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Occupational Hygiene implications of processing waste at Materials Recycling Facilities (MRFs)

Exposure to bioaerosol and dust

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Occupational Hygiene implications of processing waste at Materials Recycling Facilities (MRFs)

Exposure to bioaerosol and dust

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This report presents the findings of a study to investigate exposures to dust and its microbiological components amongst workers employed at Materials Recycling Facilities (MRFs).

The report shows the potential for workers to be exposed to general airborne dust above the level where it is considered a substance hazardous to health (10 mg/m^3 as an 8-hr TWA). Also, there is the potential for exposure to fungi and bacteria, as well as endotoxins, which are agents known to have harmful effects on human health. Endotoxin exposures may be at levels greater than the health-based limit identified by the Dutch Expert Committee on Occupational Safety of 90 EU/m^3.

MRFs play an important role in meeting the demand on UK government to substantially reduce the amount of waste sent to landfill. Provision of MRF sites will be necessary to meet demands for recycling and this industry is likely to expand in the long term. Although recycling and sorting of waste is increasingly mechanised, reliance on manual operations still remains.

The report concludes that the health implications of employee exposure to dust and bioaerosols was not fully considered at the sites visited. This was associated with a lack of corporate occupational health strategies and a failure to adequately manage health and hygiene provision. Areas for improvement identified included: undertaking suitable and sufficient risk assessments; adoption of well implemented, risk-based health surveillance programmes; and the provision of adequate hygiene facilities.

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KEY MESSAGES

The UK government's ongoing commitment to substantially reduce the amount of waste sent to landfill sites will lead to an increase in demand for recycling. Materials Recycling Facilities (MRFs) will play an important role in meeting this demand and so the industry is likely to expand in the long term. Although the recycling and sorting of waste is increasingly mechanised, there remains a heavy reliance on manual operations.

The work described in this report identifies the potential for employees working in MRFs to be exposed to general airborne dust above the level where it is considered a substance hazardous to health (10 mg/m^3 as an 8-hr TWA). There is also the potential for exposure to fungi and bacteria; and to endotoxins, agents known to have harmful effects on human health (Ref 1). Exposure to endotoxins may be at levels greater than the health-based limit identified by the Dutch Expert Committee on Occupational Safety (DECOS) of 90 EU/m^3 (Ref 2).

At the sites visited, there was a lack of suitable and sufficient COSHH risk assessments and corporate Occupational Health strategies, accompanying policy and arrangements for their implementation. This suggests that the health implications of exposure to dust and bioaerosols are not being addressed at a management/corporate level.

The results from the study showed that, overall, the management of employee health and the provision of hygiene facilities were not adequate. There was a general lack of understanding by management of the value of a well-implemented, risk-based health surveillance programme.

Within the MRF industry, control of inhalation exposure to hazardous substances relies on the provision of effective general ventilation and the correct wearing of disposable respirators. Local exhaust ventilation (LEV) was not in common use. The provision of information to, and training and supervision of, staff dealing with health issues were all found to be deficient. There needs to be greater focus on applying the principles of good occupational hygiene control detailed in the COSHH Regulations and ensuring that staff are given the training and proper equipment to control the health risks adequately.

Greater emphasis should be placed on targeting, defining and implementing control measures, including the design and layout of the facility and the flow of workers through the site. Respirators were often made available to all and, occasionally, recommended for certain tasks. However, there were no clear policies in place for their use. The need to use RPE and the selection of respirator type did not appear to have been fully considered. Where RPE was used, no fit testing had been carried out and it was not always worn correctly. This indicates that the training and supervision of users could be improved. Better industry guidance might be appropriate in this area. Similarly, general ventilation systems installed in picking cabins appeared to focus on the comfort of the user rather than the control of exposure. This meant that the standard of general ventilation was also variable.

As a consequence of the proposal by DECOS to reduce the 8-hr TWA health-based exposure limit for endotoxin from 200 to 90 EU/m^3 (Ref 2), the proportion of employees in this study exceeding the limit of would increase from 14% (approximately 1 in 7) to 34% (approximately 1 in 3).

EXECUTIVE SUMMARY

Introduction

There is an obligation on the UK Government to reduce the amount of waste sent to landfill. Under the European Landfill Directive (Council Directive 1999/31/EC), the UK must reduce the quantity of biodegradable municipal solid waste sent to landfill to 35% of 1995 levels before 2020. Fundamental to achieving these targets is the recycling and re-use of waste. Materials Recycling Facilities (MRFs) are specialised plant that separate, process, grade and store solid waste fractions, prior to onward dispatch to re-processors.

The processes involved during recycling can generate organic dust, which may lead to exposure to airborne microorganisms and their toxic by-products. This may cause health problems in workers involved in handling waste.

This report presents the findings of a study to investigate exposures to dust and its microbiological components. It also details the exposure control measures implemented at the MRFs visited and presents the findings of a parallel occupational health study.

Methodology

The study involved occupational hygiene surveys at seven MRFs. Each visit was conducted over one or two days and aimed to measure exposures to substances hazardous to health at all stages of the recycling process. Air sampling, predominantly personal monitoring, was used. Wherever possible, task-specific air monitoring was conducted, with full-shift exposures being calculated based on the individual task-specific results for each worker.

In addition to measuring exposures, exposure control strategies were assessed. This included management systems (COSHH assessments, operator training etc), engineering controls and the PPE regime.

A parallel occupational health survey of employees was also carried out at each site. A standard questionnaire, completed by interview, was used, to allow consistent information to be collected from each of the seven sites visited.

Findings

Air monitoring

A total of one hundred and thirty nine exposures were measured for inhalable dust and microorganisms. Sampling was conducted during periods that were representative of typical working conditions.

8-hr TWA exposures to inhalable dust ranged from 0.15 to 22.63 mg/m^3. Seven (5%) of the exposures were above 10 mg/m^3, the level at which the COSHH definition (Ref 7) of a substance hazardous to health includes inhalable dust of any kind. These were to workers in the sorting cabins at two of the MRFs where they had high-energy sorting machines. These agitated the waste and may have been responsible for generating higher levels of airborne dust.

The results from forty-six static samples indicated background concentrations ranging from 0.11 to 9.91 mg/m^3 for inhalable dust, and from less than the limit of detection (LOD) to 0.91 mg/m^3 for respirable dust.

Exposures to endotoxin ranged from less than the LOD to 2399 EU/m^3 (8hr TWA). Forty seven (34%) of the exposures were above the 8hr TWA health based occupational exposure limit, not yet implemented, but proposed by DECOS for airborne endotoxin of 90 endotoxin units (EU)/m^3. The majority of the exposures over 90 EU/m^3 were measured at MRF's that used high energy sorting machinery. During this study the proposed limit was reduced from 200 EU/m^3 to 90 EU/m^3. As a consequence of this the number of samples exceeding the proposed limit increased from 14% to 34%.

The results from forty-six static samples indicated background endotoxin concentrations ranging from less than the LOD to 351 EU/m^3 and background respirable endotoxin concentrations ranging from less than the LOD to 30.37 EU/m^3.

Exposure to inhalable bacteria ranged from 10^2 to 10^5 cfu/m^3. None of the exposures were greater than 10^6. However, one hundred and two (73%) exposures were greater than 10^4.

Exposure to inhalable fungi ranged from 10^2 to 10^5 cfu/m^3. None of the exposures were greater than 10^6 and one hundred and thirteen (81%) were greater than 10^4.

Based on data from other studies of exposure to organic dusts, the measured air levels of bacteria and fungi were predominantly within the medium range (between 10^4 and 10^5 cfu/m^3). This is more than ten times the normal upper concentration found in ambient air (Ref 3&4). However, some areas were found to have concentrations greater than 10^5 cfu/m^3. This is comparable to industries where the air has a higher organic load, such as animal and poultry houses (Ref 1,5&6).

Identified species of bacteria and fungi were typical of those found in organic dust, including *Bacillus* bacteria and *Aspergillus fumigatus* fungi, the latter also being associated with composting of materials and recognised as potential allergens.

Exposure to *Aspergillus fumigatus* (a major allergen) ranged from less than the LOD to 10^5 cfu/m^3. Seventeen (12%) of the exposures were greater than 10^4 and a further twenty were greater than 10^3.

Exposure Control

Corporate Occupational Health strategies, accompanying policies and arrangements for their implementation were not evident at the sites visited.

COSHH risk assessments had either not been carried out or were in need of review, at most of the sites visited.

None of the seven sites visited used LEV inside the sorting stations to reduce operator exposure. One applied LEV to the process outside the sorting cabins, with capturing hoods placed in areas where there was the potential for dust to be generated. However, exposures measured at this site were amongst the highest found during the study, indicating limited effectiveness of this LEV in controlling exposure. This site was also the most enclosed of those visited, meaning that non-mechanical general ventilation through doorways etc. was likely to be less than at other sites.

Forced general ventilation was present in sorting cabins at four of the MRFs. However, some of the systems were in a state of disrepair. A large number of cabins were fitted with recycling air-conditioning units, provided for worker comfort. Water mist dust suppression systems were installed at two sites in waste reception and baling areas.

Respiratory protective equipment (RPE) in some form was supplied at all of the sites visited. Disposable masks ranged from single strap ‘nuisance dust’ type to respirators of FFP3 standard. Most sites supplied FFP1 or FFP2 respirators; some were supplied on demand while at others the wearing of RPE was mandatory. At one MRF a hierarchy system was in place, in which FFP1 respirators were worn in the sorting cabins and FFP3 in areas where high exposures were anticipated. At another site, no basic RPE was supplied for general use. However, employees carrying out hand-sweeping during cleaning were supplied with Airshield pro TH2P-S fan-assisted RPE.

Face-fit testing of respirators, as set out in the Guidance to the COSHH Approved Code of Practice (Ref 7), had not been performed on employees at any of the sites.

