ORIGINAL ARTICLES AAEM

Ann Agric Environ Med 1997, 4, 53–61

A JOB EXPOSURE MATRIX RELATED TO BIOAEROSOL EXPOSURE DURING COLLECTION OF HOUSEHOLD WASTE*

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Breum NO, Nielsen M, Würtz H, Ivens UI, Hansen J, Schibye B, Nielsen BH, Poulsen OM: A job exposure matrix related to bioaerosol exposure during collection of household waste. A*nn Agric Environ Med* 1997, **4**, 53-61.

Abstract: Personal bioaerosol exposure in collecting household waste is correlated to governing parameters including type of the waste, collection unit at the houses, type of collection vehicle, and the waste collector's job description. It is difficult to generalize from exposure data on an individual waste collector to a large group of collectors. To solve this problem a job-exposure matrix (JEM) was constructed using matrix elements characterized in terms of governing parameters. Exposure data for a matrix element were obtained by personal sampling in the field. For elements with no measured data the exposure was extrapolated from elements with measured data using exposure modifiers and a multiplicative model. It is concluded that the matrix allows exposure of subgroups of waste collectors to be estimated on the basis of easily obtained data on governing parameters.

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Key words: household waste, bioaerosol exposure, fungi, bacteria, waste collection, refuse collector, dustman, organic dust.

INTRODUCTION

Epidemiological studies may fail to reveal an existing dose-response relationship because of misclassification of exposure, which may occur if the exposure is insufficiently characterized. For waste collectors, the bioaerosol exposure is governed by a series of parameters related to their work conditions, i.e. type of the waste, season of the year, type of collection unit at the households, type of collection vehicle, and organisation of work [10]. In addition a multitude of different bioaerosol exposure parameters may be relevant with respect to the risk of developing occupational health problems. Due to this multitude of parameters it is extremely expensive and time consuming to obtain a detailed exposure characterization of even a restricted number of waste collectors, and it is difficult to generalize from exposure data on an individual waste collector to a large group of collectors. Therefore, the purpose of the present study was to solve this problem by characterizing the exposure of subgroups of collectors according to their general work conditions, thereby establishing a job exposure matrix (JEM). A matrix element was characterized in terms of governing parameters, and measurements of bioaerosol exposure on waste collectors belonging to the matrix element provided an exposure description of the element. For matrix elements with no measured data available the exposure level was estimated by extrapolation from elements with measurement data.

MATERIALS AND METHODS

The study was based on the assumption that homogenous subgroups of waste collectors can be defined according to their general work conditions. For each waste collector detailed information on work conditions was obtained by a questionnaire [6]. These data were used

Received: 13 September 1996
Accepted: 31 January 1997

*Presented at the International Meeting: “Waste Collection and Recycling - Bioaerosol Exposure and Health Problems”, Køge, Denmark, 13-14 September 1996.

to establish a job matrix. A matrix element was characterized in terms of a distinct combination of governing parameters, i.e. type of waste, type of waste collection unit, type of collection vehicle, and organisation of work. Hence, the job of each waste collector was characterized by the time he spent working in defined matrix elements.

To enable the establishment of a job exposure matrix the exposure profiles of selected matrix elements were characterized in detail. A high number of different matrix elements are possible in theory, but many of these were actually relevant for only a few or none waste collectors. Consequently, detailed exposure measurements were performed at elements which were relevant for a high number of waste collectors. Exposure data were obtained with the assistance of crews of waste collectors (1-3 persons) working under specified sets of governing parameters (see below). Full shift personal sampling was used, and 171 samples were collected [1, 2, 8, 9, 13, 19]. Dust was collected on 25 mm, 8.0 µm membrane filters of mixed esters of cellulose using closed-face Millipore field monitors with a 5.6 mm inlet operated at 1.9 l/min. The collected mass was determined by weighing the filter before and after the sampling and the dust was analysed for content of endotoxin. Closed-face Nuclepore field monitors operated at 1.0 l/min were used for collecting microbial samples on 25 mm, 0.4 µm polycarbonate filters. Microorganisms were quantified by a modification of the CAMNEA-method [12] which includes determination of airborne microorganisms by epifluorescence microscopy (total counts) and cultivation (viable counts). Concentrations of culturable fungi (cfu/m^3), counts of fungal spores (cells/m^3), and total counts of microorganisms (cells/m^3) were used as parameters for characterizing the exposure. Details on sampling techniques, analytical methods and exposure concentrations of microorganisms, dust and endotoxin are reported elsewhere [1, 2, 8, 9, 13, 19].

