects on an unborn or breastfed child can arise at much lower levels of exposure. It is not known what proportion of scrap yard workers who are exposed to lead are under medical surveillance and it is possible that the number of workers that are experiencing adverse effects arising from lead poisoning are significantly greater than reflected in the HSE figures. It seems plausible that over-exposure to other widely used metals may also occur.

The crushing and separation of mixed metal waste at materials recovery plants may be associated with increased exposures to a range of metals that reflect the general usage of metals in consumer goods. These include iron and aluminium as major components and a wide range of minor components including other metals used in steel such as manganese and nickel and lead and copper. The potential for exposure may be greatest when processes are performed at MRFs, MBT plants and other indoor facilities. Where equipment is fully contained and fitted with extraction, there should be no significant exposure to dust containing metals during routine operation, provided that untreated air is not vented into the workplace. Provided that exposures to dust are controlled to below 1 mgm^{-3}, it is unlikely that excessive exposures to individual metals will arise, although the effects of exposure to a mixture of metals that are associated with similar effects are uncertain. Higher levels of exposure are likely to occur during cleaning and maintenance operations. Where workers are frequently clearing blockages through the working shift, this could give rise to potentially significant exposures to iron, copper, aluminium, lead, nickel, manganese and possibly other metals in relation to the UK WELs, although the outcome of exposure modelling suggests that the WELs are likely to be normally met. The crushing and processing of end of life vehicles would normally be undertaken outdoors and may be associated to exposure to dust containing iron and a mixture of metals that are present in steel and other alloys present in vehicles. Given that these operations are remotely operated and undertaken outside, it is likely that inhalation exposure to metals is relatively small.

Inadvertent ingestion of dust at scrap yards and other material recovery facilities may be a substantially more important route of exposure than inhalation. Inadvertent ingestion may arise as a result of subconscious hand to mouth contact and through contamination of cigarettes, food and drinking vessels as a result of dirty hands and can be a significant route of exposure to hazardous substances at work (Cherrie et al, 2006). The risks of inadvertent ingestion are greatest where personal hygiene is poor and is likely to be associated with inadequate washing facilities, the failure to provide a clean environment for breaks, poor or no separation of work and nonwork clothing and poor worker awareness of the potential hazard. Inadvertent ingestion may play an important role in giving rise to elevated exposures to lead (and potentially other metals) at scrap yards and could also give rise to significant exposure to metals at other sites where significant quantities of settled dust containing metals are present. Where a worker is spending a significant proportion of the shift undertaking dusty tasks such as clearing blockages, it is conceivable that their combined exposure to some individual metals through inhalation and ingestion would be substantially greater than the intake associated with the WEL. This could give rise to increased risks of a range of irreversible health effects including impaired kidney or liver function, impaired neurobehavioural performance and increased risks of dementia and other neurodegenerative diseases, adverse effects on cardiac and respiratory health and possibly increased cancer risks.

Dermal contact may be an important route of exposure to fuel and other hydrocarbons during the processing of end of life vehicles and similar wastes, particularly where workers have a poor awareness of hazard and do not use appropriate PPE. This could give rise to increased risks of a range of irreversible health effects including impaired kidney or liver function, increased risks of dementia and other neurodegenerative diseases and increased cancer risks, particularly for leukaemia (associated with benzene in petrol) and skin cancer (associated with dermal contact with engine oil and diesel).

The downstream processing of metal recyclate occurs within the metals industry and exposures are likely to be similar to those associated with primary production, although there are a small quantity of data indicating that metals recycling may be associated with above background levels of exposure to PCDD/Fs. The reported exposure levels would not be expected to be associated with a significant increase above background levels of exposure to these substances in food and would not be expected to have significant impacts on health.

Paper and cardboard baling

The exposures of concern are bioaerosol and dust. The dust liberated from paper and cardboard will have a high organic component giving rise to a risk of respiratory irritation and irritation to the eyes at exposure levels well below the current UK WELs for dust. Long term exposures at concentrations that are 3% of the current inhalable dust limit may be associated with increased risks of chronic bronchitis and other respiratory illness. The adverse effects of dust are likely to be enhanced by the presence of endotoxin and other biological components. The presence of airborne fungi in dust is likely to be associated with increased risks of sensitisation and the development of asthma and other allergic respiratory illness.

The baling of waste paper and cardboard is likely to be conducted indoors and to be highly automated but are unlikely to be fully contained as the dust is unlikely to be regarded as hazardous. There are no measurement data but it seems unlikely that the processes are particularly high energy and the potential for dust generation should be much less than during the crushing and processing of other dry wastes. It is still probable, however, that operators working in close proximity to partially contained equipment would be exposed to airborne dust levels that could cause respiratory irritation and increased risks of chronic respiratory illness. Workers with pre-existing respiratory conditions such as asthma or pre-existing sensitisation to common moulds may experience an exacerbation of symptoms at very low exposure levels. Allergic illness is likely to be a significant issue for workers who remain in post for periods of months to years, particularly in those with atopy.

11.3 DISCUSSION

There are a number of industry-wide issues that may contribute to increased risks to worker health:

- Traditionally viewed as a dirty industry;
- New technology and processes;
- Control of dust exposure to meet existing UK limits without adjustment for dust composition;
- Mobile workforce and use of agency workers; and
- Limits on emissions to outdoor air.

Poor housekeeping and poor personal hygiene can lead to greatly increased exposures of workers to airborne dust and hazardous substances. Settled dust in the working environment can be readily disturbed to become airborne. Probably more importantly, a dirty workplace combined with poor personal hygiene is likely to be associated with significant exposure by inadvertent ingestion to hazardous substances such as metals, infectious agents and oils. Site managers and workers who have been in the waste business for a number of years may view "dirty" as normal and acceptable. In our experience, there is a noticeable difference between site variation in the standard of housekeeping. There are also substantial differences in other factors that affect exposure risk such as the quality of washing and other welfare facilities, the provision of work wear, changing facilities and a laundry service for work wear and the provision of appropriate PPE including face fit tested RPE. Tight operating margins may lead site managers to skimp on spending on items such as proper washing facilities, provision and laundering of work wear, face fit testing and regular maintenance of LEV systems and other protective equipment, all of which are likely to increase the potential exposure of workers to hazardous substances and give rise to elevated risks of ill-health.

The use of new technology and processes introduces a number of factors that could lead to increased risks to work health. Equipment that is not widely in use may be subject to frequent process problems that require cleaning and maintenance operations to be undertaken leading to elevated exposures to dust and specific hazards such toxic metals or infected material. Additionally, specialist plants may be installed at sites where the site manager has extensive experience of working in the waste industry but little knowledge of hazardous substances and the potential effects of exposures to substances such as lead and mercury. A poor understanding of hazard and potential risk to health is likely to contribute to inadequate standards of exposure control.

The current UK limits for exposure to airborne dust have been set for inert dusts whereas most dusts generated by waste handling processes are not inert and have the potential to cause adverse health effects at much lower levels of exposure than "inert" dusts. Factors leading to the increased harmfulness of dusts created in the waste industry include the presence of bioaerosol associated with handling most waste types and the presence of hazardous metals and other hazardous substances in dusts associated with metals and WEEE recycling. Additionally, there is substantial evidence that exposures to dust concentrations that are well below the current UK limits are likely to be associated with greatly increased risks of chronic bronchitis, emphysema and other serious lung disease.

A significant proportion of workers at individual waste facilities remain in post for periods of only weeks to months rather than years and the industry uses a lot of agency labour. Agency workers may be at particular risk of over-exposure to dust and hazardous substances if they are not provided with adequate training, risk assessments and/or PPE. Agency workers may have a poor awareness of the hazards associated with the work that they undertake in the waste industry and may not have access to occupational healthcare or be included in industry health surveillance programmes. The short tenure of many workers combined with the use of agency workers may obscure increased rates of respiratory (and other) illnesses as workers may move on as they become ill or not develop symptoms until long after their period of employment. Some of the labour mobility in the waste industry may be due to workers developing respiratory (or other) symptoms that become intolerable. Other negative factors about the workplace such as continuous exposure to malodour may contribute to negative well-being that may translate to an increased likelihood of sickness absence or resignation due to perceived ill health. Many workers in the waste industry are of low social status and/or do not have English as a first language. These individuals may have difficulty in articulating concerns about the working environment or their health and are likely to leave rather than follow through issues of work-related ill health with management. The response to our questionnaire survey suggests that workers may be at increased risk of work-related stress at some plants due to the repetitive nature of the work and inability to control work speed. This may contribute to overall levels of sickness absence and loss of workers from the industry, although there is no evidence that work-related stress is a major issue in the waste industry.

The need to wear coveralls for most tasks in the waste industry greatly increases the risk of heat related illness as even undertaking gentle physical activity on a warm summer day is likely to lead to workers being uncomfortably hot. It is possible that there is a substantial burden of mild ill health in the industry due to heat related illness that is unrecognised because the impacts are generally insufficient to lead to sickness absence and/or it contributes to effects such as cardiovascular illness that are not attributed to an individual's occupation. The response to our questionnaire survey suggests that there is little awareness of the potential for heat related illness to arise at ambient outdoor temperatures.

Concerns about emissions of bioaerosol and odour or hazardous vapours to outdoor air has led to many waste handling facilities recirculating air internally rather than emitting treated air to the outdoor environment. Although this may address the Environment Agency and community concerns in relation to emissions, it may lead to greatly increased levels of worker exposure to dust, bioaerosol and other substances, particularly if inadequate air treatment measures are in place. The overloading or other failures of filters could lead to a significant build up of hazardous substances in workplace air.

11.4 CONCLUSIONS

The main health exposures and health issues associated with each of the processes considered are summarised in Table 11.1. Exposures to dust and bioaerosol at many waste handling sites are likely to give rise to significantly increased risks of chronic respiratory illness. It is likely that exposures to dust and bioaerosol at a substantial proportion of composting sites exceed thresholds for the development of chronic (and disabling) respiratory illness. Excessive exposure to dust and bioaerosol is also likely to arise in the waste reception areas of most waste facilities unless handling processes are entirely automated and enclosed with effective extract ventilation and there is a good supply of fresh air to the workplace. Small quantities of biological material are present in most wastes, giving rise to a potential for exposure to bioaerosol. Storage of organic-rich wastes, including untreated MSW, greatly increases the potential for bioaerosol emissions. Harmful levels of exposure to airborne dust with or without bioaerosol can occur where operations are undertaken inside in limited space and limited fresh air supply. Elevated exposures are most likely where workers are working on picking lines or in close proximity to processes such as crushing, shredding, grading, sieving, conveyor transfer or filling, if these processes are not entirely contained and fitted with effective extract ventilation. It may be particularly difficult to reduce the exposure of workers on picking lines to levels below the thresholds for the development of respiratory symptoms. Harmful levels of exposure to airborne dust with or without bioaerosol can also occur during cleaning and maintenance operations at most types of waste handling facilities. Frequent equipment failure, entry into relatively confined spaces and the use of compressed air to clear blockages may all contribute to extremely high exposures to airborne dust. Although exposures can be controlled through the use of appropriate RPE, RPE is only effective if properly fitted and maintained. In addition, if there are frequent equipment failures, compliance with PPE requirements may slip.