Health Survey

Results from a health survey of one hundred MRF workers, 96 of whom were male, indicated that:

- Health problems reported included skin, respiratory, gastrointestinal and musculoskeletal symptoms and dexterity problems.

- 84% of workers reported health problems that they attributed to their job; 15% of these were seen by their General Practitioner.

- There was a lack of showers, hand washing facilities and clothes-washing and changing facilities.

- There were generally no or inadequate facilities to store uniforms or work clothes separately from non-contaminated, non-work clothes.

- Training for new starters was variable. Where provided, the content and frequency of worker training was not formalised and did not cover specific work-related health issues.

Management aspects

- The reasons for worker absence were not explored by organisations. Opportunities to obtain information about worker ill-health, such as exit and return-to-work interviews and local health surveys, were not utilised.

- Those organisations perceived as treating agency staff the same as their own staff, had a longer serving, more stable workforce.

- The contribution of the Occupational Health Service (OHS) to organisational management of health risks was not clearly specified and therefore not integrated into any health and safety management system.

- The value that a risk-based health surveillance programme would be to the organisation was generally not understood. Where an organisation believed it had a health surveillance (HS) programme in place, it was not risk-based, no health records were available for inspection and no grouped information, which could identify the early indicators of disease, was available.

CONTENTS PAGE

1. INTRODUCTION

There is an obligation on the UK Government to reduce the amount of waste sent to landfill. Under the European Landfill Directive (Council Directive 1999/31/EC), the UK must reduce the quantity of biodegradable municipal solid waste sent to landfill to 35% of 1995 levels before 2020. Consequently, there has been an increase in re-use and recycling; and sorting of recyclable household waste has become an important component part of the waste management industry. Materials Recycling Facilities (MRFs) are specialised plant that separate, process, grade and store solid waste fractions, for onward dispatch to re-processors.

Collection, separation and composting of household waste generates organic dusts. Several studies indicate that exposure to airborne microorganisms and their toxic products may cause health problems among workers handling waste. Given the potential increase in the number of employees working in the waste and recycling industry, it is reasonable to anticipate that there will be greater exposure to such hazards, particularly in collecting and sorting activities where human involvement is essential.

The COSHH definition of a substance hazardous to health includes dust of any kind when present at a concentration in air equal to or greater than 10 mg/m^3 (as a time weighted average over an 8 hour period) of inhalable dust or 4 mg/m^3 (as a time weighted average over an 8 hour period) of respirable dust (Ref 7). Good occupational hygiene practice recommends that those levels should be the highest concentrations of dust to which employees should be exposed.

The microorganisms, predominantly fungi and bacteria, which form part of the airborne dust in recycling plants, could cause respiratory allergies and infection. There are no occupational exposure limits for microorganisms and the results of this study can only be compared to those of other studies.

Endotoxin is a breakdown product of the cell walls of gram-negative bacteria and inhalation exposure is associated with 'flu' like symptoms, also known as "organic toxic dust syndrome." The Dutch expert committee on occupational standards (DECOS), a committee of the health council of the Netherlands, have proposed a health based occupational exposure limit for airborne endotoxin of 90 endotoxin units $(EU)/m^3$ based on personal inhalable dust exposure measured as an eight hour time weighted average (Ref 2). Initially the proposed limit was 200 EU/m^3 but this was revised to 90 EU/m^3 during the period of this project. At the present time there is no UK workplace exposure limit (WEL) set for exposure to endotoxin and so, for the purposes of this report the DECOS proposed limit has been used for reference.

This report presents a summary of the findings from investigations at seven MRFs between 18th February and 13th August 2010. Three sites were operated by local authorities, with the remaining four operated by two separate private companies. Investigations included the measurement of exposures to dust and its microbiological components, assessment of control measures employed to prevent exposure and a health survey.

2. METHODOLOGY

2.1 VISIT PROTOCOL

Each visit was conducted over one or two days and aimed to measure inhalation exposures to substances hazardous to health at all stages of the recycling process. Air sampling, predominantly personal monitoring, was used and wherever possible was task-specific, with full-shift exposures calculated based on the individual task-specific results for each worker. In addition to measuring exposures, exposure control strategies were assessed. This included management systems (COSHH risk assessments, operator training etc), engineering controls and the PPE regime. A health survey was carried out in the form of a one-to-one interview with selected employees exposed to organic dust. A standard questionnaire was followed to allow consistent information to be collected.

2.2 EXPOSURE MEASUREMENT METHODS

Personal and static air samples for inhalable dust, and static air samples for respirable dust were taken in line with HSE Guidance MDHS14/3 (Ref 8). Inhalable dust was collected using quartz filters mounted in IOM sampling heads, aspirated at 2 litres/minute. Respirable dust was collected onto quartz filters loaded into cyclone samplers and aspirated at 2.2l/min Samples were analysed for inhalable/respirable dust using gravimetric techniques and for microorganisms and endotoxin. Details of the microbiological and endotoxin analytical techniques are given in Appendix 2.

Gravimetric, microbial and endotoxin analysis was carried at HSL's Buxton Laboratory.

2.3 HEALTH SURVEY

The health survey consisted of a questionnaire completed by interview and covering the following areas:

- Worker profile
- Worker experiences of the effect of their work on their health
- Worker training regarding health issues
- Common findings regarding organisational management of occupational health issues.

Information on the organisational management of health risks was obtained during interviews with key managers and the Occupational Health service provider.

Every site visited participated in the health survey, resulting in interviews of 100 workers (96% male) who carried out a variety of tasks within the MRFs.

3. FINDINGS

3.1 OVERVIEW OF SITES VISITED

Site 1 This council-run MRF sorted mixed bags of recyclable waste, mainly from the local area. The waste originated from doorstep collections, recycling banks and household waste recycling centres. Eighteen operatives, a shift manager and four drivers were employed on each of two shifts.

Site 2 This council-run MRF sorted mixed bags of recyclable waste, mainly from the local area. The waste came from doorstep collections, recycling banks and household waste recycling centres. Twenty five staff were employed at the MRF, working on a single day shift.

Site 3 This MRF was operated by a private company and sorted recyclable waste from the entire surrounding county. The waste originated from household collections and twelve waste recycling centres located throughout the county. Processing of waste at this site utilised a higher than average amount of high-energy sorting machinery. On the day shift, twelve company operatives and twenty four agency operatives were employed and, on the night shift, four company and twenty five agency operatives were employed.

Site 4 This council-run MRF sorted mixed recyclable waste from the local and surrounding areas. The waste came from kerbside collections that had already been pre-sorted. The MRF operated a single shift pattern and employed four general operatives, three drivers and a supervisor in the recycling area.

Site 5 This large MRF was operated by a private company and recycled waste from the entire surrounding county. The waste originated from household collections, private companies and waste recycling centres. Processing of waste at this site utilised a higher than average amount of high-energy sorting machinery. There were two shifts in operation at the MRF, a day and a night shift. Each shift was staffed by sixty to seventy employees, all of whom were provided by an agency, with the exception of the shift supervisors.

Site 6 This MRF was privately-operated and sorted recyclable waste, mainly from the local area. The waste came from doorstep collections, civil amenity sites and from other private recycling companies. The MRF operated a single day shift and employed up to nineteen staff in the recycling area.

Site 7 This MRF was privately-operated and sorted bags of dry recyclable waste from the local area and recyclable waste rejected by other MRFs. The waste originated from doorstep collections, recycling banks and household waste recycling centres. The site also had a civic amenities section where the public could bring general household waste; and a Mechanical Biological Treatment (MBT) plant, referred to as a BioMRF, for processing other waste. The MRF operated a three-shift system with twenty operatives per shift. The BioMRF ran a long day-shift, employing thirteen operatives over staggered work periods. The civic amenities section ran a single day shift and employed six operatives.

3.2 PROCESS DESCRIPTION

The MRFs that took part in this study used similar processes and recycling techniques, these are described in the following paragraphs. However, the level of mechanised sorting employed varied from site to site and ranged from almost fully-mechanised (site 3) to one where little mechanised sorting was carried out (site 6).

In general, MRFs sort and separate large volumes of household, municipal, commercial and industrial waste material to produce a range of recyclable outputs. A combination of advanced mechanical separation techniques and manual sorting is used to separate the materials. The recyclable waste is typically separated into:

- Glass
- Aluminium and steel cans
- Paper
- Cardboard
- Plastic bottles and packaging
- Other, non-recyclable material

3.2.1 Waste Reception Area

Mixed recyclable waste enters the reception area in collection vehicles from kerbside collections, municipal waste sites and private companies. The vehicles tip the waste in a reception area, which is usually staffed by a loader driver and/or a banksman.

Waste bags are fed into a bag opener by a mechanical shovel, telehandler or via a conveyor belt. Automated bag openers can be used for splitting single or multiple layer bags made from polythene, paper, interwoven plastic and polythene-lined paper. As the bags enter, a slowly turning drum with a series of fingers carries them round; the bags are then pulled towards another drum rotating in the opposite direction. When the bags are pulled through the two drums they are ripped open and are dropped with the contents onto a conveyor belt.

At site 4 the loose, partially separated recyclables were tipped directly into a hopper which fed the plant via a conveyor belt.

Site 7 incorporated a BioMRF in addition to its MRF (see section 3.2.7). A large proportion of the waste delivered was a mix of general waste contained in black plastic bags and dry recyclables in orange plastic bags. The black bags were shredded and processed in the BioMRF. The orange bags were separated out using an optical recognition system (Optibag system) attached to the BioMRF and then transported to the MRF for processing.

3.2.2 Pre-sort Cabins

This is the first stage of sorting where any unwanted items, or items which may damage or block the downstream processing, are removed by hand.

At three of the seven MRFs, the recyclables went through a separate pre-sort cabin staffed by two to six operatives. The other MRFs did not have a pre-sort facility.