The governing parameters selected for the JEM were type of waste, type of waste collection unit at the households, type of collection vehicle, and the waste collector's job description.

Type of waste. Among Danish municipalities a variety of different approaches for source separation of household waste are enforced and the following types of waste were considered for the bioaerosol sampling strategy: mixed household waste (MHW), bio-degradable waste (BDW), non-degradable waste (NDW), recyclable paper and cardboard, paper and glas, and garden waste. Breum *et al.* [1] reported that workers collecting garden waste were exposed to higher bioaerosol concentrations than workers collecting paper and cardboard ($p < 0.05$; Mann-Whitney test). Würtz *et al.* [19] observed that workers collecting paper and cardboard were exposed to significantly lower concentrations than workers collecting mixed household waste ($p < 0.05$; Mann-Whitney test). No significant ($p = 0.22$) difference in bioaerosol exposure was observed among workers collecting mixed, bio-degradable or non-degradable waste (unpublished results). For the JEM these three types of waste were considered identical (MH-BD-ND-waste) in terms of bioaerosol exposure. Measurements of bioaerosol exposure were also made for workers collecting paper and glas at the same time, and the matrix thus included the following four types of waste: MH-BD-ND (w_1), paper and cardboard (w_2), garden waste (w_3), and paper and glas (w_4).

Type of waste collection unit at the households. For storage of waste outside the house several types of units are in use including sacks of paper or plastic in stands with lids, bins or containers. The following types were considered for the bioaerosol sampling strategy: sacks, bins without wheels (approx. 0.1 m^3), bins with two wheels (approx. 0.2 m^3), and containers with four wheels (approx. 0.4-0.6 m^3). Nielsen *et al.* [8] observed that collection of bio-degradable waste in bins (without wheels) resulted in more heavily bioaerosol exposure than collection of waste in sacks ($p < 0.05$; Mann-Whitney test). Compared to collectors using two-wheeled bins no significant ($p = 0.13$) difference was observed in bioaerosol exposure for collectors using four-wheeled containers (unpublished results). The JEM thus included the following three types of collection units: sacks (u_1), bins without wheels (u_2), and wheeled bins or containers (u_3).

Type of collection vehicle. In Denmark compactor vehicles are often used for collecting the waste. At the rear the collection vehicles are fitted with a hydraulic lifting device for loading the waste into the vehicle. Basically two different systems are used. For some vehicles the waste is emptied into a scoop and when the scoop is full the waste is pushed into a closed compartment. In this process the waste is compacted. In loading the scoop a bin, container or sack is lifted approx. 1.5 m above the ground ('low loading'). In another type of collection vehicle, waste is loaded from the top which involves automatic lifting of the sack, bin or container approx. 4 m above the ground ('high loading'). Würtz *et al.* [19] reported that 'low loading' was associated ($p < 0.05$; Mann-Whitney test) with high exposure to bioaerosols compared to 'high loading'. In some municipalities platform vehicles are used for collecting bio-degradable waste in sacks, and Nielsen *et al.* [8] observed that 'low loaded' compactor vehicles caused collectors to be more heavily exposed to bioaerosols than collectors using platform vehicles ($p < 0.05$; Mann-Whitney test). Based on these studies the JEM included three types of collection vehicles: 'low loaded' compactor vehicles (v_1), 'high loaded' compactor vehicles (v_2), and platform vehicles (v_3).