Exposures to harmful levels of heavy metals occurs at some metals recovery facilities such as scrap yards with a substantial proportion of scrap yard workers have blood lead levels that are associated with toxicity. Some WEEE processing operations are also associated with harmful exposures to heavy metals, particularly lead and mercury. In addition exposures to metal mixtures may give rise to adverse effects at exposure levels below the WELs for individual metals. Associated adverse effects include increased risks of kidney or liver dysfunction and neurotoxicity. Inadvertent ingestion is likely to be an important exposure route in both metals recovery operations and WEEE processing. Dermal contact with fuel and other hydrocarbons where end of life vehicles and similar wastes are handled may also give rise to harmful levels of exposure. Potential adverse effects arising from these exposures include increased risks of kidney or liver dysfunction, dementia and cancer.

Occasional exposure to significant infection risks or hazardous substances such as asbestos may occur wherever workers are in close contact with wastes on picking lines or during cleaning and maintenance operations involving untreated or partially treated wastes causing most risk. Provided workers use appropriate PPE and there are well established procedures in place to handle high risk incidents, the risk to worker health should be small.

Current industry practice of controlling dust exposures to meet the UK workplace limits for “inert” dusts does not provide adequate protection for worker health in any sector of the waste industry. Most dusts that are encountered during waste handling are not “inert”. They may have elevated organic matter contents and be associated with bioaerosol or elevated metals contents that are likely to contribute to respiratory inflammation and wider systemic toxicity. In addition, the HSE’s own advisory committee, WATCH, have indicated that the existing limits for inert dust are associated with a significant risk of developing chronic respiratory illness. The IOM guidelines for exposure to respirable and inhalable inert dusts are 1 and 5 mgm^{-3} respectively. Where materials with a high organic content are handled (eg MSW, compostable material, food waste), inhalable dust concentrations should be controlled to below 1 mgm^{-3} and ideally below 0.3 mgm^{-3} in order to reduce the risks of chronic respiratory illness including work-related asthma. Where dusts are likely to have a high metals content, account should be taken of the individual WELs and the possibility that some metals may have additive effects. Lead-rich dusts for example should be controlled to concentrations less than 0.15 mgm^{-3} (the WEL for lead).

Exposure to heat may be an issue for much of the waste industry because of the use of PPE and RPE to protect the worker from chemical and biological hazards. Workers undertaking even gentle physical tasks such as sampling at compost sites or handpicking at MRFs may be at risk of heat related illness on a warm day because of the requirement to wear coveralls. Workers required to undertake maintenance tasks on hot equipment are at particular risk of heat related illness, particularly if this requires entry into a confined space. Operational pressures may lead to workers undertaking maintenance tasks before equipment has completely cooled. Individual workers vary considerably in their susceptibility to heat. It is possible that heat contributes to a significant burden of minor ill health and reduced well being and contributes to increased risks of more serious illness such as cardiovascular problems that are not attributed to the working environment.

There are insufficient exposure (or health) data to determine the extent of work-related illness in the waste industry. Potential exposures will be very low at a well run facility where there is good staff training and hazard awareness combined with an appropriate level of process containment and appropriate ventilation as well as appropriate staff welfare facilities. The mobility of the labour force and the long time scale over which serious respiratory illness may develop mean that there may be a hidden burden of respiratory ill-health associated with exposures in the waste industry over recent years as new technologies have been adopted. There may be a substantial healthy worker effect as those workers that develop respiratory symptoms may choose to leave the waste industry. Those with pre-existing respiratory conditions such as asthma and/or have a predisposition to develop allergic illness are most likely to develop respiratory symptoms. A significant proportion of individuals employed in the waste industry have low social status and may have difficulty in raising issues of work-related ill health with management.

Table 11.1: Summary of health risks associated with waste handling operations

Process	Hazards	Exposure	Risk to health	Comments
Landfill	Bioaerosol, dust, landfill gas	Mostly low, use of sealed cabs and air filtration important to control exposure	Small	Requirement to control explosion hazard means exposure to hazardous substances in landfill gas is small
Anaerobic digestion	Bioaerosol, dust, biogas	Not known – bioaerosol exposure likely during initial waste reception and processing	Over-exposure to bioaerosol is associated with increased risks of serious respiratory ill health and symptoms such as fatigue and nausea	Better exposure/process information required in order to assess risk
Composting – open windrow	Bioaerosol and dust	Variable, use of sealed cabs and air filtration important to control exposure	Over-exposure to bioaerosol and dust is associated with increased risks of serious respiratory ill health; exposure to bioaerosol may give rise to symptoms such as fatigue and nausea	Exposure levels at composting sites are highly variable but are sufficient to give rise to long term respiratory ill health at a large number of sites
Composting - indoors	Bioaerosol and dust	Variable, will depend on extent of process enclosure and ventilation	Over-exposure to bioaerosol and dust is associated with increased risks of serious respiratory ill health; exposure to bioaerosol may give rise to symptoms such as fatigue and nausea	Exposure levels at composting sites are highly variable but are sufficient to give rise to long term respiratory ill health at a large number of sites
High temperature incineration	Bioaerosol and dust associated with untreated waste; dust, metals, PCDD/Fs associated with incineration residues	Measurement data indicate elevated exposures to bioaerosol may occur where waste is stored, low exposures to metals, PCDD/Fs. Elevated exposures to dust possible during cleaning and maintenance	Small where there is a high level of automation and process containment and no significant operational problems that require frequent intervention	Process problems leading to frequent exposure to dust (and possibly bioaerosol) could give rise to a significant risk of chronic respiratory illness. Correct use of PPE essential to manage exposure
Pyrolysis, plasma, gasification	Bioaerosol and dust associated with untreated waste; dust associated with air pollution control residues, other residues may be associated with some potential for dust exposure	Elevated exposures to bioaerosol may arise if waste is stored prior to processing. Elevated exposures to dust possible during cleaning and maintenance	Small where there is a high level of automation and process containment and no significant operational problems that require frequent intervention	Process problems leading to prolonged waste storage could lead to increased risks of bioaerosol exposure
Auto-clave	Bioaerosol and dust associated with untreated waste	No information about exposure levels, exposure in waste reception area may be similar to that for other processes	Small where there is a high level of automation and process containment but bioaerosol exposure prior to waste processing may be associated with elevated risks of respiratory illness and symptoms such as fatigue and nausea.	Better exposure/process information required in order to assess risk

Process	Hazards	Exposure	Risk to health	Comments
MRFs including trammel mills and screens	Bioaerosol and dust	Workers on handpicking lines are likely to be exposed to levels of dust and bioaerosol associated with adverse effects if processes such; as crushing, shredding and screening are not entirely enclosed and fitted with extraction ventilation. Then workers who spend a substantial proportion of their working shift in close proximity to these processes are likely to have elevated exposures to dust and bioaerosol. Cleaning and maintenance operations are also likely to be associated with elevated exposures	Elevated exposure to bioaerosol and dust is associated with increased risks of serious respiratory ill health; exposure to bioaerosol may give rise to symptoms such as fatigue and nausea	Better exposure and process information required in order to better quantify extent of potential risks, sites and processes where exposure problems may exist. It is likely to be difficult to reduce exposures associated with handpicking below threshold levels for adverse respiratory effects. The practice of recirculating air within the workplace rather than emitting extracted air to the outdoor environment may contribute to over-exposure to dust and bioaerosol
MBT	Bioaerosol and dust	Where there is a high level of process enclosure with appropriate extract ventilation, exposures will be well below threshold limits for the development of respiratory illness. Significant exposures could occur during cleaning and maintenance such that frequent equipment failures could be associated with increased long term levels of exposure	Where there are lower standards of process enclosure or process problems leading to frequent exposures during unplanned maintenance, elevated exposure to bioaerosol and dust may give rise to increased risks of serious respiratory ill health; exposure to bioaerosol may give rise to symptoms such as fatigue and nausea	Better exposure and process information required in order to better quantify extent of potential risks and sites and processes where exposure problems may exist.
HWRC and transfer stations	Bioaerosol and dust, occasional exposures to hazardous substances	Exposure levels generally low but elevated exposures to bioaerosol possible where MSW and other wastes are stored and elevated exposures to dust and bioaerosol are possible during materials transfer operations performed indoors and not entirely enclosed or workers operating plant do not have sealed cabs with air filtration	The risks of developing chronic respiratory illness are low except where poor containment and lack of ventilation in an indoor environment lead to elevated levels of bioaerosol exposure. Exposures to substances such as asbestos are likely to be infrequent and not associated with a significant increase in cancer risk or other adverse health outcome	Better exposure information required to in order to identify sites and processes where exposure problems may exist; current control of exposure to meet UK dust limits may be insufficient for the protection of health

Process	Hazards	Exposure	Risk to health	Comments
Glass, plastic and wood separation plants	Dust and bioaerosol, bioaerosol possible even for waste streams such as plastics and glass due to the presence of residue food and other biological matter	These materials are not regarded as toxic and it seems unlikely that processes or materials are fully enclosed and fitted with extraction ventilation at all or even most sites, it is likely that exposure to dust and bioaerosol will exceed threshold levels for the development of respiratory illness at many sites	Elevated exposure to dust and bioaerosol is likely to give rise to increased risks of chronic respiratory illness; elevated bioaerosol exposure may also give rise to symptoms such as fatigue and nausea	Better exposure information required to in order to identify sites and processes where exposure problems may exist; current control of exposure to meet UK dust limits may be insufficient for the protection of health
WEEE recycling	Hazardous metals, brominated fire retardants	Where processes or materials are not entirely enclosed and/or housekeeping is poor, significant exposures to hazardous metals, particularly lead and mercury are possible with inadvertent ingestion being an important route of exposure	Excessive exposure to metals is associated with a range of toxic effects depending on the metal but many metals are associated with damage to the kidneys, central nervous system and respiratory symptom and some are also carcinogens. There is no evidence that exposure to BRFs associated with WEEE is associated with significant adverse health effects	The extent to which over-exposure to metals occurs during WEEE processing is not known
Fridge recycling	Refrigerant gases, metals	Exposures to refrigerant cases	Health risk associated with refrigerant gases is low; risks associated with metal and plastic scraps similar to those for other WEEE	Assessment based on assumption that gas handling procedures will be designed to prevent any gas escape to the wider environment
Metal crushing and aluminium separation	A wide range of metals including iron, aluminium, copper, lead, manganese, nickel depending on the materials being handled	Where processes or materials are not entirely enclosed and/or housekeeping is poor, significant exposures to hazardous metals, particularly lead are possible with inadvertent ingestion being an important route of exposure	Low, if processes and materials are enclosed, appropriate ventilation in place and a high standard of house-keeping and personal hygiene are employed; where significant levels or airborne and/or settled dust are present, metals exposure may be sufficient to cause systemic toxicity and/or dust levels sufficient to give rise to a significant increased risk of respiratory illness	Better exposure information required to assess risk
Paper and cardboard baling	Dust and bioaerosol	It is relatively unlikely that processes have been designed to control exposures below the thresholds associated with respiratory illness	Significant risk of serious respiratory illness resulting from long term exposure unless processes are entirely enclosed to prevent exposure	Better exposure/process information required in order to assess risk