3.2.3 Mechanical Sorting Machines

Recyclable materials are then further sorted by mechanical sorting machines. Typical of these are trommels. A trommel is a large rotating drum equipped with an inner, perforated drum of smaller diameter. Waste is passed into the inner drum and smaller items are separated out by passing through the perforations into the outer one.

The waste remaining (paper, plastics and cardboard) is then carried by conveyor to the sorting stations. Smaller-sized material is carried from the outer drum and larger material from the inner drum along separate lines.

Trommels can be used to separate the biodegradable proportion from mixed waste and to separate recyclable materials such as newspaper or cardboard. The sized waste is transported to an over-band magnet that removes steel, and then through an Eddy Current Separator that removes aluminium.

Ballistic Separators are also used for removing larger volume materials such as plastic bottles, aluminium and steel cans from domestic and industrial waste. There are a series of paddles that oscillate in pairs so the material is agitated in such a way that the light fractions move forward and the larger fractions move backwards. The paddle angle is set according to material separation requirements.

3.2.4 Sorting Cabins

Sorting cabins allow the manual sorting of waste in a potentially clean and safe environment. Waste passes through the cabins on conveyor belts that have operatives stationed along their length. Materials are picked off by hand and usually directed to a bunker underneath the sorting cabin where they are stored, or to bins at the side of the operatives' workstation.

All the sites visited relied heavily on hand processing of waste in sorting cabins. These cabins varied in size. For example, at site 1, sixteen sorters were divided in to five separate cabins/areas, whereas site 5 had a large sorting cabin consisting of three sorting lines staffed by twenty eight operatives.

3.2.5 Baling area

The sorted recyclables are usually compressed and baled by machine for dispatch to processors. At the smaller sites, baling was carried out by one operative using a single baling machine. However the larger sites (3 and 7) had two baling machines operated by two operatives, and site 5 had three baling machines operated by three.

Non-recyclable material that is separated out during the process is collected and dispatched to landfill.

3.2.6 Auxiliary workers

Other operatives included lifting and loader drivers, QC checkers and supervisors.

3.2.7 BioMRF

A BioMRF is used to process non-recyclable but biodegradable household waste. It uses a biological process where the residual microbial flora in the waste is used to partially decompose and dry it. The process takes place in a fully enclosed building where negative air pressure is maintained to minimise environmental impact. The waste is formed into large windrows on a raised perforated floor. Using fans and a system of ductwork, air is drawn through the waste via the void beneath the raised floor. This air is passed through bio-filters mounted on the roof that neutralise odours before release to atmosphere. The bio-filters consist of wood and bark. The airflow is computer controlled to ensure optimal temperatures (50-60 ^{0}C). The activity of the microbial flora produces the heat, which evaporates the water present in the waste to give a much dryer material. The material is said to be stabilised, sanitised and almost odour free in 12-15 days. The dry material can then be used as a fuel, usually in power stations.

The only site to operate a BioMRF was site 7 where a Mechanical Biological Treatment (MBT) plant (Systema Ecodeco TM) had been installed.

3.3 SAMPLING RESULTS

3.3.1 Measured exposures

Summary results for exposure to each analyte are presented in Appendix 1, Tables 1 to 5, and for the results of static samples in Tables 6 and 7. Table 8 in Appendix 1 details the predominant fungi and bacteria identified in the air samples.

A total of one hundred and thirty nine exposures were measured for each analyte. Sampling was conducted during periods representative of typical production.

Dust exposure:

- 8-hr TWA exposure to inhalable dust ranged from 0.15 to 22.63 mg/m^3 (n=139).
- Seven of these exposures (5%) were above 10mg/m^3. These occurred for workers in the sorting cabins at site 3 and 5. These two sites were highly mechanised and had high-energy sorting machines, which agitated the waste.
- The results from forty-six static samples indicated background inhalable dust concentrations ranging from 0.11 to 9.91 mg/m^3.
- Respirable dust from the static samples ranged from <LOD-0.91 mg/m^3.

Endotoxin exposure:

- 8-hr exposure to endotoxin ranged from <LOD to 2399 EU/m^3 (n=139).
- Forty seven (34%) of these exposures were above the proposed DECOS occupational exposure limit of 90 endotoxin units (EU)/m^3. The reduction of the proposed limit from 200 to 90 EU/m^3 resulted in the number of samples exceeding the limit increasing from 19 (14%) to forty seven (34%).
- The majority of exposures that exceeded 90 EU/m^3 were, again, to employees working at the highly mechanised plants of sites 3 and 5. A number of high exposures were also measured at sites 6 and 7.
- The results from forty-six static inhalable samples indicated background concentrations ranging from <LOD to 351 EU/m^3.
- Endotoxin concentrations from the static respirable samples ranged from <LOD-30.37 EU/m^3.

Exposure to microorganisms:

There are no occupational exposure limits for exposure to microorganisms. Results can only be compared to other studies and published data on typical levels of airborne microorganisms (Ref 1,5&6)**.** General ambient airborne levels of fungi and bacteria are found at concentrations of up to 10^3 cfu/m^3 (Ref 3&4). In the current study, exposures at higher than ten times this figure (>10^4) have been considered an indicator of medium exposure and those at >10^6 an indicator of high exposure. These figures are based on comparisons with other industries where there is exposure to organic dusts. In summary:

- Bacteria and fungi were in general at concentrations in the medium range of >10^4 cfu/m^3, ten times the upper concentrations found in ambient air. None of the exposures were >10^6 cfu/m^3.

- Some areas were found to have concentrations >10^5 cfu/m^3, which, although still in the medium range, is comparable to industries where the air has a higher organic load such as animal and poultry houses.

- Exposure to bacteria ranged from 10^3 to 10^5 cfu/m^3 and 102 exposures (73%) were >10^4 cfu/m^3.

- Exposure to fungi ranged from 10^2 to 10^5 cfu/m^3 and 113 (81%) were >10^4 cfu/m^3.

- Identified species of bacteria and fungi were typical of those found in organic dust, including *Bacillus* bacteria and *Aspergillus fumigatus* fungi, the latter also being associated with composting of materials and recognised as potential allergens.

Aspergillus fumigatus is an opportunistic pathogen as well as an allergen. For the purposes of this work exposure of >10^3 cfu/m^3 has been defined as medium exposure and >10^4 cfu/m^3 as high exposure:

- Exposure to *Aspergillus fumigatus* ranged from <LOD to 10^5 cfu/m^3.

- Seventeen (12%) of the exposures were >10^4 cfu/m^3 and a further twenty (14%) were >10^3 cfu/m^3.

In general, the concentrations of microorganisms from the static samples were of a similar magnitude to or ten times less than the personal exposures.

3.4 EXPOSURE CONTROL

3.4.1 Management controls

Most, if not all, companies visited had not developed a corporate Occupational Health strategy with accompanying policies and arrangements for implementation. Similarly, COSHH risk assessments either had not been carried out or reviewed.

3.4.2 Local Exhaust Ventilation (LEV)

None of the sites visited used LEV inside the sorting cabins as a control measure to reduce operator exposure.

Site 3 had a large LEV system fitted to various parts of the plant (not inside sorting cabins). It was reported that this was not part of the original plant specification and had been installed after the plant had been built. It consisted of a large fan and filter unit located outside the building, ducted to capturing hoods placed around the plant. Typically these were placed where there was potential for dust to be generated, for example, where waste dropped from one level to another. It was not possible to fully inspect this LEV system as it was inside the interlocked areas of the plant, so it would have required the plant to be shut down in order to do so.

3.4.3 General Ventilation

Site 1 had ceiling vents in the sorting cabins, which were said to be ‘redundant’. In the past these had been used to deliver fresh air from outside the main building. The cabins also had redundant air conditioning units. Oscillating axial fans were also present in the cabins, to provide air movement on hot days. General dilution ventilation was achieved through the large open doors.

Site 2 had forced mechanical ventilation in all the sorting cabins. Each one was fitted with two ventilation systems. Air was blown in via high level vents located on the side wall of the cabin. On the opposite side of the cabin was a series of low-level extraction ducts. In addition to this, air-conditioning units located on the roof controlled the temperature within the sorting cabins. It was reported that filtered air was blown in through ceiling vents down one side of the cabin and extracted by ceiling vents on the opposite side. The doors to the waste reception area were left open to allow natural ventilation. Mechanical ventilation was not provided.

Site 3 had wall mounted recirculating air conditioning units installed in the sorting cabins, although these were primarily there to control the climate inside the cabin. General ventilation and air movement throughout the rest of the MRF was provided by the LEV system and from natural sources (i.e. opening and closing of doors).

Site 4 had no forced ventilation. A high degree of dilution ventilation was achieved due to the open fronted work areas.

Site 5 had general ventilation within the main sorting cabin, provided by an air-conditioning system that was intended to force chilled air from outside into ducts that ran the length of the cabin. These ducts had outlet vents spaced at regular intervals along their length. The air conditioning system was not directly connected to the ductwork in the cabin, which significantly compromised its efficiency. Some of the windows in the sorting cabin were also open on the day of the visit.

There was also a small vent located in the plastics sorting cabin. It appeared to supply air into this cabin, although this was not verified.

Site 6 achieved general movement of air via open external doors and open doors to the sorting cabins. There were three ceiling fans in the main sorting cabin that were designed to force air in to provide general ventilation. Although these were operational (but not in use on the day of the visit), the ducting, which linked the fans to the external air source, had been removed. Hence the fans, if used, would deliver contaminated air into the sorting cabins. One fan was blocked and another found to be very noisy.

Site 7 did not have any mechanical ventilation systems however some general air movement may have been achieved in the baling area and reception area of the MRF through openings in the building. However, no ventilation was provided to the sorting cabins.

While the work stations in the Bio-MRF were not provided with engineering controls, there was a large and complex extraction system fitted to the process. This system was not examined as part of this survey.

