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AIR QUALITY AND WORKER HEALTH EFFECTS IN MATERIALS RECOVERY FACILITIES (MRFS) IN ENGLAND AND WALES

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1. INTRODUCTION AND LITERATURE REVIEW

There are varying types of Materials Recycling Facilities (MRFs, also known as Materials Recovery Facilities, or Materials Recycling Factories) in operation in the UK and throughout Europe. A full outline of the various types of MRF operations is given by the Institute of Wastes Management (IWM 2000). This review concentrates on MRFs used to sort and process source-segregated household and commercial waste, the most common type. A MRF that deals with household and commercial waste is defined as *a central operation where source-segregated, dry, recyclable materials are sorted, mechanically or manually, to market specifications for processing into secondary materials* (IWM 2000 p.7).

The number of MRFs in the UK is likely to increase as the European Landfill Directive (1999/31/EC) and UK Government's waste strategies increase the pressure for recycling of paper and packaging-related materials such as plastic. As a result the number of MRFs in the UK has increased rapidly from 6 in the late 1980s/1990s to 100+ in 2002. The average number of MRF employees is between 11 and 19 workers, with a range from 5-49 (IWM 2000), to 4-40 in this study (Gladding 2002a, 2002b). Therefore between 1000 and 2000 workers are handsorting waste in England and Wales at present. The upper end of the Government's estimate gives a total of 400 MRFs, employing between 4,000 and 8,000 workers full-time, by the end of the strategy period. In view of the expanding work force employed in MRFs, employers, regulators and physicians will increasingly need to know potential health hazards to MRF workers.

This paper summarises and reviews previous work that has been carried out on the health of MRF workers in the UK and internationally. This research included exposure measurements at eleven MRFs in England and Wales. The measurement campaign concentrated on air quality, noise and electromagnetic frequencies (EMFs). At nine of the eleven MRFs studied, the health of workers was assessed from self-reported questionnaires about symptoms and from objective measurements such as blood counts and lung function testing. The research compared these eleven different MRFs for mode of operation, size, materials accepted, materials collection method, residue rates and location.

The literature reports a variety of papers that have investigated waste sorting in an occupational context. These references are summarised in Table 1.

Table 1. Waste sorting in an occupational context: summary of literature

Author	*Country*	*Facility-type*	*Contaminants & Concentrations*
Nersting *et al* (1991)	Denmark	Source segregated waste	• Bioaerosols from 6 x 10^2 to 4.7 x 10^4 colony forming units (cfu)/m^3. One sorting hall with no ventilation/temporary shielding had fungi levels of 1.4 x 10^5 cfu/m^3 and 5.4 x 10^5 cfu/m^3 Gram-negative bacteria were found when large quantities of waste were sorted. Endotoxins up to 14.41 ng/m^3. Dust concentrations less than 5 mg/m^3.
Sigsgaard (1993)	Denmark	Source segregated waste compared to paper and composting operatives	• Fungi levels around 1.4 x 10^4 cfu/ m^3 and bacteria between 5 x 10^3- 10^5 cfu/m^3 in waste handling plant. Significantly higher endotoxin concentration was found in waste handling plant compared to paper sorting plant.
IEERR (1995)	USA	Six MRFs	• Environmental measurements Pb 0.07 µg/m^3, Hg 0.006 µg/m^3. Occupational measurement silica 0.12 mg/m^3 & metals all below 0.01 µg/m^3. Total dust up to 2.50 mg/m^3, respirable 0.57 mg/m^3. Peaks of microorganisms at different sites seen in Table 5. Suspended particulates up to 122.75 µg/m^3.
Sigsgaard *et al* (1996)	Denmark	Source segregated waste compared to paper and composting	• Lead up to 3.9 µg/l, mercury 2.3 µg/l in the blood. Cadmium up to 3.6 µg/l in blood of waste workers compared with 1.7 µg/l in controls. Total dust highest in waste handling plant, at 0.74 mg/m^3. Waste handling and compost plant showed the highest viable counts of bacteria and fungi up to 83 x 10^4 cfu/m^3.
Gladding *et al* (1997)	UK	Source segregated MRFs	• Bacteria and fungi to 2.5 x 10^5 cfu/m^3 with total dust levels to 18 mg/m^3.
Kivranta *et al* (1999)	Finland	Source segregated sorting	• Viable fungi, bacteria and Gram-negative bacteria to 10^5 cfu/m^3, VOCs peaking at 3000 µg/m^3 considered to be the limit for discomfort.
Lavoie *et al* (2001)	Canada	Segregated materials	• Bacteria to 2.1 x 10^4 cfu/m^3, Gram-negative bacteria to 3.2 x 10^3 cfu/m^3, fungi to 1.4 x 10^4 cfu/m^3. CO_2, CO, NO and NO_2 not measured in significant amounts. EMFs low, noise exceeded 90 dB(A) in one plant. Ergonomics a possible risk factor for MRF workers.