11.5 RECOMMENDATIONS

One of the main conclusions of this study is that exposures in the waste industry could give rise to a significant burden of ill health but there are too little data to determine whether a significantly raised risk of widespread work-related ill health actually exists. The most significant issues appear to be dust, bioaerosol and hazardous metals. We recommend that further work is undertaken to better characterise the extent of risk. Before waiting for the results of further investigation, however, we recommend that the industry is proactive in monitoring worker exposure to dust and other hazardous substances and that it adopts much lower exposure limits for respirable and inhalable dust than currently required under UK law. The IOM recommends that employers should aim to keep exposure to respirable "inert" dust below 1 mgm^{-3} and inhalable dust below 5 mgm^{-3}. Lower limits would be advisable for dusts with a high organic matter or metals content. We also recommend that the industry reviews the potential for heat related illness wherever it is necessary for workers to wear coveralls and they are not working within an air conditioned space. It is likely that mild heat related illness contributes to a hidden burden of mild ill-health in workers, although the impacts on worker health are likely to be smaller than those associated with exposure to dust, bioaerosol and/or metals. It is important to ensure that whoever undertakes any monitoring work for the industry is both qualified and knowledgeable in practical risk assessment and experienced in the establishment of practical occupational hygiene and health programmes at multisite locations. Exposure/measurement/control and survey work should be led by a suitably qualified and experienced occupational hygienist who is a Member or Fellow of the Faculty of Occupational Hygiene. Health surveillance and the analysis of occupational health data should be directed by a suitably qualified and experienced occupational physician who is a Member or Fellow of the Faculty of Occupational Medicine.

Our understanding of the risks to worker health that may be associated with employment in the waste industry is limited by the poor availability of exposure information in the public domain. We understand that most of the major players in waste industry already make/commission occupational hygiene measurements and that some operators are willing to release this data for the purposes of a future study. We recommend that the waste industry pools and reviews its existing exposure data in order to identify the types of process and other factors that are associated with elevated exposures that might represent a risk to health and where further/better data are required. It is likely that there is a paucity of information about exposures at sites operated by small operators who should be included in any initiative to better understand workplace exposures in the waste industry. There is also likely to be a paucity of information about exposure by dermal contact and inadvertent ingestion. Although it is difficult to undertake routine measurements of exposure by these routes, they should be included in any overall assessment of exposure and risk. Some indirect inferences about the likely importance of these exposure routes can be made from observations of levels of workplace cleanliness, provision and laundering of workplace clothing, required hygiene measures, the cleanliness of eating and rest areas and the use of PPE.

The industry may decide that its existing data are of insufficient quality to inform a review (for example, measurement data may not be clearly linked to processes and control measures) and decide to commission an independent measurement survey that includes representative sites for all the key processes. The advantages of a new survey are that it would be possible to ensure a systematic approach to measurement and recording of the factors that may influence exposure and it would provide information about current rather than past conditions. Provided appropriate quality assurance measures were included in the sampling and analytical protocols and the measurements were made by suitably qualified people there would be a high level of confidence in the resultant data. The disadvantage would be that it may be difficult to get sufficient coverage within reasonable cost to be confident that the survey results were representative for each process type. This could be addressed by undertaking a phased programme over several years focussed on specific sectors of the industry.

As a first stage in the review of existing data and/or developing a new measurement programme, it may be beneficial to start the process with a series of baseline reviews of operational sites by suitably qualified occupational hygienists. The aim would be to test the issues raised in this report and prioritise the actions for subsequent investigation and/or control. This iterative approach has been widely used in other industries to help focus resources rather than attempt to address all issues in depth simultaneously. With the multitude of potential issues identified, simple baseline reviews of typical conditions on operating sites by informed specialists would help in the development of a stratified programme where future actions can be derived from the outcome of the previous steps. By adopting a plan with a series of manageable and pragmatic steps, some issues may be eliminated at an early stage whereas other may benefit from greater attention.

In addition to reviewing exposures, the introduction of systematic industry-wide approaches to health surveillance and recording and sickness absence monitoring could provide key data to inform a future epidemiological investigation of the health risks associated with working in the waste industry. In order for data to be informative about work-related ill health, a specific focus on conditions that could be work-related such as respiratory ill health and infection is required.

12 References

Aatamila M, Verkasalo PK, Korhonen MJ, Suominen AL, Hirvonen MR, Viluksela MK, Nevalainen A. (2011). Odour annoyance and physical symptoms among residents living near waste treatment centres. *Environmental Research*; 111(1):164-70.

AEA Technology. (2006). WEEE & hazardous waste Part 2. *AEA Technology;* AEAT/ENV/R2233. A report produced for Defra.

Agency for Toxic Substances and Disease Registry. (2000). Toxicological Profile for Polychlorinated Biphenyls (PCBs) (Updated). *Agency for Toxic Substances and Disease Registry*; PB/2000/108027. Available at: http://www.atsdr.cdc.gov/ToxProfiles/tp.asp?id=142&tid=26

Agency for Toxic Substances and Disease Registry. (2003). Toxicological Profile for Selenium. *Agency for Toxic Substances and Disease Registry*; PB2004-100005. Available at: http://www.atsdr.cdc.gov/ToxProfiles/tp.asp?id=153&tid=28

Agency for Toxic Substances and Disease Registry. (2004). Toxicological Profile for Ammonia (Updated). *Agency for Toxic Substances and Disease Registry*; PBPB2004-107331. Available at: http://www.atsdr.cdc.gov/toxprofiles/tp126.html

Agency for Toxic Substances and Disease Registry. (2005). Toxicological Profile for Tungsten. *Agency for Toxic Substances and Disease Registry*; PB2006-100007. Available at: http://www.atsdr.cdc.gov/ToxProfiles/tp.asp?id=806&tid=157

Agency for Toxic Substances and Disease Registry. (2006). Toxicological Profile for Hydrogen Sulphide (Updated). *Agency for Toxic Substances and Disease Registry*; PB2007-100675. Available at: http://www.atsdr.cdc.gov/toxprofiles/tp114.html

Agency for Toxic Substances and Disease Registry. (2006). Toxicological Profile for Methyl Mercaptan (Draft for public comments). *Agency for Toxic Substances and Disease Registry*. Available at: http://www.atsdr.cdc.gov/toxprofiles/tp139.html

Agency for Toxic Substances and Disease Registry. (2011). Toxicological Profile for Polychlorinated Biphenyls (PCBs): Addendum. *Agency for Toxic Substances and Disease Registry*; PB/2000/108027. Available at: http://www.atsdr.cdc.gov/toxprofiles/pcbs_addendum.pdf

Atenstaedt RL. (2010). Parents--why it is now legal to put your child's nappy in the dustbin. *The Medico-Legal Journal*. 78(Pt 3):101-4. Review.

Baan R, Grosse Y, Straif K, et al. A review of human carcinogens—Part F: Chemical agents and related occupations. Lancet Oncology 2009;10:1143–1144.

Bell IR, Miller CS, Schwartz GE, Peterson JM and Amend D. (1996). Neuropsychiatric and somatic characteristics of young adults with and without self-reported chemical odour intolerance and chemical sensitivity. *Archives of Environmental Health*; 51(1):9-21.

Berman DW, Crump K. (2004). Technical support document for a protocol to assess asbestos-related risk. (Draft prepared). *US Department of Transportation and US Environmental Protection Agency*.

Bie R, Li S, Wang H. (2007). Characterization of PCDD/Fs and heavy metals from MSW incineration plant in Harbin. *Waste Management*; 27(12):1860-9.

Blenkham. (2006). Lowering standards of clinical waste management: do the hazardous waste regulations conflict with the CDC's universal/standard precautions? *The Journal of Hospital Infection*; 62(4): 467-472.

Boffetta P, Mundt KA, Adami HO, Cole P, Mandel JS. (2011). TCDD and cancer: a critical review of epidemiologic studies. *Critical Reviews in Toxicology*; 41(7):622-36.

Brunekreef B, Forsberg B. (2005). Epidemiological evidence of effects of coarse airborne particles on health. *The European Respiratory Journal*; 26(2):309-18.

Bulsing PJ, Smeets MA, Van den Hout MA. (2009). The implicit association between odors and illness. *Chemical Senses*; 34(2):111-9.

Bunger J, Schappler-Scheele B, Hilgers R, Hallier E. (2007). A 5-year follow-up study on respiratory disorders and lung function in workers exposed to organic dust from composting plants. : *International Archives of Occupational Environmental Health*; 80(4):306-12.

Carlsson F, Karlson B, Ørbaek P, Osterberg K and Ostergren PO. (2005). Prevalence of annoyance attributed to electrical equipment and smells in a Swedish population, and relationship with subjective health and daily functioning. *Public Health*; 119(7):568-77.

Chang FK, Chen ML, Cheng SF, Shih TS, Mao IF. (2007). Evaluation of dermal absorption and protective effectiveness of respirators for xylene in spray painters. *International Archives of Occupational and Environmental Health*; 81(2):145-50.

Chung TL, Liao CJ, Chang-Chien GP. (2010). Distribution of polycyclic aromatic hydrocarbons and polychlorinateddibenzo-p-dioxins/dibenzofurans in ash from different units in a municipal solid waste incinerator. *Waste Management and Research*; 28(9):789-99.

Cobo M, Gálvez A, Conesa JA, Montes de Correa C. (2009). Characterization of fly ash from a hazardous waste incinerator in Medellin, Colombia. *Journal of Hazardous Materials*; 168(2-3):1223-32.

Calvert GM, Wall DK, Haring Sweeney MH, Fingerhut MA. (1998). Evaluation of cardiovascular outcomes among US workers exposed to 2,3,7,8 tetrachlorodibenzo-p-dioxin. *Environmental Health Perspectives*; 106, 635-643.

Charbotel B, Hours M, Perdrix A, Anzivino-Viricel L, Bergeret A. (2005). Respiratory function among waste incinerator workers. *International Archives of Occupational and Environmental Health;*78(1):65-70.

Lee J, Kang D, Lee KH, Ichiba M, Zhang j, Tomokuni K, Hwang ES, Park CG, Ha M, Kim S, Han SD, Choi JW, Lee E, Jang JY, Strickland PT, Hirvonen A, Cho SH. (2002). Influence of GSTM1 genotype on association between aromatic DNA adducts and urinary PAH metabolites in incineration workers. *Mutation Research*; 514(1-2):213-21.