The civic amenities area relied on natural general ventilation. The processing was conducted in a very open area and the sheds were open-sided and had large open entrances. These were large enough to allow vehicles to enter the building when they delivered the waste.

3.4.4 Other Controls

Site 3 had water-mist dust suppression installed in the waste reception bay and in the baling area, to reduce airborne dust. However, on the day of the site visit, the latter was not switched on until it was brought to the attention of the supervisor. The measured airborne dust concentrations at this site were amongst the highest measured in this study. This indicates that the dust suppression system was not wholly effective in minimising the amount of airborne dust. It was not clear whether the water-mist suppression system was fed by mains water however a water holding tank located within the MRF was subject to a cleaning regime.

At site 7, both of the sheds in the civic amenity tip had dust suppression, in the form of water spray/mist generators. The spray was generated from water storage tanks located outside the building. Measured dust concentrations in these areas were low, indicating that this and the other dust control measures employed in this area were effective. However, the microorganism concentrations in the air were in the medium range. No information was gathered on the cleaning regime for the water-mist suppression system.

Most mechanical shovels and loaders used on the sites had enclosed cabs fitted with air conditioning that included filters of some type. The efficiency of the cab filtration systems was not investigated in detail. However, the air monitoring results indicate that these worked effectively.

3.4.5 Personal Protective Equipment (PPE)

Wearing high visibility clothing, gloves, hard hats or knock caps and safety boots was mandatory on all of the sites visited. However, hard hats were not always worn in the sorting cabins. At one of the sites it was mandatory to wear hearing protection when tipping bins of tin cans down a chute into a storage bay. Eye protection was supplied at some of the sites.

Respiratory protective equipment (RPE) in some form was supplied at 6 of the 7 sites.

Site 1 provided operators with FFP3 disposable respirators for specified tasks, for example when emptying the bins associated with a bag suction system.

Site 2 provided employees who carried out hand sweeping during cleaning activities with powered (fan-assisted helmet) respirators (TH2P-S).

Site 3 provided FFP1 and FFP2 disposable respirators on demand to all staff but RPE was not widely used except during cleaning activities.

Site 4 supplied FFP2 disposable respirators however these were not seen to be used by staff on the day of the visit.

Site 5 supplied FFP2 disposable respirators to all staff and these were widely used by staff in the sorting cabins.

Site 6 did not provide any RPE. They only provided single strap nuisance dust masks on demand. These masks had no markings or information supplied to indicate the standard to which they were made.

Site 7 employed a hierarchy system in which FFP1 respirators were worn in the sorting cabins and FFP3 in the optibag (bag sorting) area, where it was perceived that the risk of exposure to organic dust was higher.

Face-fit testing of the respirators on staff had not been performed at any of the sites where tight-fitting facepieces were supplied. Workers using respirators were regularly observed with incorrectly donned respirators and/or using tight-fitting face facepieces when unshaven.

3.4.6 Cleaning

Most of the sites adopted dry sweeping in some form as part of the cleaning regime. This was usually performed pre- or post- shift. At site 3, a dedicated team of four operatives remained at the end of the shift for up to two hours, to sweep the floors underneath the sorting equipment.

3.5 RESULTS OF HEALTH SURVEY

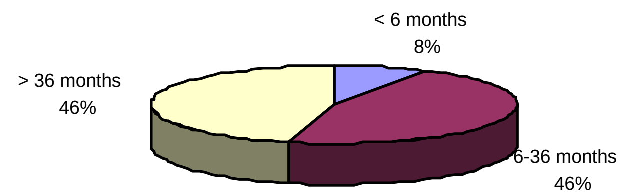
The findings are given below, in the following areas:

- Worker profile
- Worker experiences of the effect of their work on their health
- Worker training regarding health issues
- Common findings regarding health risk management.

3.5.1 Worker profile

Of the workers interviewed 96% were males (the four women interviewed worked at the same location) and the split for employee status was 42% directly employed by the company and 58% agency staff.

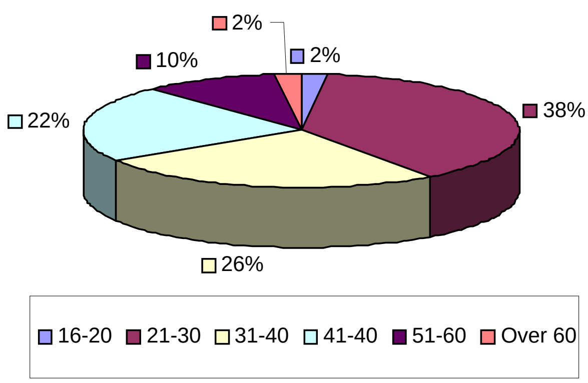
Figure 1. Length of Service



Although agency workers represented over half of those interviewed, the length of service indicates a stable workforce. Workers' reports during the interviews indicated that those organisations which were perceived to treat their agency workers similarly to their own staff (e.g. providing them with the organisation's uniforms after working on site for a month, providing adequate welfare facilities) had less worker turnover.

A wide age group was interviewed,

Figure 2. Ages of workers interviewed



3.5.2 Worker experiences of work on their health

16% of workers had not experienced any health problem associated with their job.

15% of workers identified they had visited their General Practitioner (GP) within the last year about a health problem they believed was linked with their job. Of these, 6% were still under the care of a GP or specialist at the time they were interviewed.

69% of those workers interviewed, who attributed ANY health problem to work, self-diagnosed and self-medicated where necessary, and did not see a GP / specialist.

Health problems experienced by workers were categorised as:

- skin symptoms,
- respiratory symptoms,
- gastrointestinal symptoms,
- musculo-skeletal symptoms and
- dexterity problems.