The majority of these studies investigated waste sorting and particulates, heavy metals and bioaerosol exposure (in particular exposure to viable particles) as being the issues of concern in MRFs. Previously, collection and disposal work was mainly an outdoor activity; therefore contaminants may have been dispersed into the atmosphere. When indoor waste sorting facilities appeared in the 1970s, a number of studies were initiated to investigate the effects of sorting primarily mixed waste (Diaz *et al.* 1976, Constable *et al.* 1979). Since the 1980s (Crook *et al.* 1987) little other research was carried out, as plant had mostly disappeared through economic circumstances. It was only when sorting was re-introduced in Denmark that further studies were instigated, and these were in direct response to observed health effects among the workers in this plant (Sigsgaard 1990, Malmros *et al.* 1994).

A Danish review concluded bioaerosols were of most concern during waste sorting, where concentrations may reach up to 10^8 cfu/m^3 and should be considered potentially harmful, and recommended plant sorting waste should be designed to limit bioaerosol exposure (Poulsen *et al.* 1995). This review showed sorting of unseparated waste generated bioaerosols in the region of 10^6 to 10^7 cfu/m^3 and sorting of separated waste generating bioaerosols in the region of 10^4 to 10^5 cfu/m^3. Specific activities such as manual sorting and baling, leading to greater aerosolisation, may pose higher risks for operatives. Areas where additional exposures may occur have been recognised, for instance in Germany guidelines are available for the protection of workers in sorting plants (TBRA 1999). This specifies that workers should be separated from waste and that personal protection should be supplied when separation is not possible. It was also thought that exposure might be linked to method of operation or waste inputs.

In terms of health effects, it is thought that, because of the relatively short employment time of this 'new' industry, chronic health effects are not yet reported (Sigsgaard *et al.* 1994). Symptoms most commonly seen in the research are pulmonary disorders, organic dust-like symptoms, gastrointestinal problems, eye inflammation, and irritation of the skin and upper airways. The term 'waste recycling worker syndrome' has been suggested for the fever, influenza-like symptoms, upper airway irritation and eye inflammation often seen in waste handling (Poulsen *et al.* 1995). However, limited information existed on the magnitude of risks and the causal factors of these problems, particularly in relation to different facilities and different working tasks.

Danish research concluded that the microbiological causative agents are a complex mixture of endotoxins from Gram-negative bacteria, glucan from fungi, and possibly enterotoxin from bacteria (Malmros *et al.* 1994). In Denmark and some other European countries, the handling of waste is at present associated with a range of respiratory diseases and symptoms in exposed workers, e.g. dry cough, exercise-induced dyspnoea, asthma, organic dust toxic syndrome (ODTS), diarrhoea and gastrointestinal problems. Early research emphasised viable microorganisms (cfu); more recent research has used total counts, endotoxin and lately glucan analysis to disclose the causative capabilities of organic dusts. Their exact mechanisms, the components or combinations of components of the dust that elicit specific effects, and their dose-response relationships, are not yet well understood. Considering these issues, a recent UK study compared MRFs and the occupational health effects experienced by MRF workers. This study is outlined below.

2. STUDY ON MRFS IN ENGLAND AND WALES

The literature review indicated various gaps in the reported studies of MRFs. European BIOMED2 and the Environment Agency for England and Wales therefore co-funded a study on physical and chemical hazards in MRFs, and the health effects of bioaerosol exposures. The study was carried out at eleven MRFs throughout England and Wales handling a mixture of household and commercial waste materials. Nine of the eleven MRFs participated in the collection of health data. The waste collection authorities were using various waste collection systems.