Crawford, J.O., Graveling, R.A., Cowie, H.A., Dixon, K. (2010). The health safety and health promotion needs of older workers. *Occupational Medicine*; 60: 184-192.

Committee on the Medical Effects of Air Pollutants. (2010). Long term exposure to air pollution: Effect on mortality.2009; *Committee on the Medical Effects of Air Pollutants;* Department of Health.

Committee on the Medical Effects of Air Pollutants. (1998). Quantification of the effects of air pollution on health in the United Kingdom. *Committee on the Medical Effects of Air Pollutants;* Department of Health. HMSO.

Cristaudo A, Sera F, Severino V, De Rocco M, Di Lella E, Picardo M. (2005). Occupational hypersensitivity to metal salts, including platinum, in the secondary industry. *Allergy*; 60(2):159-64.

Dalton PH, Jaén C. (2010). Responses to odors in occupational environments. *Current Opinion in Allergy and Clinical Immunology*; 10(2):127-32.

Department for Environment Food and Rural Affairs. (2004). Review of Environmental and Health Effects of Waste Management: Municipal Solid Waste and Similar Wastes. *Written by Enviros Consulting Ltd and University of Birmingham with Risk and Policy Analysts Ltd, Open University and Maggie Thurgood*

Department for Environment Food and Rural Affairs and CIWMEB, (2007.) Trail to establish waste electrical and electronic equipment (WEEE) protocols. *Defra ub association with the Chartered Institution of Wastes Management Environment Body*

Delgado-Rodríguez M, Ruiz-Montoya M, Giraldez I, López R, Madejón E, Díaz MJ. (2011). Influence of control parameters in VOCs evolution during MSW trimming residues composting. *Journal of Agricultural and Food Chemistry*; 59(24):13035-42.

Domingo JL, Nadal M. (2009). Domestic waste composting facilities: a review of human health risks. *Environment International*; 35(2):382-9.

Donaldson K, Tran L, Jimenez LA, Duffin R, Newby DE, Mills N, MacNee W, Stone V. (2005). Combustion-derived nanoparticles: a review of their toxicology following inhalation exposure. *Particle and Fibre Toxicology*; 2:10.

Dounias G, Rachiotis G. (2006). Prevalence of hepatitis A virus infection among municipal solid-waste workers. *International Journal of Clinical Practice*; 60(11):1432-6.

Dutch Expert Committee on Occupational Safety. (2010). Endotoxins - Health-based recommended occupational exposure limit. The Hague: *Health Council of the Netherlands*; publication no. 2010/04OSH.ISBN 978-90-5549-804-8

Dzaman K, Wojdas A, Rapiejko P, Jurkiewicz D. (2009). Taste and smell perception among sewage treatment and landfill workers. *International Journal of Occupational and Environmental Health*; 22(3):227-34.

Environment Agency. (2004). Guidance on the management of landfill gas. LFTGN 03

EPAQS. (2008). Department for Environment, Food and Rural Affairs, Scottish Executive, National Assembly of Wales, Department of the Environment in Northern Ireland Expert Panel on Air Quality Standards Guidelines for metals and metalloids in ambient air for the protection of human health

Eskenazi, B; Mocarelli, P; Warner, M; Samuels, S; Vercellini, P; Olive, D; Needham, LL; Patterson DG, J, r; Brambilla, P; Gavoni, N; Casalini, S; Panazza, S; Turner, W; Gerthoux, PM. (2002). Serum dioxin concentrations and endometriosis: A cohort study in Seveso, Italy. *Environmental Health Perspectives*; 110: 629-634.

European Commission. (2008). 2008 Review of Directive 2002/96 on Waste Electrical and Electronic Equipment (WEEE) Annex to the final report. Contract No: 07010401/2006/442493/ETU/G4 ENV.G.4/ETU/2006/0032

Fierens S, Mairesse H, Heilier JF, De Burbure C, Focant JF, Eppe G, De Pauw E, Bernard A. (2003). Dioxin/polychlorinated biphenyl body burden, diabetes and endometriosis: findings in a population-based study in Belgium. *Biomarkers*; 8(6):529-34.

Fonte R, Agosti A, Scafa F, Candura SM. (2007). Anaemia and abdominal pain due to occupational lead poisoning. *Haematologica*; 92(2):e13-4.

Gold DR, Litonjua A, Schwartz J, Lovett E, Larson A, Nearing B, Allen G, Verrier M, Cherry R, Verrier R. (2000). Ambient pollution and heart rate variability. *Circulation*; 101(11):1267-73.

Harri M, Svoboda P, Mori T, Mutanen P, Kasai H, Savela K.(2005). Analysis of 8-hydroxydeoxyguanosine among workers exposed to diesel particulate exhaust: comparison with urinary metabolites and PAH air monitoring. *Free Radical Research*;39(9):963-72.

Health and Safety Executive (1996). Working with sewage The health hazards: A guide for employers. *Health and Safety Executive.* Available at: http://www.hse.gov.uk/pubns/indg198.pdf

Health and Safety Executive (1998). Plastics recycling. Plastics Processing Sheet No 2. *Health and Safety Executive.* Available at: http://www.hse.gov.uk/pubns/ppis2.pdf

Health and Safety Executive (2004). The safe recovery of petrol from end of life vehicles. *Health and Safety Executive.* Available at: www.hse.gov.uk/pubns/waste10.pdf

Health and Safety Executive (2005). Green waste collection: Health issues. *Health and Safety Executive.* Available at: http://www.hse.gov.uk/pubns/waste02.pdf

Health and Safety Executive (2005). The Control of Substances Hazardous to Health Regulations 2002 (as amended). Approved code of practice and guidance. *Health and Safety Executive.* Available at: http://books.hse.gov.uk/hse/public/saleproduct.jsf?catalogueCode=9780717629817

Health and Safety Executive. (2006). Final Regulatory Impact Assessment for the Control of Asbestos Regulations 2007. Available at: http://www.hse.gov.uk/ria/chemical/asbestosregria.pdf

Health and Safety Executive (2007). Safe handling of asbestos waste at civic amenity (CA) sites. *Health and Safety Executive.* Available at: www.hse.gov.uk/pubns/waste07.pdf

Health and Safety Executive (2007). Health hazards in the waste and recycling industry. Waste 15, 10/07 Available at: http://www.hse.gov.uk/pubns/waste15.pdf

Health and Safety Executive (2011) Health and safety in motor vehicle repair and associated Industries. HSG 261 Available at: http://www.hse.gov.uk/pubns/priced/hsg261.pdf

Health and Safety Executive (2009). Handling needles in the waste and recycling industry. *Health and Safety Executive.* Available at: http://www.hse.gov.uk/pubns/waste19.pdf

Health and Safety Executive. (2009). Managing offensive/hygiene waste. *Health and Safety Executive.* Available at: http://www.hse.gov.uk/pubns/waste22.pdf

Health and Safety Executive. (2010). Delivering for health: HSE action on occupational respiratory disease. *HSE*/10/94

Health and Safety Laboratory. (2009). Review of sickness absence data in the waste and recycling industry. *Health and Safety Laboratory*. HSE Research Rerpot RR750

Health and Safety Laboratory. (2010). Bioaerosol emissions from waste composting and the potential for workers' exposure. *Prepared by the Health and Safety Laboratory for the Health and Safety Executive* 2010 RR786

Health and Safety Laboratory. (2011). Good control practice for workers' exposure to gases in landfill Sampling and measurement report. *Health and Safety Laboratory*. Health and Safety Executive Research Report 870.

Health Effects Institute. (1991). Asbestos in public and commercial buildings: a literature review and synthesis of current knowledge. Cambridge, MS: HEI.

Health Protection Agency. (2006. Fungal diseases in the UK - The current provision of support for diagnosis and treatment: assessment and proposed network solution. Report of a working group of the HPA Advisory Committee for Fungal Infection and Superficial Parasites. London: *Health Protection Agency*. Available at: http://www.hpa.org.uk/infections/topics_az/fungal_infections/documents/fungal_diseases_report_06.pdf

Health Protection Agency. (2008). Eye of the Needle HepB HepC HIV United Kingdom Surveillance of Significant Occupational Exposures to Bloodborne Viruses in Healthcare Workers. *Health Protection Agency*. Available at: www.hpa.org.uk/webc/HPAwebFile/HPAweb_C/1227688128096

Health Protection Agency. (2008). Polycyclic aromatic hydrocarbons. *Health Protection Agency.* Available at: http://www.hpa.org.uk/webc/HPAwebFile/HPAweb_C/1227169968068

Health Protection Agency. (2011). Diesel. H*ealth Protection Agency Compendium of Chemical Hazards*. Available at: http://www.hpa.org.uk/webc/HPAwebFile/HPAweb_C/1194947407378

Health Protection Agency. (2011). Petrol. *Health Protection Agency Compendium of Chemical Hazards*. Available at: http://www.hpa.org.uk/webc/HPAwebFile/HPAweb_C/1194947397385

Heaney CD, Wing S, Campbell RL, Caldwell D, Hopkins B, Richardson D, Yeatts K. (2011). Relation between malodor, ambient hydrogen sulfide, and health in a community bordering a landfill. *Environmental Research*; 111(6):847-52

Hodgson J, Darnton A. (2000). The quantitative risks of mesothelioma and lung cancer in relation to asbestos exposure. *Annals of Occupational Hygiene*; 44: 565-601.

Hoet P, Boczkowski J. (2008). What's new in Nanotoxicology? Brief review of the 2007 literature. *Nanotoxicology*; 2: 171-182.

Horii Y, Ok G, Ohura T, Kannanct K. (2008). Occurrence and profiles of chlorinated and brominated polycyclic aromatic hydrocarbons in waste incinerators. . *Environmental Science and Technology*; 42(6):1904-9.

Horton RA, Wing S, Marshall SW, Brownley KA. (2009). Malodor as a trigger of stress and negative mood in neighbors of industrial hog operations. *American Journal of Public Health*; 99 Suppl 3:S610-5.

Hours M, Anzivino-Viricel L, Maitre A, Perdrix A, Perrodin Y, Charbotel B, Bergeret A. (2003). Morbidity among municipal waste incinerator workers: a cross-sectional study. *International Archives of Occupational and Environmental Health*; 76(6):467-72. Epub 2003 May 23.

Hu SW, ChangChien GP, Chan CC. (2004). PCDD/Fs levels in indoor environments and blood of workers of three municipal waste incinerators in Taiwan. *Chemosphere*; 55(4):611-20.