Figure 3. Skin symptoms experienced by workers

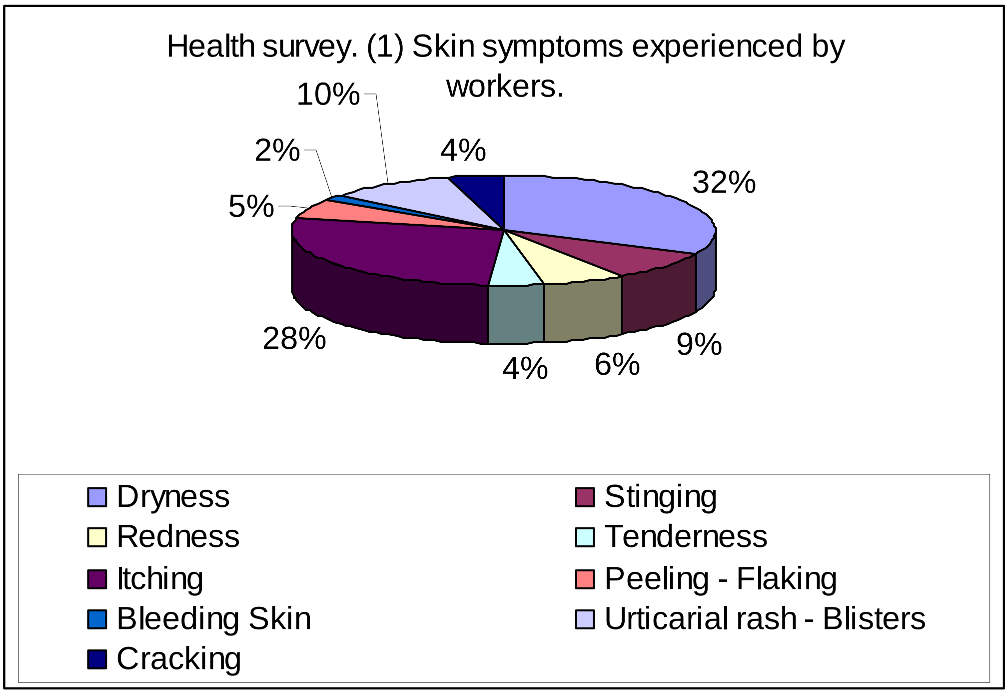


Figure 4. Respiratory symptoms experienced by workers

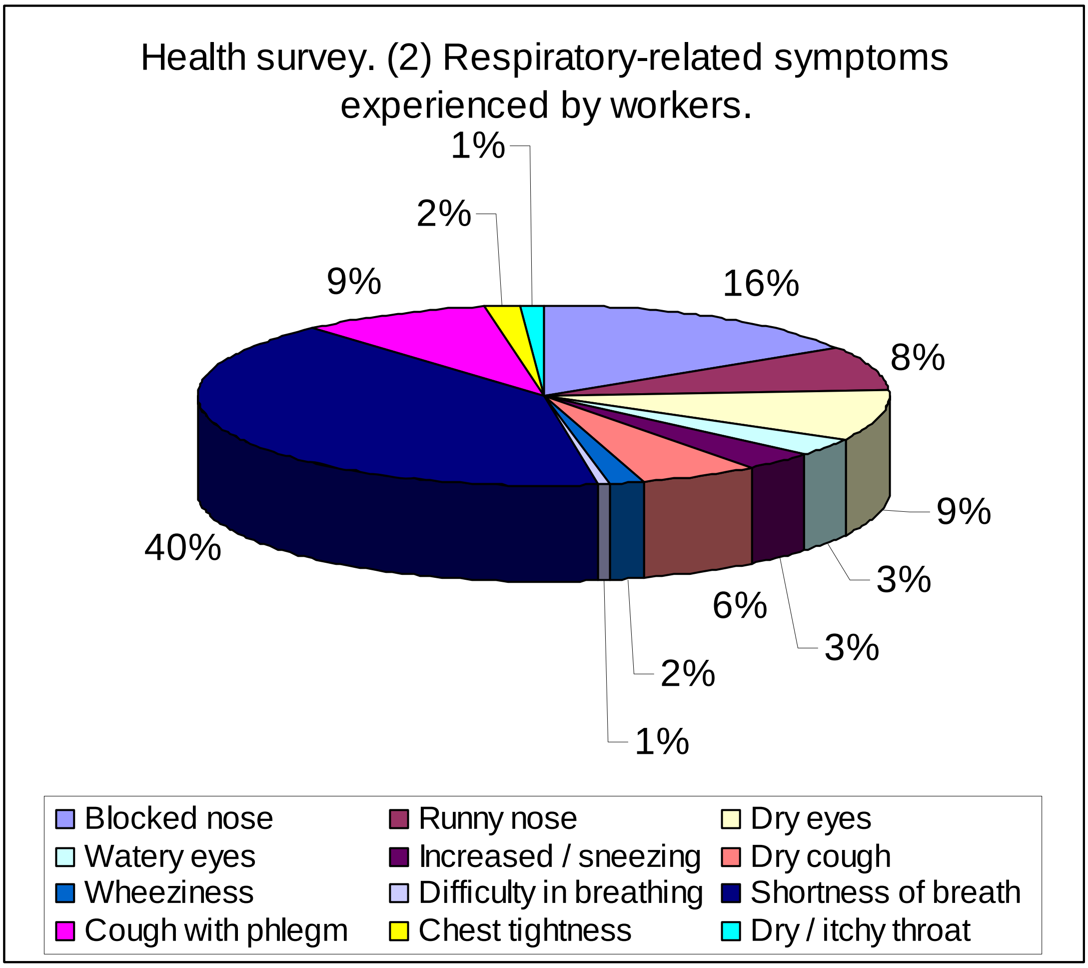


Figure 5. Gastro-intestinal symptoms experienced by workers

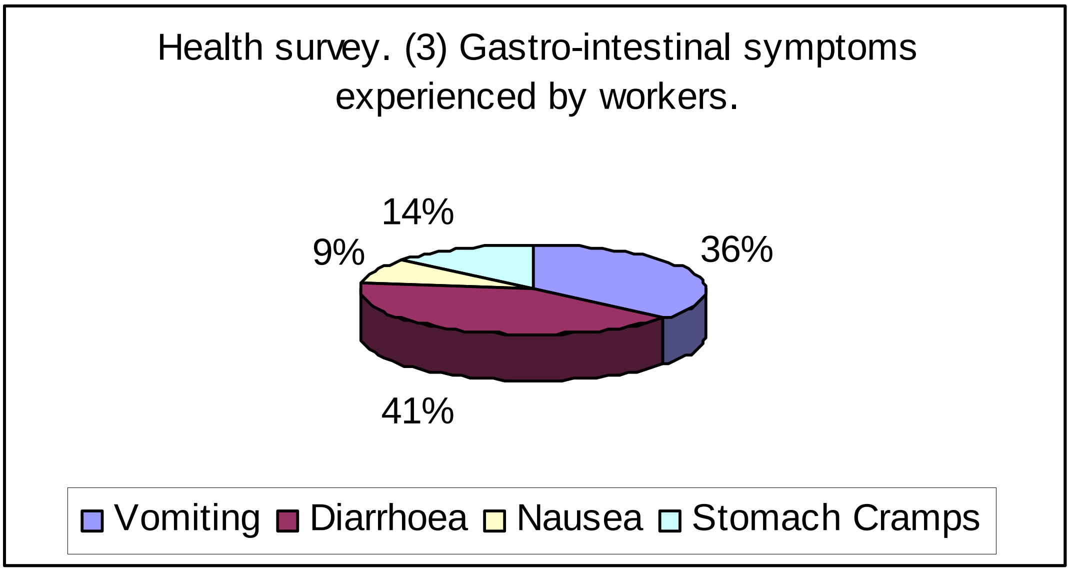
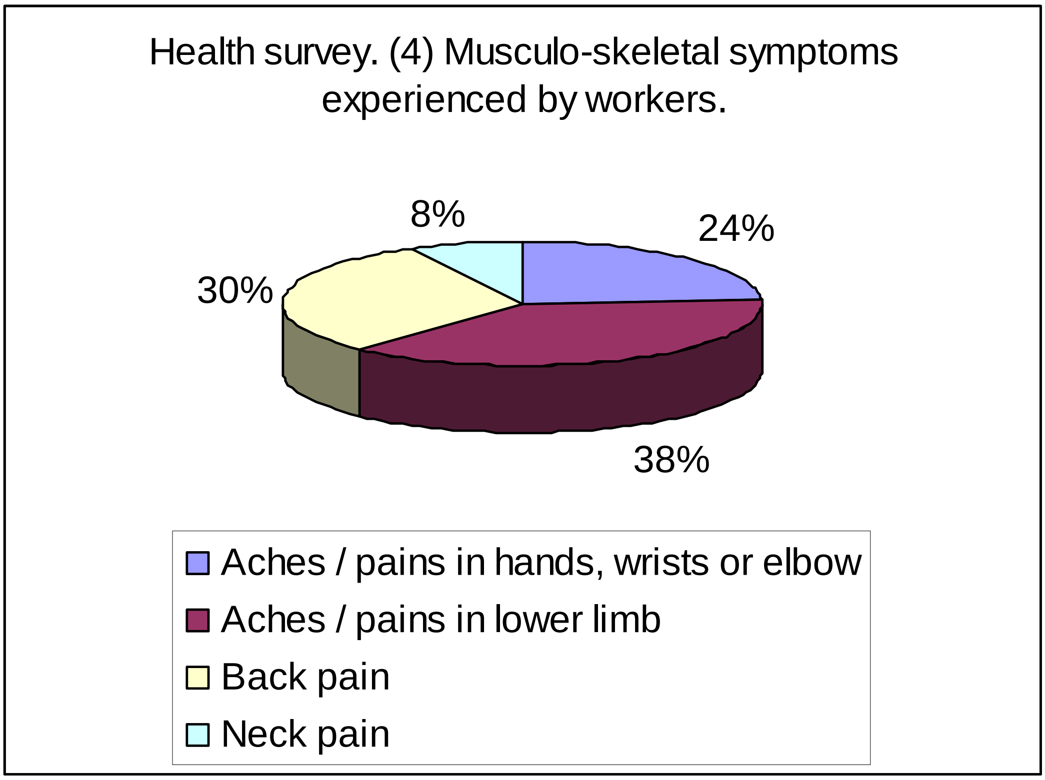


Figure 6. Musculo-skeletal symptoms experienced by workers



Reduction of dexterity experienced by workers

Workers experienced difficulties when working at low temperatures. These were described as:

- fingers going numb,
- fingers changing colour,
- getting pins and needles in fingers
- difficulty in gripping objects when sorting
- generally reduced dexterity.

The numbers of workers experiencing these symptoms varied, with 50% of workers complaining if working in an outdoors facility or a large facility with extraction. This was compared to 10 – 20% of workers in the small – medium facilities.

Aggravating features identified by workers

During the interview, workers identified a range of factors, which they believed aggravated their health problem. These included:

- Poor posture from bending over the sorting line,
- Prolonged standing on cold (metal) flooring.
- Fingers getting wet and cold whilst sorting
- Gloves provided which were not suitable for the job
- Poor (or lack) of ventilation
- Aggressive ventilation which chilled the air
- Lack of (or inadequate) hand washing facilities
- No facilities to shower before going home
- Unable to wash or change clothes before going home
- No facilities to store uniform or work clothes
- Unsuitable face masks being provided
- Workers who used compressed air to blow dust around
- Inadequate PPE provided for wet work (e.g. when undertaking maintenance on sump)

3.5.3 Worker training on health issues

In general, training for new starters was provided by line management, though not repeated. The content was variable and depended on whether the worker was an agency or non-agency worker. Those workers (agency and non-agency) who had received more training by the organisation were in skilled or multi-skilled operational roles such as maintenance, driving, quality and supervisory roles.

The relevant topics covered at all sites were:

(a) what personal protective equipment (PPE) was required to be worn and

(b) how to correctly wear the PPE.

Some relevant topics, which were also included, were:

(a) how to put on and take off PPE without the worker contaminating themselves,

(b) what the worker had to do to prevent catching an infection from work that might cause diarrhoea or vomiting,

(c) what to do if the worker had a needle-stick / sharps injury and

(d) what the worker had to do to prevent being exposed to substances which might cause breathing or skin problems.

Those relevant topics least likely to be included were:

(a) the signs and symptoms of dermatitis,

(b) the signs and symptoms of respiratory ill-health,

(c) how and where to store clean clothes to prevent contamination with work clothes / overalls,

(d) how often to change dirty work clothes / overalls,

(e) what procedures to follow if the worker believed they had developed a work-related ill-health condition,

(f) details of the organisational arrangements for health surveillance or health monitoring.

3.5.4 Common findings regarding organisational management of occupational health issues

Reasons for absence and trends in worker absence by site or occupation were not proactively explored or used by any organisation. Also, those management opportunities which could obtain information about worker ill–health, such as exit interviews, return to work interviews and local health surveys, were not utilised by organisations.

The contribution of the Occupational Health Service (OHS) to organisational management of health risks was not clearly specified nor integrated into any health and safety management system. As examples, where specific activities such as health surveillance (HS) were undertaken, (a) the OHS contribution was not formalised in specific health policies and procedures, (b) information from the OHS, about their interventions outputs or outcomes, was not detailed in terms of purpose, content, frequency and dissemination routes and (c) any health surveillance or monitoring activities were not risk-based.

The ongoing relationship between the MRF management and the agency which supplied workers for the MRF, was dependent on the individuals involved. As examples, agreed and regular communication to share information about worker health, agreements about provision of training content and provision of PPE etc., were variable and inconsistent, even within the same organisation.

The value a risk-based health surveillance programme would make to the organisation was generally not understood. Where an organisation believed it had a health surveillance (HS) programme in place it was not risk-based, no health records were available for inspection and no grouped information, which could identify the early indicators of disease, was available.

The content and frequency of worker training was not formalised and did not cover specific work-related health issues.