Dusts and bioaerosols, including endotoxin and glucan, were measured by methods reported in previous papers (Rylander 1997, Rylander 1999). Volatile organic compounds (VOCs), cadmium and mercury, were also measured by methods similar to those reported in previous papers (Sigsgaard *et al.* 1996, Wilkins 1997). EMFs were measured for the first time in UK MRFs.

Cross-sectional questionnaires were used at personal interviews to operatives working within the nine MRFs (n=159) during 1999. The questionnaire has recently been standardised and used in a recent research project on health effects amongst waste handlers in the BIOMED2 programme. It is a proposed standard questionnaire for workers in the waste industry. Questions covered previous work history, type of work carried out, relevant out-of-work activities and smoking habits. These were followed by questions on symptoms specifically related to work, *e.g.* cough (dry or with phlegm), chest tightness, eye, nose and throat irritations, itchy or congested nose, nausea, and diarrhoea; and on episodes of fever and influenza-like symptoms. Blood tests (three MRFs) and lung function tests (two MRFs) were also carried out in a similar manner to previous studies (Sigsgaard *et al.* 1994, Gladding *et al.* 1997).

Analysis used standard SPSS-PC software. Bivariate analyses were carried out using conventional chi-square methods, tests for trends, and appropriate non-parametric independent sample tests. Differences were considered statistically significant at $p<0.05$. Multi-variate analysis using logistic regression estimated adjusted odds ratios with 95% confidence intervals (controlling for smoking status, age and gender).

3. RESULTS FROM THE MRF STUDY

Exposure results are summarised in Table 2 (Gladding *et al* 2003).

Table 2. Concentrations of dust, endotoxin and glucan

Parameter	N	Min	Max	Mean
Total Dust (mg/m^3)	260	0	62.61	6.27
Endotoxin (ng/m^3)	128	0.19	198.17	10.89
Glucan (ng/m^3)	119	0	137.37	18.84

Dust levels, and subsequently endotoxin and glucan were significantly higher in facilities accepting twin-wheeled bin materials as shown in Figure 1.

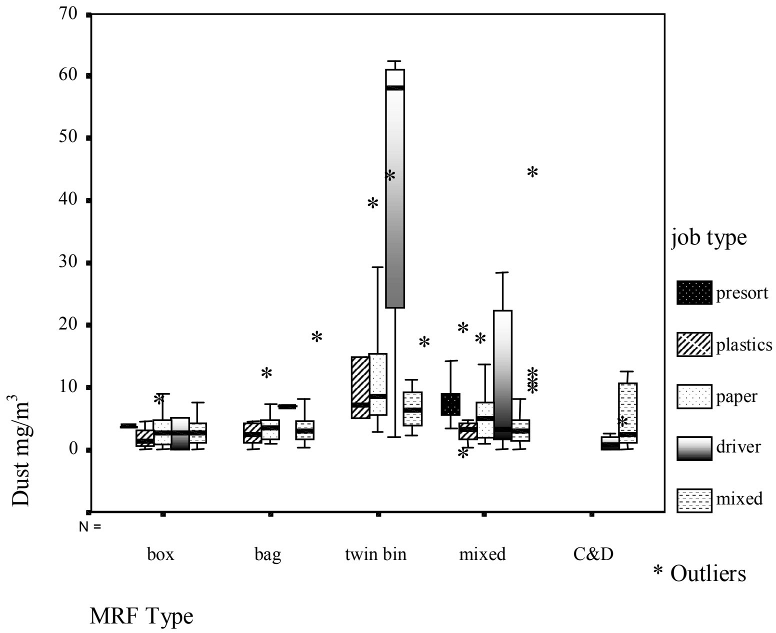

Fig 1. Total Dust measured by job and MRF type

To relate reported symptoms to exposures within MRFs, the mean and median concentrations of dust, endotoxin and (1→3)-ß-D-glucan were plotted. Sites were then ranked by exposure groups according to the prevalent concentrations. This ranking is shown in Table 3 below.