Hu SW, Lin P, Chen CC. (2008). Association of cytochrome P450 1B1 gene expression in peripheral leukocytes with blood lipid levels in waste incinerator workers. *Annals of Epidemiology*t; 18(10):784-91

International Agency for Research on Cancer. (1997). Polychlorinated dibenzo-para-dioxins. *International Agency for Research on Cancer;* Summary & Evaluation, Volume 69. Available at: http://www.inchem.org/documents/iarc/vol69/dioxin.html

International Agency for Research on Cancer. (1999). Chromium and chromium compounds. *International Agency for Research into Cancer;* vol 49. Available at: http://www.inchem.org/documents/iarc/vol49/chromium.html

International Agency for Research on Cancer, (2006), Inorganic and organic lead compounds. *International Agency for Research into Cancer*; Vol 87. Available at: www.inchem.org/documents/iarc/vol87/volume87.pdf

International Chemical Safety Cards. Available at: http://www.inchem.org/pages/icsc.html

International Programme for Chemical Safety. (1986). Selenium. *International Programme for Chemical Safety;* Environmental Health Criteria Document 58. Available at: www.inchem.org/documents/ehc/ehc/ehc58.htm

International Programme for Chemical Safety. (1988). Chromium. *International Programme for Chemical Safety;* Environmental Health Criteria Document 61. Available at: www.inchem.org/documents/ehc/ehc/ehc61.htm

International Programme for Chemical Safety. (1990). Environmental Health Criteria Monograph for Methyl Isobutyl Ketone. *International Programme for Chemical Safety*; Environmental Health Criteria 117. Available at: http://www.inchem.org/documents/ehc/ehc/ehc117.htm

International Programme for Chemical Safety. (1991). Chlorofluorocarbons, partially halogenated (methane derivatives. *International Programme for Chemical Safety;* Environmental Health Criteria Document 126. Available at: http://www.inchem.org/documents/ehc/ehc/ehc126.htm

International Programme for Chemical Safety. (1991a). Nickel. *International Programme for Chemical Safety;* Environmental Health Criteria Document 108. Available at: www.inchem.org/documents/ehc/ehc/ehc108.htm

International Programme for Chemical Safety. (1992). Cadmium. *International Programme for Chemical Safety;* Environmental Health Criteria Document 134. Available at: www.inchem.org/documents/ehc/ehc/ehc134.htm

International Programme for Chemical Safety. (1992). Polychlorinated Biphenyls and Terphenyls. -- 2nd ed. *International Programme for Chemical Safety*; Environmental Health Criteria 140, World Health Organization. Available at: www.inchem.org/documents/ehc/ehc/ehc140.htm

International Programme for Chemical Safety. (1997). Aluminium. *International Programme for Chemical Safety;* Environmental Health Criteria Document 194. Available at: http://www.inchem.org/documents/ehc/ehc/ehc194.htm

International Programme for Chemical Safety. (1998). Acetone. *International Programme for Chemical Safety;* Environmental Health Criteria Monograph 207. Available at: http://www.inchem.org/documents/ehc/ehc/ehc207.htm

International Programme for Chemical Safety. (1998). Copper. *International Programme for Chemical Safety;* Environmental Health Criteria Document 200. Available at: www.inchem.org/documents/ehc/ehc/ehc200.htm

International Programme for Chemical Safety. (1998). Methyl Isobutyl Ketone. *International Programme for Chemical Safety;* Environmental Health Criteria Monograph 117. Available at: http://www.inchem.org/documents/ehc/ehc/ehc117.htm

International Programme for Chemical Safety. (1998). Polycyclic aromatic hydrocarbons, selected non-heterocyclic. *International Programme for Chemical Safety*; Environmental Health Criteria 202. Available at: http://www.inchem.org/documents/ehc/ehc/ehc202.htm

International Programme for Chemical Safety. (1999). Manganese and its compounds. *International Programme for Chemical Safety*; Concise International Chemical Assessment Document 12. Available at: www.inchem.org/documents/cicads/cicads/cicad12.htm

International Programme for Chemical Safety. (1999b). Platinum. *International Programme for Chemical Safety;* Environmental Health Criteria Document 125. Available at: www.inchem.org/documents/ehc/ehc/ehc125.htm

International Programme for Chemical Safety. (2000). Crystalline silica, quartz. *International Programme for Chemical Safety;* Concise International Chemical Assessment Document 24. Available at: http://www.who.int/ipcs/publications/cicad/en/cicad24.pdf

International Programme for Chemical Safety (2001a) Arsenic and arsenic compounds. *International Programme for Chemical Safety;* Environmental Health Criteria Document 224. Available at: http://www.inchem.org/documents/ehc/ehc/ehc224.htm

International Programme for Chemical Safety. (2001b). Barium and barium compounds. *International Programme for Chemical Safety;* Concise International Chemical Assessment Document 33. Available at: www.inchem.org/documents/cicads/cicads/cicad33.htm

International Programme for Chemical Safety. (2001c). Beryllium and beryllium compounds. *International Programme for Chemical Safety;* Concise International Chemical Assessment Document 32. Available at: www.inchem.org/documents/cicads/cicads/cicad32.htm

International Programme for Chemical Safety. (2001). Vanadium Pentoxide and other inorganic vanadium compounds. *International Programme for Chemical Safety;* Concise International Chemical Assessment Document 29. Available at: http://www.inchem.org/documents/cicads/cicads/cicad29.htm

International Programme for Chemical Safety. (2001). Zinc. *International Programme for Chemical Safety;* Environmental Health Criteria Document 221. Available at: www.inchem.org/documents/ehc/ehc/ehc221.htm

International Programme for Chemical Safety. (2002). Palladium. *International Programme for Chemical Safety;* Environmental Health Criteria Document 226. Available at: www.inchem.org/documents/ehc/ehc/ehc226.htm

International Programme for Chemical Safety. (2003). Elemental mercury and inorganic mercury compounds: human health aspects. *International Programme for Chemical Safety;* Concise International Chemical Assessment Document 50. Available at: www.inchem.org/documents/cicads/cicads/cicad50.htm

International Programme for Chemical Safety. (2005). Tin and organic tin compounds. *International Programme for Chemical Safety* ;Concise International Chemical Assessment Document 65. Available at: www.inchem.org/documents/cicads/cicads/cicad65.htm

International Programme for Chemical Safety. (2006). Cobalt and inorganic cobalt compounds. *International Programme for Chemical Safety;* Concise International Chemical Assessment Document 69. Available at: http://www.inchem.org/documents/cicads/cicads/cicad69.htm

International Programme for Chemical Safety. (2009). Inorganic chromium (III) compounds. *International Programme for Chemical Safety*; Concise International Chemical Assessment Document 76. Available at: www.inchem.org/documents/cicads/cicads/cicad76.pdf

Japanese Environment Agency. (1999). Report on tolerable daily intake (TDI) of dioxins and related compounds (Japan). *Environment Agency of Japan*

Jensen L.K., Larsen A., Mølhave L., Hansen M.K., Knudsen B. (2001). Health evaluation of volatile organic compound (VOC) emissions from wood and wood-based materials. , *Archives of Environmental Health;* 56(5): 419-32.

Julander A, Karlsson M, Hagström K, Ohlson CG, Engwall M, Bryngelsson IL. (2005). Polybrominated diphenyl ethers--plasma levels and thyroid status of workers at an electronic recycling facility. *International Archives of Occupational and Environmental Health*; 78(7):584-92.

Kim MK, Oh S, Lee JH, Im H, Ryu YM, Oh E, Lee J, Lee E, Sul D. (2004). Evaluation of biological monitoring markers using genomic and proteomic analysis for automobile emission inspectors and waste incinerating workers exposed to polycyclic aromatic hydrocarbons or 2,3,7,8, tetracholrodedibenzo-p-dioxins. *Experimental and Molecular Medicine*; 36(5):396-410.

Kitamura K, Kikuchi Y, Watanabe S, Waechter G, Sakurai H, Takada T. (2000). Health effects of chronic exposure to polychlorinated dibenzo-P-dioxins (PCDD), dibenzofurans (PCDF) and coplanar PCB (Co-PCB) of municipal waste incinerator workers. *Journal of Epidemiology*; 10(4):262-70.

Konishi K, Sasaki S, Kato S, Ban S, Washino N, Kajiwara J, Todaka T, Hirakawa H, Hori T, Yasutake D, Kishi R. (2009). Prenatal exposure to PCDDs/PCDFs and dioxin-like PCBs in relation to birth weight. Environmental Research;109(7):906-13

Kozajda A, Szadkowska-Stańczyk I. (2009). Selected health complaints, allergic diseases, hygiene behaviors and knowledge of biohazards among workers of waste sorting plants. *Medycyna Pracy*; 60(6):491-9. [English abstract of Polish article]

Kumagai S, Koda S, Miyakita T, Ueno M. (2002). Polychlorinated dibenzo-p-dioxin and dibenzofuran concentrations in serum samples of workers at intermittently burning municipal waste incinerators in Japan. *Occupational and Environmental Medicine;* 59(6):362-8.

Kumagai S, Koda S, Miyakita T, Yamaguchi H, Katagi K, Yasuda N. (2000). Polychlorinated dibenzo-p-dioxin and dibenzofuran concentrations in the serum samples of workers at continuously burning municipal waste incinerators in Japan. *Occupational and Environmental Medicine*; 57(3):204-10.

Kumagai S, Koda S, Oda H. (2003). Exposure evaluation of dioxins in municipal waste incinerator workers. *Industrial Health*; 41(3):167-74.

Kumagai S, Koda S. (2005). Polychlorinated dibenzo-p-dioxin and dibenzofuran concentrations in serum samples of workers at an infectious waste incineration plant in Japan. *Journal of Occupational and Environmental Hygiene*; 2(2):120-5

Kumagai S, Oda H, Tabuchi T, Akasaka S, Kosaka H, Yoshida J, Koda S, Mouri I. (2004). Relationships between dioxin concentrations in deposited dust and those in serum of workers at municipal waste incineration plants. *Sangyo Eiseigaku Zasshi*;.46(1):1-9. [English abstract of Japanese article]

Kuusimäki L, Peltonen Y, Kyyrö E, Mutanen P, Peltonen K, Savela K. (2002). Exposure of garbage truck drivers and maintenance personnel at a waste handling centre to polycyclic aromatic hydrocarbons derived from diesel exhaust. *Journal of Environmental Monitoring*;4(5):722-7.

Kuusimäki L, Peltonen Y, Mutanen P, Peltonen K, Savela K.(2004). Urinary hydroxy-metabolites of naphthalene, phenanthrene and pyrene as markers of exposure to diesel exhaust. *International Archives of Occupational and Environmental Health*;77(1):23-30.

Lawson CC, Schnorr TM, Whelan EA, Deddens JA, Dankovic DA, Piacitelli LA, Sweeney MH, Connally LB. (2004). Paternal occupational exposure to 2,3,7,8-tetrachlorodibenzo-p-dioxin and birth outcomes of offspring: birth weight, preterm delivery, and birth defects. *Environmental Health Perspectives;* 112(14):1403-8.

Lee J, Kang D, Lee KH, Ichiba M, Zhang J, Tomokuni K, Hwang ES, Park CG, Ha M, Kim S, Han SB, Lin YS, Chen KS, Lin YC, Hung CH, Chang-Chien GP. (2008). Polychlorinated dibenzo-p-dioxins/dibenzofurans distributions in ash from different units in a municipal solid waste incinerator. *Journal of Hazardous Materials;* 154(1-3):954-62.