4. DISCUSSION

Collection, separation, and composting of household waste generates organic dust. MRFs handle large volumes of household, municipal, commercial and industrial material to produce a range of recyclable outputs. Government targets for reducing the amount of waste sent to landfill sites mean that this relatively new industry is likely to grow over the next few years and will continue for the foreseeable future.

Seven MRFs, operated by five different organisations, were visited during this study. These employed a combination of advanced mechanical sorting techniques and manual separation to process the waste materials. Some of the larger sites carried out a significant amount of sorting using automated mechanical processes. However, like the smaller less-mechanised sites, they still relied heavily on manual sorting in the later stages of the process.

Exposure to inhalable dust was below 10 mg/m^3 for the majority of the activities monitored. However, a small number of exposures at the more mechanised plant were above this value.

Approximately one third of the measured exposures to endotoxin exceeded the DECOS-proposed limit of 90 EU/m^3. Although spread across a variety of activities, the majority of the high exposures were to staff working at the more mechanised MRFs, especially those using high-energy sorting machinery.

Exposures to microorganisms (fungi and bacteria) were considered to be at medium levels (between 10^4 and 10^5 cfu/m^3) when compared to data from other studies (Ref 1,5&6). These levels are more than 10 times higher than the upper concentrations normally found in general ambient air (10^3 cfu/m^3) (Ref 3&4). Some exposures were a further order of magnitude higher, similar to those from animal and poultry houses. The bacteria and fungi species identified were typical of those usually found in organic dust and included *Aspergillus fumigatus*, which is recognised as an allergen.

For the MRFs visited, the exposure control strategies for dust and bioaerosols relied heavily on general ventilation and the use of RPE, with only one site having applied LEV. Two sites had water mist-suppression units installed, one in the main MRF and the other in the reception areas of a civic amenity recycling site.

Site three had both LEV and water mist-suppression installed in the reception and baling areas to control dust. This site had some of the highest inhalable dust and endotoxin levels measured. This calls into question the effectiveness of this control strategy. It should also be noted that this was the newest and one of the most enclosed sites visited during the study.

Where forced general ventilation was employed in sorting cabins its quality and design was generally not of a good standard. Systems were found where ductwork was not complete, where airflows where low and where systems were not subject to routine maintenance and testing. It appeared that the majority of the general ventilation systems in sorting cabins were designed to address operator comfort rather than the control of dust exposure.

RPE selection, use and management standards were deficient at most MRFs visited. In general, the need for using RPE had not been fully assessed. RPE was usually available for use, either all the time or for specific tasks; but no selection process, face-fit testing, training or supervision of use had been implemented. At all sites the RPE issued was mostly in the form of disposable ori-nasal respirators.

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5. CONCLUSIONS

The general absence of corporate health strategies and policies and suitable risk assessments dealing with exposure to dust and bioaerosol indicates a need for management intervention to (a) adopt a strategic approach to health risk management and (b) ensure the level of control is improved and monitored.

Prevention of work-related ill-health and any cross-contamination in MRFs requires not only the provision of adequate welfare facilities and lockers for both men and women; but also the design of a workplace layout that ensures workers are directed to use them prior to eating, drinking or leaving the workplace.

A system for monitoring and managing work-related health risks in MRFs needs to be devised by Managers with the involvement and agreement of the Occupational Health Service. It should adopt a risk-based approach which requires specific timely feedback to the organisation. This system is best integrated within the existing health and safety framework.

A health surveillance scheme, comprising a mix of low- and high- level techniques, with onward referral to the Occupational Health Service for further investigation and diagnosis, should detect early any cases of work-related breathing problems.

Workers (both agency and direct workers) require specific health advice and training regarding health risks, from the main organization. This should include details of what each party needs to do in order to protect health.

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7. APPENDICES

7.1 APPENDIX 1 RESULTS SUMMARY TABLES

Table 1. Summary of exposures to inhalable dust.

Inhalable Dust 8hr-TWA mg/m^3															
Site	Presort cabin			Sorting cabins/stations			Baler area			FLT, Telehandler, Shovel drivers			Supervisors, banksmen and shop floor		
	range	> 5mg	>10mg	range	> 5mg	>10mg	range	> 5mg	>10mg	range	> 5mg	>10mg	range	> 5mg	>10mg
Site 1 MRF	na	na	na	0.52-1.44 (n=10)	0	0	na	na	na	0.34-0.64 (n=3)	0	0	0.36 (n=1)	0	0
Site 2 MRF	1.31-2.16 (n=4)	0	0	0.42-1.45 (n=8)	0	0	na	na	na	0.43-1.42 (n=2)	0	0	0.84-3.04 (n=2)	0	0
Site 3 MRF	7.66-22.63 (n=3)	3	2	1.92-10.34 (n=9)	6	3	3.39-5.26 (n=2)	1	0	1.55-5.18 (n=3)	1	0	na	na	na
Site 4 MRF	na	na	na	0.23-2.84 (n=6)	0	0	0.99 (n=1)	0	0	1.85 (n=1)	0	0	na	na	na
Site 5 MRF	na	na	na	1.04-11.63 (n=20)	8	2	1.50-7.78 (n=3)	1	0	0.57-5.91 (n=5)	2	0	0.90-4.40 (n=2)	0	0
Site 5 Mini MRF	na	na	na	1.13-4.35 (n=7)	0	0	na	na	na	as above			1.93 (n=1)	0	0
Site 6 MRF	na	na	na	0.63-5.43 (n=8)	1	0	0.30-0.85 (n=2)	0	0	0.15-1.56 (n=3)	0	0	na	na	na
Site 7 MRF	5.53 (n=1)	1	0	0.38-0.95 (n=12)	0	0	2.21 (n=1)	0	0	0.16-0.93 (n=2)	0	0	0.39 (n=1)	0	0
Site 7 Bio-MRF	na	na	na	na	na	na	na	na	na	0.2- 3.55 (n=2)	0	0	0.17-3.60 (n=7)	0	0
Site 7 Civil amenities	na	na	na	na	na	na	na	na	na	1.79-2.17 (n=2)	0	0	0.55-1.95 (n=4)	0	0

na=not applicable

Table 2. Summary of exposures to inhalable endotoxin.

	8hr-TWA EU/m^3														
Site	Presort cabin			Sorting cabins/stations			Baler area			FLT, Telehandler, Shovel drivers			Supervisors, banksmen and shop floor		
	range	>45	>90	range	>45	>90	range	>45	>90	range	>45	>90	range	>45	>90
Site 1 MRF	na	na	na	<LOD-62.46 (n=10)	2	0	na	na	na	<LOD-2.55 (n=3)	0	0	3.84 (n=1)	0	0
Site 2 MRF	1.24-54.69 (n=4)	1	0	<LOD-20.05 (n=8)	0	0	na	na	na	<LOD-1.96 (n=2)	0	0	<LOD (n=2)	0	0
Site 3 MRF	155-432 (n=3)	3	3	<LOD-516 (n=9)	8	8	<LOD- 137 (n=2)	1	1	<LOD (n=3)	0	0	na	na	na
Site 4 MRF	na	na	na	<LOD-59.18 (n=6)	1	0	132.03 (n=1)	1	1	78.52 (n=1)	1	0	na	na	na
Site 5 MRF	na	na	na	<LOD-50.64 (n=20)	17	13	80.38-121.77 (n=3)	3	2	14.75-132.42 (n=5)	1	1	14.80-134.13 (n=2)	1	1
Site 5 Mini MRF	na	na	na	19.71-2399 (n=7)	2	1	na	na	na	as above	1	1	95.14 (n=1)	1	1
Site 6 MRF	na	na	na	29.50-184.81 (n=8)	6	5	2.55-14.00 (n=2)	0	0	<LOD (n=3)	0	0	na	na	na
Site 7 MRF	624.89 (n=1)	1	1	21.67-268.40 (n=12)	7	2	100.72 (n=1)	1	1	<LOD-23.10 (n=2)	0	0	18.17 (n=1)	0	0
Site 7 Bio-MRF	na	na	na	na	na	na	na	na	na	<LOD-254.55 (n=2)	1	1	<LOD-280.00 (n=7)	4	3
Site 7 Civil amenities site	na	na	na	na	na	na	na	na	na	55.68-81.41 (n=2)	2	0	23.74-134.26 (n=4)	3	1

na=not applicable, <LOD=less than limit of detection

Table 3. Summary of exposures to inhalable bacteria.