Table 3. Exposure splits (Gladding 2002a, 2002b)

Variable	**Exposure Groups**	***Site Numbers***	**Exposure Levels**	**No. workers per group**
Total dust	Higher	4, 5, 7	>5.0 mg/m^3	42 (26.4%)
	Medium	2, 3, 9	3.0 to 4.9 mg/m^3	78 (49.1%)
	Lower	1, 6, 8	<3.0 mg/m^3	39 (24.5%)
Endotoxin	Higher	3, 4, 7	>8.0 ng/m^3	75 (47.2%)
	Medium	6, 8, 9	4.0 to 7.9 ng/m^3	49 (30.8%)
	Lower	1, 2, 5	<4.0 ng/m^3	35 (22.0%)
Glucan	Higher	3, 4, 8	>12.0 ng/m^3	60 (37.7%)
	Medium	1, 7	5 to 12.0 ng/m^3	42 (26.4%)
	Lower	2, 5, 6, 9	<5.0 ng/m^3	57 (35.8%)

This split was taken by plotting mean vs. median exposure between the sites. Each group of workers was large enough to allow meaningful statistical analysis of symptoms by group. Cross-tabulations for symptoms at the different sites were compared for exposure and the number of symptoms. Two tests for significance were carried out, one concerning whether there was a significant difference between the groups, and another to test for linear-by-linear association (to determine whether linear trends in relation to exposure are significant).

Further significance testing showed that current smokers were significantly (p=0.054) more heavily concentrated in the dust high exposure group (69% of the individuals) than in the lower (53.8%) and medium (62.8%) dust exposure groups. However, this was not true for endotoxin (p=0.964) and was marginal for glucan (p=0.060). Age, gender and presence of chronic disease such as asthma were not associated with differences between any exposure groups. Length of time working at a MRF may be unevenly distributed between exposure groups, with a bias towards longer serving workers being in the higher exposure groups. Significance tests showed that length of service and nature of the job were not associated with exposure to dust or endotoxin. However, chi-square tests for glucan exposure, showed that workers in the higher exposed group worked at MRFs longer, a difference found to be significant (p=0.032). This could have a confounding effect, but could also be interpreted as healthy worker selection effect.

Previous studies have reported under-representation of asthma among waste handling workers (Sigsgaard 1993). In particular, a recent German study found that individuals with atopic diseases were significantly under-represented among compost workers (p=0.003), interpreting this as the result of healthy worker selection (Bünger *et al*. 2000). Therefore health effects due to exposure to bioaerosols may be underestimated in waste management.

Table 4 illustrates symptoms compared to exposure grouping.

Table 4. Exposure vs. No. of workers suffering named symptom (%) (Gladding 2002a, 2002b)

Symptom/ Exposure	Higher Exp.	Middle Exp.	Lower Exp.	Linear	Chi
Total Dust					
Itchy Red Skin	4.8	20.5	7.7	0.648	0.026*
Skin Rash	2.4	10.3	0	0.691	0.043*
Diarrhoea	45.2	44.9	20.5	0.026*	0.024*
Flu symptoms	21.4	42.3	13.2	0.493	0.002*
Endotoxin					
Cough with phlegm	33.3	20.4	17.1	0.048*	0.114
Dry cough	37.3	16.3	40.0	0.760	0.022*
Stuffy nose	64.0	61.2	45.7	0.090	0.180
Hoarse/parched throat	33.3	12.2	20.0	0.048*	0.022*
Glucan					
Cough with phlegm	33.3	28.6	16.7	0.039*	0.107
Hoarse/parched throat	31.6	28.6	13.3	0.021*	0.049*
Stuffy nose	66.7	57.1	53.3	0.145	0.326

*Indicates significant association between exposure and health (p=0.05).

Gradients can clearly be seen in Table 3 between higher compared to lower exposed sites. Odds ratios (adjusted for smoking, age and gender) were used to compare low exposure to medium, and low exposure to high for each reported symptom. The purpose of this exercise was to detect any dose-response relationships, where an increased odds ratio would be evident from low to medium compared to low to high exposure. The results are shown in table 5.