Linaker C, Smedley J. (2002). Respiratory illness in agricultural workers. *Occupational Medicine (Lond)*; 52(8):451-9.

Luginaah IN, Taylor SM, Elliott SJ and Eyles JD. (2000). A longitudinal study of the health impacts of a petroleum refinery. *Social Science and Medicine;* 50(7-8):1155-66.

Luginaah IN, Taylor SM, Elliott SJ and Eyles JD. (2002). Community reappraisal of the perceived health effects of a petroleum refinery. *Social Science and Medicine*; 55(1):47-61.

Mahar S, Reynolds SJ, Thorne PS. (1999). Worker exposures to particulates, endotoxins, and bioaerosols in two refuse-derived fuel plants. *American Industrial Hygiene Assoication Journal*; 60(5):679-83.

Mahar S. (2002). Worker health in refuse-derived fuel plants, a five-year followup. *Archiv za Higijenu Rada I Toksikologiju;* 53(3):191-6.

Mao IF, Tsai CJ, Shen SH, Lin TF, Chen WK, Chen ML. (2006). Critical components of odors in evaluating the performance of food waste composting plants. *The Science of the Total Environment*; 370(2-3):323-9.

Mari M, Borrajo MA, Schuhmacher M, Domingo JL. (2007). Monitoring PCDD/Fs and other organic substances in workers of a hazardous waste incinerator: a case study. *Chemosphere*; 67(3):574-81.

Mari M, Schuhmacher M, Domingo JL. (2009). Levels of metals and organic substances in workers at a hazardous waste incinerator: a follow-up study. *International Archives of Occupational and Environmental Health;* 82(4):519-28.

Matsui M, Kashima Y, Kawano M, Matsuda M, Ambe K, Wakimoto T, Doi R. (2003). Dioxin-like potencies and extractable organohalogens (EOX) in medical, municipal and domestic waste incinerator ashes in Japan. *Chemosphere; 5*3(8):971-80.

Mayrhofer S, Mikoviny T, Waldhuber S, Wagner AO, Innerebner G, Franke-Whittle IH, Mark TD, Hansel A, Insam H. (2006). Microbial community related to volatile organic compound (VOC) emission in household biowaste. *Environmental Microbiology*; 8(11):1960-74.

Muller T, Thissen R, Braun S, Dott W, Fischer G. (2004a). (M)VOC and composting facilities. Part 1: (M)VOC emissions from municipal biowaste and plant refuse. *Environmental Science and Pollution Research International;* 11(2):91-7.

Nadal M, Inza I, Schuhmacher M, Figueras MJ, Domingo JL. (2009). Health risks of the occupational exposure to microbiological and chemical pollutants in a municipal waste organic fraction treatment plant. *International Journal of Hygiene and Environmental Health*; 212(6):661-9.

New York State Department of Health. (2007). Metal recycling industry project. *New York State Department of Health Bureau of Occupational Health*

NIOSH Pocket guide to chemical hazards. Available at: www.cdc.gov/**niosh**/npg

Nordic Expert Group. (2006). Fungal Spores. *The Nordic Expert Group for Criteria Documentation of Health Risks from Chemicals;* 139

Nordic Expert Group. (1998). Antimony. NEG criteria document 123 – 1998:11 Sb *The Nordic Expert Group for Criteria Documentation of Health Risks from Chemicals*. Available at: http://www.inchem.org/documents/kemi/kemi/ah1998_11.pdf

Occupational Safety and Health Administration. (2008). Guidance for the Identification and Control of Safety and Health Hazards in Metal Scrap Recycling. *US Occupational Safety and Health Administration*; OSHA 3348-05 2008.

Oh E, Lee E, Im H, Kang HS, Jung WW, Won NH, Kim EM, Sul D. (2005). Evaluation of immuno- and reproductive toxicities and association between immunotoxicological and genotoxicological parameters in waste incineration workers. *Toxicology*; 210(1):65-80.

Park H, Ikonomou MG, Kim HS, Choi JW, Chang YS. (2009). Dioxin and dioxin-like PCB profiles in the serum of industrial and municipal waste incinerator workers in Korea. *Environment International;* 35(3):580-7.

Pelclova D, Fenclova Z, Dlaskova Z, Urban P, Lukas E, Prochazka B, Rappe C, Preiss J, Kocan A, Vejlupkova J. (2001). Biochemical, neuropsychological, and neurological abnormalities following 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD) exposure. *Archives of Environmental Health*; 56(6):493-500.

Persoons R, Parat S, Stoklov M, Perdrix A, Maitre A. (2010). Critical working tasks and determinants of exposure to bioaerosols and MVOC at composting facilities. *International Journal of Hygiene and Environmental Health*; 213(5):338-47.

Pettersson-Julander A, van Bavel B, Engwall M, Westberg H. (2004). Personal air sampling and analysis of polybrominated diphenyl ethers and other bromine containing compounds at an electronic recycling facility in Sweden. *Journal of Environmental Monitoring*; 6(11):874-80.

Pless-Mulloli T, Edwards R, Howel D, Wood R, Paepke O, Herrmann T. (2005). Does long term residency near industry have an impact on the body burden of polychlorinated dibenzo-p-dioxins, furans, and polychlorinated biphenyls in older women? *Occupational and Environmental Medicine;* 62(12):895-901.

Pohl HR, Holler J, De Rosa CT. (1999). ATSDR's Guidance Values for dioxins. Risk Assessment And Risk Management. *Organohalogen Compounds*; Vol 44 (1999).

Raemdonck A, Koppen G, Bilau M, Willems JL. (2006). Exposure of maintenance workers to dioxin-like contaminants during the temporary shutdown of a municipal domestic solid waste incinerator: a case series. *Archives of Environmental and Occupational Health;* 61(3):115-21.

Rix BA, Villadsen E, Engholm G, Lynge E. (1997). Risk of cancer among paper recycling workers. *Occupational and Environmental Medicine*; 54(10):729-33.

Rodahl, K. (1989) The physiology of work, CRC. *Taylor and Francis, London.*

Ruder AM, Yiin JH. (2011). Mortality of US pentachlorophenol production workers through 2005. *Chemosphere*; 83(6):851-61.2005.

Rylander R. (2010). Organic dust induced pulmonary disease - the role of mould derived beta-glucan. *Annuals of Agricultural and Environmental Medicine*; 17(1):9-13.

Schecter A, Colacino JA, Harris TR, Shah N, Brummitt SI. (2009). A newly recognized occupational hazard for US electronic recycling facility workers: polybrominated diphenyl ethers. *Journal of Occupational and Environmental Medicine*; 51(4):435-40.

Schecter A, Päpke O, Ball M, Lis A, Brandt-Rauf P. (1995). Dioxin concentrations in the blood of workers at municipal waste incinerators. *Occupational and Environmental Medicine;* 52(6):385-7.

Schiffman SS and Williams CM. (2005). Science of odour as a potential health issue. *Journal of Environmental Quality;* 34(1):129-38.

Schlosser O, Huyard A, Cartnick K, Yañez A, Catalán V, Quang ZD. (2000). Bioaerosol in composting facilities: occupational health risk assessment. *Water Environmental Research;* 81(9):866-77.

Scientific Committee on Occupational Exposure Limits. (1986). Recommendation from the *Scientific Committee on Occupational Exposure Limits*; Risk assessment for Hexavalent Chromium SCOEL/SUM/86.

Scientific Committee on Occupational Exposure Limits. (2002). Recommendation from the Scientific Committee on Occupational Exposure Limits Chromium Metal, Inorganic Chromium (II) Compounds, and Inorganic Chromium (III) Compounds. *Scientific Committee on Occupational Exposure Limits;* SCOEL/SUM/50.

Scientific Committee on Occupational Exposure Limits. (2002). Recommendation from the Scientific Committee on Occupational Exposure Limits for lead and its inorganic compounds. *Scientific Committee on Occupational Exposure Limits;* SCOEL/SUM/83.

Scientific Committee on Occupational Exposure Limits. (2004). Committee for Occupational Exposure Limits for vanadium pentoxide. *Scientific Committee on Occupational Exposure Limits;* SCOEL/SUM/62.

Scientific Committee on Occupational Exposure Limits. (2007). Recommendation from the Scientific Committee on Occupational Exposure Limits for elemental mercury and inorganic divalent mercury compounds. *Scientific Committee on Occupational Exposure Limits;* SCOEL/SUM/84.

Scientific Committee on Occupational Exposure Limits. (2010). Recommendation from the Scientific Committee on Occupational Exposure Limits for cadmium and its inorganic compounds. *Scientific Committee on Occupational Exposure Limits;* SCOEL/SUM/136.

.
Scientific Committee on Occupational Exposure Limits. (2003). Recommendation from the Scientific Committee on Occupational Exposure Limits for tin and inorganic tin compounds. *Scientific Committee on Occupational Exposure Limits;* SCOEL/SUM/97.

Scientific Committee on Occupational Exposure Limits. (2007). Recommendation from the Scientific Committee on Occupational Exposure Limits for Hydrogen Sulphide. *Scientific Committee on Occupational Exposure Limits;* SCOEL/SIM/124.

Searl A. (2010). Exposure-response relationships for bioaerosol emissions from waste treatment processes. *Defra Project*; WR0606. Available at: http://randd.defra.gov.uk/Document.aspx?Document=WR0606_8696_FRP.pdf.

Shih TS, Chen HL, Wu YL, Lin YC, Lee CC. (2006). Exposure assessment of polychlorinated dibenzo-p-dioxins and dibenzofurans(PCDD/Fs) in temporary municipal-waste-incinerator maintenance workers before and after annual maintenance. *Chemosphere*; 64(9):1444-9.

Sigsgaard T, Schlunssen V. (2004). Occupational asthma diagnosis in workers exposed to organic dust. *Annuals of Agricultural and Environmental Medicine;* 11(1):1-7.

Sjödin A, Carlsson H, Thuresson K, Sjölin S, Bergman A, Ostman C. (2001). Flame retardants in indoor air at an electronics recycling plant and at other work environments. *Environmental Science and Technology*; 35(3):448-54.

SNIFFER. (2007). Best practice guidance for the management of hygiene waste for key processes in Northern Ireland and Scotland. Project UKW01

Squeri R, La Fauci V, Sindoni L, Cannavò G, Ventura Spagnolo E. (2006). Study on hepatitis B and C serologic status among municipal solid waste workers in Messina (Italy). *Journal of Preventative Medicine and Hygiene*;47(3):110-3.

Steinheider B. (1999). Environmental odours and somatic complaints. *Zentralblatt für Hygiene und Umweltmedizin*; 202(2-4):101-19.

Sucker K, Both R and Winneke G. (2001). Adverse effects of environmental odours: reviewing studies on annoyance responses and symptom reporting. *Water Science and Technology;* 44(9):43-51.