Bacteria cfu/m^3															
Site	Presort cabin			Sorting cabins/stations			Baler area			FLT, Telehandler, Shovel drivers			Supervisors, banksmen and shop floor		
	range	$>10^4$	$>10^6$	range	$>10^4$	$>10^6$	range	$>10^4$	$>10^6$	range	$>10^4$	$>10^6$	range	$>10^4$	$>10^6$
Site 1 MRF	na	na	na	$1.76x10^{4}$-$3.56x10^{5}$ (n=10)	10	0	na	na	na	$1.54x10^{4}$-$5.60x10^{4}$ (n=3)	3	0	$4.80x10^{4}$ (n=1)	1	0
Site 2 MRF	$2.98x10^{3}$-$1.35x10^{4}$ (n=4)	1	0	$2.14x10^{3}$-$4.96x10^{4}$ (n=8)	2	0	na	na	na	$1.48x10^{3}$-$5.26x10^{3}$ (n=2)	0	0	$1.02x10^{3}$-$2.93x10^{3}$ (n=2)	0	0
Site 3 MRF	$7.16x10^{4}$-$1.78x10^{5}$ (n=3)	3	0	$4.29x10^{3}$-$6.75x10^{5}$ (n=9)	8	0	$1.07x10^{5}$-$1.43x10^{5}$ (n=2)	2	0	$9.37x10^{4}$-$1.73x10^{5}$ (n=3)	3	0	na	na	na
Site 4 MRF	na	na	na	$6.03x10^{3}$-$4.82x10^{4}$ (n=6)	5	0	$1.13x10^{4}$ (n=1)	1	0	$2.18x10^{4}$ (n=1)	1	0	na	na	na
Site 5 MRF	na	na	na	$6.77x10^{3}$-$1.05x10^{5}$ (n=20)	18	0	$1.62x10^{4}$-$2.48x10^{4}$ (n=3)	3	0	$3.81x10^{2}$-$2.15x10^{4}$ (n=5)	2	0	$6.77x10^{3}$-$2.42x10^{4}$ (n=2)	2	0
Site 5 Mini MRF	na	na	na	$9.12x10^{3}$-$1.60x10^{4}$ (n=7)	6	0	na	na	na	as above			$1.17x10^{5}$ (n=1)	1	0
Site 6 MRF	na	na	na	$7.16x10^{3}$-$1.25x10^{5}$ (n=8)	7	0	$8.53x10^{3}$-$1.35x10^{4}$ (n=2)	1	0	$4.80x10^{3}$-$8.75x10^{3}$ (n=3)	0	0	na	na	na
Site 7 MRF	$4.57x10^{4}$ (n=1)	1	0	$5.10x10^{3}$-$4.76x10^{4}$ (n=12)	8	0	$6.13x10^{4}$ (n=1)	1	0	$1.93x10^{3}$-$3.10x10^{3}$ (n=2)	0	0	$1.13x10^{4}$ (n=1)	1	0
Site 7 Bio-MRF	na	na	na	na	na	na	na	na	na	$3.01x10^{3}$-$4.66x10^{5}$ (n=2)	1	0	$2.02x10^{3}$-$1.67x10^{5}$ (n=7)	6	0
Site 7 Civil amenities	na	na	na	na	na	na	na	na	na	$5.17x10^{4}$-$9.07x10^{4}$ (n=2)	2	0	$7.01x10^{3}$-$4.74x10^{4}$ (n=4)	2	0

na=not applicable

Table 4. Summary of exposures to inhalable fungi.

Fungi cfu/m^3															
Site	Presort cabin			Sorting cabins/stations			Baler area			FLT, Telehandler, Shovel drivers			Supervisors, banksmen and shop floor		
	range	>10^4	>10^6	range	>10^4	>10^6	range	>10^4	>10^6	range	>10^4	>10^6	range	>10^4	>10^6
Site 1 MRF	na	na	na	$4.95x10^4$-$9.40x10^5$ (n=10)	10	0	na	na	na	$2.58x10^4$-$1.03x10^5$ (n=3)	3	0	$1.69x10^5$ (n=1)	1	0
Site 2 MRF	$5.51x10^4$-$1.66x10^5$ (n=4)	4	0	$5.64x10^3$-$7.28x10^4$ (n=8)	5	0	na	na	na	$1.09x10^4$-$1.40x10^4$ (n=2)	2	0	$2.00x10^4$-$2.67x10^4$ (n=2)	2	0
Site 3 MRF	$1.14x10^5$-$3.10x10^5$ (n=3)	3	0	6.8810^3-$9.13x10^4$ (n=9)	7	0	$6.93x10^4$-$8.00x10^4$ (n=2)	2	0	$3.90x10^3$-$8.11x10^4$ (n=3)	1	0	na	na	na
Site 4 MRF	na	na	na	$1.40x10^4$-$1.08x10^5$ (n=6)	6	0	$1.54x10^4$ (n=1)	1	0	$1.56x10^4$ (n=1)	1	0	na	na	na
Site 5 MRF	na	na	na	$3.07x10^3$-$8.12x10^4$ (n=20)	19	0	$8.28x10^3$-$1.73x10^4$ (n=3)	1	0	$2.54x10^2$-$2.05x10^4$ (n=5)	2	0	$3.85x10^3$-$4.85x10^3$ (n=2)	0	0
Site 5 Mini MRF	na	na	na	$5.99x10^3$-$1.61x10^4$ (n=7)	4	0	na	na	na	as above			$2.65x10^4$ (n=1)	1	0
Site 6 MRF	na	na	na	$5.94x10^4$-$2.34x10^5$ (n=8)	8	0	$1.17x10^4$-$1.56x10^4$ (n=2)	2	0	$3.21x10^3$-$7.97x10^3$ (n=3)	0	0	na	na	na
Site 7 MRF	$1.61x10^5$ (n=1)	1	0	$1.19x10^4$-$3.00x10^5$ (n=12)	12	0	$6.37x10^4$ (n=1)	1	0	$2.35x10^3$-$1.37x10^4$ (n=2)	1	0	$1.43x10^4$ (n=1)	1	0
Site 7 Bio-MRF	na	na	na	na	na	na	na	na	na	$1.59x10^4$-$7.61x10^5$ (n=2)	2	0	$9.44x10^3$-$6.09x10^5$ (n=7)	6	0
Site 7 Civil amenities	na	na	na	na	na	na	na	na	na	$2.43x10^4$-$4.96x10^4$ (n=2)	2	0	$1.55x10^4$ $3.36x10^4$ (n=4)	4	0

na=not applicable

Table 5. Summary of exposures to inhalable *Aspergillus fumigatus*.

Site	*Aspergillus fumigatus* cfu/m^{3}														
	Presort cabin			Sorting cabins/stations			Baler area			FLT, Telehandler, Shovel drivers			Supervisors, banksmen and shop floor		
	range	$>10^{3}$	$>10^{4}$	range	$>10^{3}$	$>10^{4}$	range	$>10^{3}$	$>10^{4}$	range	$>10^{3}$	$>10^{4}$	range	$>10^{3}$	$>10^{4}$
Site 1 MRF	na	na	na	$7.55x10^{3}$-$2.49x10^{5}$ (n=10)	10	9	na	na	na	$5.30x10^{3}$-$1.62x10^{4}$ (n=3)	3	1	$4.22x10^{4}$ (n=1)	1	1
Site 2 MRF	<LOD-$7.40x10^{1}$ (n=4)	0	0	<LOD-$7.40x10^{1}$ (n=8)	0	0	na	na	na	<LOD-$6.58x10^{2}$ (n=2)	0	0	<LOD-$7.90x10^{1}$ (n=2)	0	0
Site 3 MRF	$1.95x10^{2}$-$4.62x10^{2}$ (n=3)	0	0	<LOD-$2.00x10^{2}$ (n=9)	0	0	<LOD (n=2)	0	0	<LOD-$7.50x10^{1}$ (n=3)	0	0	na	na	na
Site 4 MRF	na	na	na	<LOD-$2.38x10^{2}$ (n=6)	0	0	<LOD (n=1)	0	0	<LOD (n=1)	0	0	na	na	na
Site 5 MRF	na	na	na	<LOD-$7.83x10^{2}$ (n=20)	0	0	<LOD-$1.51x10^{2}$ (n=3)	0	0	<LOD-$3.91x10^{2}$ (n=5)	0	0	$7.02x10^{1}$-$2.30x10^{2}$ (n=2)	0	0
Site 5 Mini MRF	na	na	na	<LOD-$1.74x10^{2}$ (n=7)	0	0	na	na	na	as above			<LOD (n=1)	0	0
Site 6 MRF	na	na	na	$5.24x10^{2}$-$1.67x10^{4}$ (n=8)	6	6	$9.64x10^{1}$-$1.96x10^{2}$ (n=2)	0	0	<LOD-$4.86x10^{2}$ (n=3)	0	0	na	na	na
Site 7 MRF	$8.95x10^{2}$ (n=1)	0	0	$4.33x10^{2}$-$2.33x10^{3}$ (n=12)	6	0	$4.45x10^{3}$ (n=1)	1	0	$3.36x10^{2}$-$1.64x10^{3}$ (n=2)	1	0	$2.17x10^{3}$ (n=1)	1	0
Site 7 Bio-MRF	na	na	na	na	na	na	na	na	na	$6.02x10^{2}$-$7.95x10^{2}$ (n=2)	0	0	$7.35x10^{2}$-$2.21x10^{3}$ (n=7)	4	0
Site 7 Civil amenities	na	na	na	na	na	na	na	na	na	$6.20x10^{2}$-$2.00x10^{3}$ (n=2)	1	0	$8.70x10^{2}$-$2.71x10^{3}$ (n=4)	3	0

na=not applicable, <LOD=less than limit of detection

Table 6. Summary of background levels of dust and endotoxin.