Table 5. Adjusted odds ratios for symptoms vs. exposure (Gladding 2002a, 2002b)

Symptom	Low vs. Medium		Low vs. High	
Total Dust				
Irritated nose/ sneeze	1.0819	(0.4848-2.4140)	2.6869	(1.0476-6.8914)
Diarrhoea	3.4162	(1.3761-8.4807)*	3.5559	(1.2945-9.7676)*
Flu Symptoms	3.6438	(1.3496-9.8383)*	1.3651	(0.4278-4.3559)
Endotoxin				
Cough with phlegm	1.2758	(0.4112-3.9586)	2.7082	(0.9724-7.5424)
Stuffy Nose	1.9825	(0.8061-4.8760)	2.3572	(1.0094-5.5042)
Glucan				
Chest tightness	3.5350	(0.7480-16.7059)	5.2799	(1.2653-22.0322)*
Cough with phlegm	2.2844	(0.8578-6.0836)	2.6736	(1.0829-6.6007)
Hoarse/Parched Throat	2.4026	(0.8699-6.6357)	3.5217	(1.3430-9.2350)*
Stomach problems	2.3113	(0.4752-11.2422)	5.7389	(1.4465-22.7692)*
Irritated nose/sneeze	2.4125	(1.0246-5.6805)*	0.8899	(0.4133-1.9162)
Stuffy nose	1.2867	(0.5630-2.9408)	2.3138	(1.0333-5.1810)

* A relative risk (odds ratio) above 3 indicates significant association between exposure and health (Taubes 1995).

These results indicate that in the MRFs studied, exposure to dust, endotoxin and glucan is dose-response related to health, and particularly to respiratory and gastrointestinal health: this is the first time the relationship has been demonstrated. The results also show that diarrhoea and skin problems are related to total dust exposure; and that upper respiratory nose and throat irritations are also related to total dust exposure, although the relationship is weaker. Endotoxin results are harder to interpret: it appears that workers in medium-exposed MRFs suffer the fewest endotoxin effects. Workers exposed to higher than normal levels of glucan may be more prone to develop symptoms of ill-health. There also appeared to be a time-related effect as shown in Table 6.

Table 6. The relationship between length of time working in a Material Recovery Facility (MRF) and prevalences (%) of reported symptoms (Gladding *et al* 2003)

Symptoms	<6 months	6-18 months	>18 months	p-values (Linear test for trends)
Subjects (n)	38	53	68	
Breathlessness	5.3	1.9	11.8	0.124
Short of breath	2.6	3.8	10.3	0.092
Irritated nose/sneezing	42.1	60.4	54.4	0.322
Cough with phlegm	21.1	24.5	29.4	0.332
Hoarse/parched throat	15.8	18.9	32.4	0.039*
Itching/burning/watery eyes	7.9	15.1	27.9	0.009*
Stuffy nose	63.2	62.3	54.4	0.338
Flu symptoms	18.4	32.1	35.3	0.085
Difficulty concentrating	2.6	7.5	14.7	0.036*
Stomach problems	2.6	11.3	16.2	0.038*
Diarrhoea	10.5	49.0	50.7	0.000*

*Indicates significant association between length of time working in a MRF and reported symptoms ($p<0.05$)

The results indicate that the longer a worker is employed at a MRF, the more likelihood they have of experiencing certain symptoms, *e.g.* hoarse parched throat, itching eyes, difficulty concentrating, stomach problems and diarrhoea. In addition, some of the symptoms, such as cough with phlegm and flu-like symptoms showed a trend towards more common occurrence with length of employment (not significant). The symptoms reported here are not unusual in workers in the waste industry. In general, increased exposure to (1→3)-β-D-glucan has been associated with symptoms such as airway inflammation, fatigue and headache (Rylander 1999).

However, it should be borne in mind that the questionnaire used self-reporting. Respondents may be more prone to report their symptoms if the symptoms have been discussed in association with working in the MRF. Thus, there may be some over-reporting, although workers were not aware of exposure levels when they responded to the questionnaire.