Sul D, Oh E, Im H, Yang M, Kim CW, Lee E. (2003). DNA damage in T- and B-lymphocytes and granulocytes in emission inspection and incineration workers exposed to polycyclic aromatic hydrocarbons. *Mutation Research;* 538(1-2):109-19.

Sweetman A, Keen C, Healy J, Ball E, Davy C. (2004). Occupational exposure to dioxins at UK worksites. *The Annals of Occupational Hygiene*; 48(5):425-37.

Sykes P, Morris RH, Allen JA, Wildsmith JD, Jones KP. (2011). Workers' exposure to dust, endotoxin and β-(1-3) glucan at four large-scale composting facilities. *Waste Management*; 31(3):423-30.

Tajimi M, Uehara R, Watanabe M, Oki I, Ojima T, Nakamura Y. (2005). Relationship of PCDD/F and Co-PCB concentrations in breast milk with infant birthweights in Tokyo, Japan. *Chemosphere*; 61(3):383-8

Takata T. (2003). Survey on the health effects of chronic exposure to dioxins and its accumulation on workers of a municipal solid waste incinerator, rural part of Osaka Prefecture, and the results of extended survey afterwards. *Industrial Health*; 41(3):189-96.

Thuresson K, Bergman K, Rothenbacher K, Herrmann T, Sjölin S, Hagmar L, Päpke O, Jakobsson K. (2006). Polybrominated diphenyl ether exposure to electronics recycling workers--a follow up study. *Chemosphere*; 64(11):1855-61.

Tolvanen O, Nykanen J, Nivukoski U, Himanen M, Veijanen A, Hanninen K. (2005). Occupational hygiene in a Finnish drum composting plant. *Waste Management*; 25(4):427-33.

Tooher R, Griffin T, Shute E, Maddern G. (2005). Vaccinations for waste-handling workers. A review of the literature. *Waste Management;* 23(1):79-86.

Umicore. (2008). Opportunities and challenges to recover scarce and valuable metals from electronic devices. *OECD-UNEP Conference on Resource Efficiency, Paris, April 24, 2008*. Available at: www.oecd.org/dataoecd/13/11/40798834.pdf

UNEP E-waste http://ewasteguide.info/node/4074

US Environmental Protection Agency. (1993). Molybdenum. *United States Environmental Protection Agency* Integrated Risk Information System. Available at: www.epa.gov/iris

US Environmental Protection Agency. (2001). Dioxin: Scientific highlights from draft reassessment (2000). *United States Environmental Protection Agency* Information Sheet 2, May 25, 2001 update

Valavanidis A, Fiotakis K, Vlachogianni T. (2008). Airborne particulate matter and human health: toxicological assessment and importance of size and composition of particles for oxidative damage and carcinogenic mechanisms. *Journal of Environmental Science and Health. Part C, Environmental Carcinogenesis Ecotoxicology Reviews*; 26(4):339-62.

Vena J, Paolo Bofetta, Becher H, Benn T, Bueno-de-Mesquita HB, Coggon D, Colin D, Littorin M, Lynge E, Matthews JD, Neuberger M, Pearce N, Pestaori AC, Saracci R, Steenland K, Kogevinas M. (1998). Exposure to dioxin and nonneoplastic mortality in the expanded IARC International cohort study of phenoxy herbicide and chlorophenol production workers and sprayers. *Environmental Health Perspectives;* 106, Supplement 2, 645-653

WATCH. (2004). Health significance of occupationally-induced declines in FEV1. *WATCH*; WATCH2004/11

WATCH (2007) Current Occupational exposure limits for a number of individual dusts. *WATCH;* WATCH2007/1 Annex 6

World Health Organization. (1998). Assessment of the health risk of dioxins: re-evaluation of the Tolerable Daily Intake (TDI): World Health Organization Executive Summary. *World Health Organization*; WHO Consultation May 25-29 1998, Geneva, Switzerland.

World Health Organization. (2000). Air quality guidelines for Europe. Second Edition. *World Health Organisation.* Available at: www.euro.who.int/__data/assets/pdf_file/0005/74732/E71922.pdf

World Health Organization. (2000a). Air quality guidelines for Europe. *World Health Organization.*

World Health Organization. (2004). Review of Health Impacts from Microbiological Hazards in Health-Care Wastes. *Department of Blood Safety and Clinical Technology and Department of Protection of the Human Environment World Health Organization*. Geneva 2004

Wick DE, Roberts SK, Basu A, Sandroni P, Fealey RD, Sletten D, Charkoudian N. (2006). Delayed threshold for active cutaneous vasodilation in patients with Type 2 diabetes mellitus. *Journal of Applied Physiology*; 100: 637-641.

Wikoff DS, Birnbaum L (2011) Human Health Effects of Brominated Flame Retardants in E. Eljarrat and D. Barcelo´ (eds.), Brominated Flame Retardants,Hdb Env Chem (2011) 16: 19–53, DOI 10.1007/698_2010_97,# Springer-Verlag Berlin Heidelberg 2010

Wrbitzky R, Göen T, Letzel S, Frank F, Angerer J. (1995). Internal exposure of waste incineration workers to organic and inorganic substances. *International Archives of Occupational and Environmental Health*; 68(1):13-21.

Wultsch G, Mišík M, Nersesyan A, Knasmueller S. (2011). Genotoxic effects of occupational exposure measured in lymphocytes of waste-incinerator workers. *Mutation Research*; 720(1-2):3-7.

Yao J, Li W, Xia F, Zheng Y, Fang C, Shen D. (2011). Heavy metals and PCDD/Fs in solid waste incinerator fly ash in Zhejiang province,China: chemical and bio-analytical characterization. Environmental Monitoring and Assessment; Jul 19.

Yoshida J, Kumagai S, Tabuchi T, Kosaka H, Akasaka S, Kasai H, Oda H. (2006). Negative association between serum dioxin level and oxidative DNA damage markers in municipal waste incinerator workers. *International Archives of Occupational and Environmental Health*; 79(2):115-22.

Yoshida J, Kumagai S, Tabuchi T, Kosaka H, Akasaka S, Oda H. (2005). Effects of dioxin on metabolism of estrogens in waste incinerator workers. *Archives of Environmental and Occupational Health*; 60(4):215-22.

Youle, A. & Parsons, K.C. (2009). The Thermal Environment Technical Guide Number 12, Addendum. *British Occupational Hygiene Society*

Youle, A., Collins, K.J., Crockford, G.W., Fishman, D.S., Mulhall, A. & Parson, K.C. (1996). The Thermal Environment, Technical Guide Number 12. *British Occupational Hygiene Society.*

Zuskin E, Mustajbegović J, Kanceljak-Macan B, Macan J, Decković-Vukres V, Vitale K. (19980. Respiratory function and allergic reactions in paper recycling workers. *Arhiv Za Higijenu Rada I Toksikologiju*; 49(2):165-77. [English abstract of Croatian article]

Appendix 1: Questionnaire responses
Health Risks in the Waste Recycling Industry

HEALTH SURVEILLANCE AND SICKNESS ABSENCE MONITORING

Do you undertake health surveillance?		
Answer Options	**Response Percent**	**Response Count**
Yes	100.0%	6
No	0.0%	0

Dependent on risk assessment, and the business activity being carried out, includes - Audiometry, hand arm vibration, respiratory.

General fitness for job/vision/hearing/skin/BP/musculoskeletal/DSE

Various - we have in excess of 20 employee categories based on potential exposures. Assessment specifics variy dependent on these. However, lung function, hearing, dermatitis, HAVs etc are fairly common across the board.

lung function

skin testing

Audiometry

Noise, manual handling, respirotory sensitisors, carcinogens, skin sentisiers, toxic, hearmful substances, sewage, clinical, vibration, night shift work.

Hearing, lung function, HAV's and skin tests

Do you routinely monitor respiratory health (eg lung function testing every 2 years)?		
Answer Options	**Response Percent**	**Response Count**
Yes	83.3%	5
No	16.7%	1

Do you systematically record sickness absence data for the purposes of future analysis?		
Answer Options	**Response Percent**	**Response Count**
Yes	83.3%	5
No	16.7%	1

Have you systematically reviewed sickness absence data to assess whether there is evidence of work-related ill-health?		
Answer Options	**Response Percent**	**Response Count**
Yes	50.0%	3
No	50.0%	3

If you answered yes to the previous question, would you be willing to provide us with information about your findings? If you answered no, please go to the next question.		
Answer Options	**Response Percent**	**Response Count**
Yes	33.3%	1
No	66.7%	2

Noise related hearing loss, hand arm vibration (particularly street cleansing and grounds maintenance)
Age related degeneration ie backs and arthritis and deteriorating hearing / vision as most of our employees have been here a decade or so and the agerage age is around 50
This varies dependent on job. For exaple, for waste collection operatives manual handling is the major cause of time off work, whereas for workers in organic waste treatment plants exposure to bio-aerosols may be the highest risk area.
Exposure to skin contaminants in workshops
This very depends on their job role - we carry out a wide variety of activities. In hazardous waste environments there are risks from carcinogens and other sentisers that may have long term health effects. In other waste environments, there is potential for airborne contaminants which could cause respiratory illness. Noise in recycling plants, AD plants and in glass collection for our municipal and commercial divisions.
Noise, HAV's

TYPICAL WORK PATTERNS

Do workers normally rotate between tasks during the course of individual shifts?		
Answer Options	**Response Percent**	**Response Count**
Yes	66.7%	4
No	33.3%	2
If you answered yes to the previous question, is the rotation		
Answer Options	**Response Percent**	**Response Count**
Formal rotation after a specific time period?	33.3%	1
Informal rotation?	66.7%	2
Other (please specify)		2

where necessary ie picking belts
Both depending upon where they are working.