Location	Number	Dust mg/m^3		Endotoxin EU/m^3	
		Respirable	Inhalable	Respirable	Inhalable
Site 1 MRF	n=10	0.07-0.14	0.1-0.6	<LOD-0.83	1.61-22.71
Site 2 MRF	n=6	0.04-0.08	0.12-0.5	<LOD	<LOD-3.66
Site 3 MRF	n=7	0.04-0.65	0.58-9.91	<LOD-28	<LOD-242
Site 4 MRF	na	na	na	na	na
Site 5 MRF	n=5	0.08-0.91	0.45-6.33	<LOD-10.13	<LOD-35.79
Site 5 Mini MRF	n=2	<LOD-0.17	0.35-3.28	<LOD	<LOD-68.82
Site 6 MRF	n=5	0.02-0.24	0.13-1.43	<LOD	<LOD-66.39
Site 7 MRF	n=7	0.06-0.21	0.37-1.97	16.98-23.77	27.61-351.11
Site 7 Bio-MRF	n=2	0.23-0.27	1.97-2.47	24.56-30.37	328.63-236.73
Site 7 Civil amenities	n=2	0.16-0.18	1.57-4.28	18.73-21.02	37.56-142.13

Table 7. Summary of background levels of bacteria, fungi and *aspergilus fumigatus.*

Location	Number	Bacteria cfu/m^{3}		Fungi cfu/m^{3}		*Aspergilus fumigatus* cfu/m^{3}	
		Respirable fraction	Inhalable fraction	Respirable fraction	Inhalable fraction	Respirable fraction	Inhalable fraction
Site 1 MRF	n=10	$3.59x10^{3}$ - $4.87x10^{4}$	$2.69x10^{4}$ - $3.78x10^{5}$	$8.86x10^{3}$ - $1.21x10^{5}$	$4.67x10^{4}$ - $7.23x10^{5}$	$3.25x10^{3}$ - $2.4x10^{4}$	$3.08x10^{3}$ – $7.57x10^{4}$
Site 2 MRF	n=6	$1.46x10^{2}$ - $4.27x10^{3}$	$3.73x10^{2}$ - $2.39x10^{4}$	$2.10x10^{3}$ - $3.04x10^{4}$	$2.10x10^{3}$ - $3.73x10^{4}$	<LOD - $1.47x10^{2}$	<LOD - 81
Site 3 MRF	n=7	$1.26x10^{2}$ - $5.26x10^{3}$	$1.17x10^{4}$ - $4.52x10^{5}$	$1.13x10^{3}$ - $6.37x10^{4}$	$1.17x10^{4}$- $4.52x10^{5}$	<LOD	<LOD - $2.70x10^{2}$
Site 4 MRF	na	-	-	-	-	-	-
Site 5 MRF	n=5	69 -$1.99x10^{3}$	$4.29x10^{3}$ - $1.79x10^{4}$	$2.41x10^{3}$ - $1.92x10^{4}$	$8.30x10^{3}$ - $6.40x10^{4}$	<LOD - $2.74x10^{2}$	<LOD - $8.28x10^{2}$
Site 5 Mini MRF	n=2	<LOD	$1.89x10^{3}$ - $1.11x10^{4}$	$4.93x10^{3}$ - $6.30x10^{3}$	$8.15x10^{3}$ - $2.92x10^{4}$	<LOD - 84	<LOD - 93
Site 6 MRF	n=5	<LOD - $2.08x10^{3}$	$1.94x10^{2}$ - $4.88x10^{4}$	$1.52x10^{3}$ - $6.70x10^{4}$	$3.40x10^{3}$ - $1.18x10^{5}$	<LOD – $4.62x10^{3}$	<LOD - $7.45x10^{3}$
Site 7 MRF	n=7	$4.29x10^{3}$ - $6.13x10^{3}$	$4.39x10^{3}$ - $1.20x10^{5}$	$8.55x10^{3}$ - $6.67x10^{4}$	$1.73x10^{4}$ - $3.33x10^{5}$	$4.19x10^{2}$ - $6.06x10^{3}$	$2.27x10^{2}$ - $2.98x10^{3}$
Site 7 Bio-MRF	n=2	$1.47x10^{3}$ - $3.52x10^{5}$	$1.92x10^{5}$ - $2.19x10^{5}$	$1.38x10^{5}$ - $1.43x10^{5}$	$2.99x10^{5}$ – $5.75x10^{5}$	$1.47x10^{4}$ - $1.91x10^{4}$	$3.32x10^{3}$ - $3.73x10^{3}$
Site 7 Civil amenities	n=2	$1.47x10^{4}$ - $1.72x10^{4}$	$3.89x10^{4}$ - $8.56x10^{4}$	$5.05x10^{4}$ - $1.33x10^{5}$	$7.44x10^{4}$ - $8.68x10^{4}$	$2.21x10^{3}$ – $5.96x10^{3}$	$1.78x10^{3}$ - $1.85x10^{-}$

Table 8. Summary of bacteria and fungi identification.

Site	Predominant Fungi	Predominant Bacteria
1	*Aspergillus sp* *Aspergillus fumigatus* *Aspergillus niger* *Aspergillus rosarium* *Verticillium. sp* *Penicillium sp*	*Micrococcus. sp* *Actinobacterium sp* *Bacillus sp* *Proteobacterium sp* *Swarming Bacillus* *Micrococcus rosarium*
2	*Aspergillus fumigatus* *Penicillin sp.* *Cladosporium sp.* *Acremonium*	*Bacillus Sp* *Micrococcineae bacterium* *Pseudomonas oleovorans* *Staphylococcus sp.* *Oerskovia paurometabola (found in sea sediments)* *Streptomyces sp.*
3	*Aspergillus fumigatus* *Penicillin sp.* *Cladosporium sp.* *Yeast* *Aspergillus niger*	*Bacillus Sp* *Thermoactinomyces vulgaris* *Acinetobacter sp.* *Micrococcus*
4	*Aspergillus terrae* *Aspergillus niger* *Penicillin sp.* *Cladosporium sp.* *Fusarium*	*Bacillus Sp* *Micrococcineae bacterium* *Pseudomonas oleovorans* *Staphylococcus sp.* *Actonimycete thermobifidis* *Rothia p.*
5	*Aspergillus fumigatus* *Penicillin sp.* *Cladosporium sp.* *Aspergillus niger*	*Bacillus licheniformis* *Saccharopolyspora rectivirgula* *Staphylococcus saprophyticus subsp. saprophyticus ATCC 15305* *Staphylococcus xylosus*
6	*Aspergillus fumigatus* *Penicilium* *Cladosporium sp.* *Botrysis* *Fusarium* *Aspergillus niger* *Verticillium* *Stachybotris* *Eurotium*	*Bacillus Sp* *Bacillus subtilis* *Bacillus lichenformis* *Staphylococcus sp.* *Micrococcus* *Roseomonas mucosa*

Site	Predominant Fungi	Predominant Bacteria
7	*Aspergillus fumigatus* *Penicillin sp.* *Cladosporium sp.* *Aspergillus niger*	*Bacillus Sp* *Staphylococcus sp.* *Streptomyces sp.* *Bacillus lichenformis* *Brevimundimonas sp.* *Streptomyces thermovulgaris* *Actinomyces thermobifidis*

7.2 APPENDIX 2 MICROBIOLOGICAL METHODS

Endotoxin Analysis

Filters from the IOM samplers were placed in pyrogen-free tubes and the collected deposits were extracted by shaking at room temperature for 2 hours in 10ml of endotoxin-free 50mM Tris buffer (Cambrex). The resulting suspension was then divided to provide samples for endotoxin analysis and microbial enumeration (see below). Samples for endotoxin analysis were then centrifuged at 1000g for 10 minutes to remove particles and dilutions of the supernatant were prepared for analysis.

Samples were analysed using the Kinetic-QCL automated system (Bio-Whittaker Inc., Walkersville, Maryland, USA). This system is widely used for assaying endotoxin in workplace samples (Reynolds et al, 2005; Liebers et al, 2007). It is a quantitative kinetic assay based on a commercial 96-well plate assay system, with assays performed in a temperature controlled plate reader. It is validated for detection of Gram-negative bacterial endotoxin, the presence of which in a sample activates a proenzyme in the Limulus Amebocyte Lysate (LAL) reagent. This results in a colour (chromatic) change, and the concentration of endotoxin in the sample is calculated automatically from the rate of colour change, compared to controls of known concentrations. Results are expressed as endotoxin units (EU)/ml, which is a measure of the biologically available endotoxin in the sample. From other assay methods, endotoxin concentration may be expressed as nanogram (ng)/ml and, for cross-reference, 10 EU is the equivalent of 1 ng (assay manufacturer's data). Each sample was analysed with a negative and positive control.

Enumeration of Culturable Micro-organisms

A sub-sample of the extracts prepared from filters for endotoxin analysis was used for microbial analysis. A dilution series was prepared from the initial extraction suspension in ¼ strength Ringer's solution and was used to inoculate agar plates.

Total mesophilic fungi were isolated on Malt extract agar incubated at 25°C for up to 10 days. Total thermotolerant fungi were isolated on Malt extract agar, incubated at 40°C for up to 10 days. Total mesophilic bacteria and bacteria capable of growth at human body temperature were isolated on Nutrient agar incubated at 25°C and 37°C respectively. Thermophilic bacteria and actinomycetes were isolated on R8 agar and incubated at 55°C for 7 days.

Following incubation, emerging colonies on agar plates were counted and, using the known volume of air sampled, air concentrations calculated as colony forming units (cfu)/m^3. Predominant bacteria and fungi were isolated into pure culture and identified.

Identification of Microorganisms

Bacterial Identification

DNA was extracted from the colonies of bacteria that had grown on the agar plates. Polymerase Chain Reaction (PCR) was used to amplify the DNA to detectable levels. This was then sequenced to allow identification of the bacteria.

Fungal identification

Fungal colonies were identified by gross morphology and microscopic examination.

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Occupational Hygiene implications of processing waste at Materials Recycling Facilities (MRFs)

Exposure to bioaerosol and dust

This report presents the findings of a study to investigate exposures to dust and its microbiological components amongst workers employed at Materials Recycling Facilities (MRFs).

The report shows the potential for workers to be exposed to general airborne dust above the level where it is considered a substance hazardous to health (10 mg/m^3 as an 8-hr TWA). Also, there is the potential for exposure to fungi and bacteria, as well as endotoxins, which are agents known to have harmful effects on human health. Endotoxin exposures may be at levels greater than the health-based limit identified by the Dutch Expert Committee on Occupational Safety of 90 EU/m^3.

MRFs play an important role in meeting the demand on UK government to substantially reduce the amount of waste sent to landfill. Provision of MRF sites will be necessary to meet demands for recycling and this industry is likely to expand in the long term. Although recycling and sorting of waste is increasingly mechanised, reliance on manual operations still remains.

The report concludes that the health implications of employee exposure to dust and bioaerosols was not fully considered at the sites visited. This was associated with a lack of corporate occupational health strategies and a failure to adequately manage health and hygiene provision. Areas for improvement identified included: undertaking suitable and sufficient risk assessments; adoption of well implemented, risk-based health surveillance programmes; and the provision of adequate hygiene facilities.

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