In common with other waste industry studies, this study has demonstrated a significant association between occupational exposure to pollutants and upper-respiratory disorders, systemic effects and gastrointestinal effects (Sigsgaard *et al.* 1994, Malmros *et al.* 1994). In particular, symptoms are prevalent in MRFs with a higher exposure to dusts, most commonly twin-wheeled bin facilities. This kind of facility typically accepts more reject materials than those MRFs where waste is delivered in boxes or bags. In the two such MRFs studied, reject rates of 40% were reported, compared to less than 10% for all other MRF types. This study has found that air quality and the presence of residues are related to workers' symptoms of ill-health.

In the MRFs with higher (1→3)-ß-D-glucan exposure, blood testing of the workers typically found a significant decrease in monocyte numbers. Such a decrease may reflect recruitment from the blood to the lung, as among the workers exposed to (1→3)-ß-D-glucan. Additionally, ESR was decreased among the workers exposed to higher amounts of (1→3)-ß-D-glucan. These results may indicate that (1→3)-ß-D-glucan has a blocking effect on the inflammatory response in blood. The implications of this are fully discussed in a related paper (Gladding *et al.* 2003).

The study also measured were volatile organic compounds (VOCs), EMFs, microorganisms, cadmium and mercury. In common with similar studies the results did not show significantly elevated amounts of these pollutants in MRFs (Lavoie *et al.* 2001). Lead was detected in the air of one facility (from 0.10 to 3.15 $\mu g/m^3$), and was found, in very small amounts, in settled dust in all of the MRFs studied (up to 128 ppm). However, results by Barratt (2000) show that concentrations detected were not excessive for urban areas, which can reach 2,000 ppm and more, particularly as the MRFs sampled were in urban areas.

Results suggest that occupational exposure of MRF workers to higher levels of total dust, endotoxin and (1→3)-ß-D-glucan exhibit symptoms, primarily respiratory and gastrointestinal, that are a response to these levels of these pollutants.

4. FUTURE RESEARCH AND CONCLUSIONS

It is clear from this study that further research is required examining MRF operatives health. Issues such as mixed exposures and longer-term lower exposure need further investigation. Interaction between airborne exposures (bioaerosols, diesel particles and chemicals such as VOCs) at waste sites might hypothetically be considered a factor in inflammatory responses often seen in this occupation (Sigsgaard *et al.* 1994, Malmros *et al.* 1994). Allerman *et al.* (2000) demonstrated that dust generated from mixed household waste handling had a high inflammatory potential without the action of other substances. Further work is needed to determine these dust constituents. Working outdoors in close proximity to vehicles may expose workers to diesel exhaust particles (DEP); or DEP may be drawn into vehicle cabs through windows, doors or inefficient cab filters. DEP is known to cause irritation of the upper respiratory tract and may therefore contribute to health risks for waste handlers, on its own and as an immunostimulant (Scheepers *et al.* 1992, Poulsen *et al.* 1995). Recent *in vitro* and animal mode studies have indicated DEP may contribute an adjuvant effect to pulmonary inflammation responses caused by endotoxin exposure. As endotoxin and DEP may both be present in the air of waste handling operations, a combined effect from the two respiratory responses should be further investigated.

The health risks associated with MRFs are being elucidated, but they need further evaluation. This may be expected to form the basis for rational improvements in waste collection and waste management working practices in the UK. The Danish Working Environment Service has banned handsorting of mixed domestic waste (Malmros *et al.* 1994), the Danish authorities having recognised that workers' health problems may be associated with the collection and recycling of household waste. Since such problems may be exacerbated by careless behaviour and personal hygiene of operatives Danish guidelines recommend improved practice. Other wastes sorted manually were to be kept moisture free and uncontaminated with household waste.

However, results suggest that MRF workers exposed to higher levels of endotoxin and (1→3)-ß-D-glucan at their work sites exhibit various work-related symptoms, and that the longer a worker is in a MRF environment, the more likely they are to become affected by respiratory and gastrointestinal symptoms. Results also suggest that differences between MRF type and operation may have an impact on worker exposure. If handsorting of materials is a hazard to workers' health, remedies may be unaffordable to businesses: the income from MRFs will never equal that from a landfill or incinerator. Conversely, MRFs may attract investment as capital costs to build plant are comparatively inexpensive. MRFs are becoming increasingly common in the UK and if they are to be a component of national waste strategies, governments will need to resolve the tension between workers' health and strategic goals.

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