Do workers normally do different tasks on different shifts?		
Answer Options	**Response Percent**	**Response Count**
Yes	33.3%	2
No	66.7%	4
If you answered yes please answer the question below. If you answered no please go to the next section.		
Answer Options	**Response Percent**	**Response Count**
Formal rotation on different tasks on different shifts	100.0%	1
Informal rotation	0.0%	0
Other (please specify)		0

EXPOSURE TO HAZARDOUS SUBSTANCES: MEASUREMENTS AND CONTROL MEASURES

Do you undertake routine monitoring of workplace exposure to dust or other chemicals such as bioaerosol, metals, VOCs, Dioxin's/Furans?		
Answer Options	**Response Percent**	**Response Count**
Yes	100.0%	4
No	0.0%	0
	answered question	**4**
	skipped question	**2**

If yes, please indicate for what substances monitoring is undertaken in the table below by clicking on the relevant boxes. If you tick other in the last column can you please describe the monitoring that is being undertaken.							
Answer Options	**Dust**	**Bioaerosol**	**Metals**	**VOCs**	**Dioxins/Furans**	**Other (please specify below)**	**Response Count**
Anaerobic Digestion	2	2	0	0	0	0	2
Composting	2	4	0	0	0	0	4
Incineration or other thermal treatments	2	0	0	0	1	0	2
MRFs	2	1	0	0	0	0	2
Waste transfer station	2	0	0	0	0	0	2
Separation and reprocessing of glass, plastics or wood	1	0	0	0	0	0	1
WEEE	0	0	0	0	0	0	0
Fridge recycling	0	0	0	0	0	0	0
Metal recycling	0	0	0	0	0	0	0
Paper and cardboard recycling	2	0	0	0	0	0	2
Other processes or substances (please specify below)	2	1	0	0	0	0	2
Other (please specify) MBT							2

Do you have exposure data in a form that could be used to inform this review?		
Answer Options	**Response Percent**	**Response Count**
Yes	50.0%	2
No	50.0%	2
	answered question	**4**
	skipped question	**2**

If you measure dust in workplace air for any of these processes – indicate approximate extent of compliance with the UK workplace exposure limit (WEL)					
Answer Options	**All measurements well below WEL**	**Most measurements below WEL**	**Rare measurements exceed WEL**	**Many measurements exceed WEL**	**Response Count**
Anaerobic digestion	1	0	0	0	1
Composting	3	0	1	0	4
Incineration, other thermal treatments	2	0	0	0	2
MRFs	2	1	0	0	3
Waste transfer station	2	1	0	0	3
Separation and reprocessing of glass, plastic or wood	0	1	0	0	1
WEEE	0	0	0	0	0
Fridge recycling	0	0	0	0	0
Metal recycling	0	0	0	0	0
Paper and cardboard recycling	0	1	0	0	1
Other (please specify below)	1	0	0	0	1
Other (please specify)					1

MBT as above. NOTE - thre are no WELs for bio-aerosols and, as such, I cannot comment. The above is for total and respirable dusts.

Are you aware of any specific exposure issues (dust, bioaerosol, VOCs, metals or any other substance) that are a problem on your sites?	
Answer Options	**Response Count**
	3
answered question	**3**
skipped question	**3**

no

Bio-aerosols: Endotoxins for most sites and AF (and other spores etc) at AD, composting and MBT plants. Others specific to treatment technology used.

No

For each type of process indicate whether conditions indicated by the column headers apply to All, Some or None of your sites or NA if this process is not undertaken

Process entirely automated and enclosed

Answer Options	All	Some	None	N/A	Response Count
Anaerobic digestion	1	0	1	0	2
Composting	1	0	1	0	2
Incineration or other thermal treatments	0	1	0	0	1
MRFs	0	0	1	0	1
Waste transfer station	0	0	1	0	1
Separation and reprocessing of glass, plastic or wood	0	0	0	0	0
WEEE	0	0	0	0	0
Fridge recycling	0	0	0	0	0
Metal recycling	0	0	0	0	0
Paper and cardboard recycling	0	0	0	0	0
Other activities (please specify in the box below)	0	1	0	0	1

Process automated and partly enclosed

Answer Options	All	Some	None	N/A	Response Count
Anaerobic digestion	1	0	0	0	1
Composting	1	0	0	0	1
Incineration or other thermal treatments	0	1	0	0	1
MRFs	0	1	0	0	1
Waste transfer station	0	1	0	0	1
Separation and reprocessing of glass, plastic or wood	0	0	0	0	0
WEEE	0	0	0	0	0
Fridge recycling	0	0	0	0	0
Metal recycling	0	0	0	0	0
Paper and cardboard recycling	0	0	0	0	0
Other activities (please specify in the box below)	1	0	0	0	1

LEV where exposure possible

Answer Options	All	Some	None	N/A	Response Count
Anaerobic digestion	0	1	0	0	1
Composting	0	1	0	0	1
Incineration or other thermal treatments	0	0	0	1	1
MRFs	0	1	0	0	1
Waste transfer station	0	0	1	0	1
Separation and reprocessing of glass, plastic or wood	0	0	0	0	0
WEEE	0	0	0	0	0
Fridge recycling	0	0	0	0	0
Metal recycling	0	0	0	0	0
Paper and cardboard recycling	0	0	0	0	0

Other activities (please specify in the box below)	1	0	0	0	1

Some manual handling of waste					
Answer Options	**All**	**Some**	**None**	**N/A**	**Response Count**
Anaerobic digestion	0	0	1	0	1
Composting	0	0	1	0	1
Incineration or other thermal treatments	0	1	0	0	1
MRFs	0	1	0	0	1
Waste transfer station	0	0	1	0	1
Separation and reprocessing of glass, plastic or wood	0	0	0	0	0
WEEE	0	0	0	0	0
Fridge recycling	0	0	0	0	0
Metal recycling	0	0	0	0	0
Paper and cardboard recycling	0	0	0	0	0
Other activities (please specify in the box below)	0	0	1	0	1

Extensive handling of waste					
Answer Options	**All**	**Some**	**None**	**N/A**	**Response Count**
Anaerobic digestion	0	0	1	0	1
Composting	0	0	1	0	1
Incineration or other thermal treatments	0	0	1	0	1
MRFs	0	1	0	0	1
Waste transfer station	0	0	1	0	1
Separation and reprocessing of glass, plastic or wood	0	0	0	0	0
WEEE	0	0	0	0	0
Fridge recycling	0	0	0	0	0
Metal recycling	0	0	0	0	0
Paper and cardboard recycling	0	0	0	0	0
Other activities (please specify in the box below)	0	0	1	0	1

No discharge of treated air to outside					
Answer Options	**All**	**Some**	**None**	**N/A**	**Response Count**
Anaerobic digestion	1	0	0	0	1
Composting	0	1	0	0	1
Incineration or other thermal treatments	0	0	0	1	1
MRFs	0	0	1	0	1
Waste transfer station	0	0	1	0	1
Separation and reprocessing of glass, plastic or wood	0	0	0	0	0
WEEE	0	0	0	0	0
Fridge recycling	0	0	0	0	0
Metal recycling	0	0	0	0	0
Paper and cardboard recycling	0	0	0	0	0

Other activities (please specify in the box below)	0	1	0	0	1

Other is MBT. NOTE - the above does not take account of task type. For example, general operatives at an AD plant will have a different exposure pattern than maintenance staff who may need to break-into enclosed systems etc.

Do you have any further comments on process controls intended to limit worker exposure to hazardous substances?	
Answer Options	**Response Count**
	2

no

The above needs to be broken-down by task and specific worker type.

For each type of process please indicate whether conditions indicated by the column headers apply at All, Some or None of your sites. Please click on N/A when the processes are not undertaken

Provision of work wear not to be worn off-site

Answer Options	**All**	**Some**	**None**	**N/A**	**Response Count**
Anaerobic digestion	1	0	1	1	3
Composting	2	0	0	0	2
Incineration or other thermal treatments	1	0	0	0	1
MRFs	1	1	0	0	2
Waste transfer station	0	1	0	0	1
Separation and reprocessing of glass, plastic or wood	0	0	0	0	0
WEEE	0	0	0	0	0
Fridge recycling	0	0	0	0	0
Metal recycling	0	0	0	0	0
Paper and cardboard recycling	1	0	0	0	1
Other (please add additional comments below)	1	0	0	0	1

Ban on eating or drinking in waste handling or treatment zones

Answer Options	**All**	**Some**	**None**	**N/A**	**Response Count**
Anaerobic digestion	2	0	0	0	2
Composting	2	0	0	0	2
Incineration or other thermal treatments	1	0	0	0	1
MRFs	2	0	0	0	2
Waste transfer station	1	0	0	0	1
Separation and reprocessing of glass, plastic or wood	0	0	0	0	0
WEEE	0	0	0	0	0
Fridge recycling	0	0	0	0	0
Metal recycling	0	0	0	0	0
Paper and cardboard recycling	1	0	0	0	1
Other (please add additional comments below)	1	0	0	0	1

Compulsory use of RPE where exposure is possible					
Answer Options	**All**	**Some**	**None**	**N/A**	**Response Count**
Anaerobic digestion	1	0	0	0	1
Composting	2	0	0	0	2
Incineration or other thermal treatments	1	0	0	0	1
MRFs	2	0	0	0	2
Waste transfer station	0	0	1	0	1
Separation and reprocessing of glass, plastic or wood	0	0	0	0	0
WEEE	0	0	0	0	0
Fridge recycling	0	0	0	0	0
Metal recycling	0	0	0	0	0
Paper and cardboard recycling	1	0	0	0	1
Other : MBT	1	0	0	0	1

Compulsory use of gloves where dermal contact is possible					
Answer Options	**All**	**Some**	**None**	**N/A**	**Response Count**
Anaerobic digestion	1	0	0	0	1
Composting	2	0	0	0	2
Incineration or other thermal treatments	1	0	0	0	1
MRFs	2	0	0	0	2
Waste transfer station	1	0	0	0	1
Separation and reprocessing of glass, plastic or wood	0	0	0	0	0
WEEE	0	0	0	0	0
Fridge recycling	0	0	0	0	0
Metal recycling	0	0	0	0	0
Paper and cardboard recycling	1	0	0	0	1
Other (please add additional comments below)	1	0	0	0	1

Provision of RPE and gloves with voluntary use					
Answer Options	**All**	**Some**	**None**	**N/A**	**Response Count**
Anaerobic digestion	0	0	1	0	1
Composting	1	0	1	0	2
Incineration or other thermal treatments	0	0	1	0	1
MRFs	1	1	0	0	2
Waste transfer station	0	1	0	0	1
Separation and reprocessing of glass, plastic or wood	0	0	0	0	0
WEEE	0	0	0	0	0
Fridge recycling	0	0	0	0	0
Metal recycling	0	0	0	0	0
Paper and cardboard recycling	1	0	0	0	1
Other - MBT	0	0	1	0	1

WORKING AT ELEVATED TEMPERATURES

Do you require workers to enter areas where the temperature is above 20°C?		
Answer Options	**Response Percent**	**Response Count**
Yes	33.3%	1
No	66.7%	2

If yes, for temperatures above 20°C please answer the following questions. If no please go to the next section

How frequently does this occur?	daily
What is the duration of work?	Very short
Are workers wearing coveralls in this environment?	
Are workers wearing respiratory protective equipment in this environment?	
Please describe the work tasks	

RISK FACTORS FOR WORK-RELATED STRESS

What proportion of workers are engaged in tasks where work rate and content is process driven with no opportunity to exercise individual control (eg picking materials from a conveyor)?	
Answer Options	**Response Count**
	3

None
MRFs - however, belt speed is controlled by workers
60%

How many hours per day do workers undertake such work?	
Answer Options	**Response Count**
	3

Na
MRFs - up to ten hours a day (not including breaks - every 2 hours at minimum)
10 hours

What proportion of workers only undertake the same (single activity) task all shift, every shift?	
Answer Options	**Response Count**
	3

None
MRFs only - 80%
10%

Do your employees work variable shifts?		
Answer Options	**Response Percent**	**Response Count**
Yes	33.3%	1
No	66.7%	2

If yes, please describe a typical shift rotation
Varies from site to site