The waste collectors' job description. A crew of waste collectors may have three members: 'the runner' operates ahead of the vehicle by taking the waste from backyards etc. to the curbside; 'the loader' empties the waste into the vehicle and takes the bins or containers (if any) back to the houses; and 'the driver' drives the vehicle

but sometimes also assists the 'loader'. It is noted that members of some crews may change job description during the day, and for crews of less than three members more than one job description is needed to characterize the type of work carried out. For this study a member having more than one job description during the day was characterized by the term 'collector'. For the collection of mixed household waste Nielsen *et al.* [9] reported the 'loader' to be more heavily exposed ($p < 0.05$; Duncan's multiple range test) to bioaerosols than the 'runner' and the 'driver', whereas no significant difference was observed between the 'driver' and the 'runner'. Although no difference was observed between the 'driver' and the 'runner', these two jobs were kept separate throughout this study. Based on the mentioned findings the JEM included four different job descriptions: 'runner' (j_1), 'loader' (j_2), 'driver' (j_3), and 'collector' (j_4).

Exposure classification of matrix elements. The variation in exposure is an important issue in the design of an exposure monitoring strategy for epidemiological purposes. In case of an individual exposure assessment strategy the within and between worker variance determine the magnitude of underestimation an exposure-response relationship [5]. In the appendix to this paper the equations are given for the estimation of the within and between worker variance. In case of a grouping exposure assessment strategy the situation is more complex and the Berkson error model should be applied [3].

This study applied a strategy of *a priori* grouping of waste collectors into homogeneous subgroups according to governing parameters in terms of type of waste, type of collection unit, type of collection vehicle, and type of job description. The JEM from this strategy was comprehensive in terms of the number of elements ($N = 33$), and for practical reasons no monitoring of bioaerosol exposure was accepted for some of the elements. An emphasis was put on characterizing the exposure level for elements considered most important.

Four governing parameters were used for the JEM: type of waste (w_i; $i = 1,2,3,4$), type of vehicle (v_n; $n = 1,2,3$), type of job function (j_m; $m = 1,2,3,4$), and type of collection unit (u_p; $p = 1,2,3$). Consider a sub-sample of matrix elements with all governing parameters kept constant except for one. This parameter may have x levels (e.g. $x = 1$ for driver, $x = 2$ for loader etc.). Consider matrix element x with measured data, C_x. Consider another element x^* with no measurement data. The exposure level of this element, C_{x*}, is extrapolated from C_x by a multiplicative model using an exposure modifier, EM_{xx*}, i.e.

$$C_{x*} = EM_{xx*} \times C_x \quad (1)$$

Assume that both C_x and EM_{xx*} are log-normally distributed, i.e.

$$C_x \subset LN(\mu_x, \beta_x^2) \qquad EM_{xx*} \subset LN(\mu_{xx*}, \beta_{xx*}^2) \quad (2)$$

The sum of two independent log-normal distributions is another log-normal distribution, i.e.

$$C_{x*} \subset LN(\mu_{xx*} + \mu_x, \beta_{xx*}^2 + \beta_x^2) \quad (3)$$

Consider another sub-sample of matrix elements with all governing parameters kept constant except for the parameter x. For this subsample measurement data are available for matrix elements x (C_x) and x^* (C_{x*}). Assume that both C_x and C_{x*} are log-normally distributed, i.e.

$$C_x \subset LN(\mu_x, \beta_x^2) \qquad C_{x*} \subset LN(\mu_{x*}, \beta_{x*}^2) \quad (4)$$

The exposure modifier EM_{xx*} is derived from the following equation

$$EM_{xx*} = \frac{C_x}{C_{x*}} \quad (5)$$

Assuming C_x and C_{x*} to be independent EM_{xx*} is log-normally distributed, i.e.

$$EM_{xx*} \subset LN(\mu_x - \mu_{x*}, \beta_x^2 + \beta_{xx*}^2) \quad (6)$$

For a few elements of the JEM two exposure modifiers were used (see results) for calculating the exposure level. It is noted that the equations for one modifier are readily expanded to include two or more modifiers.

Validation of the exposure classification. The classification of a matrix element was validated by holding the calculated exposure level against the exposure level estimated from measurement data.

RESULTS

Measurement data belonging to a matrix element were log-transformed and tested for normality (Anderson-Darling test) at a 5% level of statistical significance. Except for one element (see Table 4) the hypothesis of normality was accepted. Note that three or more data points are required for the Anderson-Darling test, and for elements with 2 data points a log-normal distribution was assumed.

Within a crew of waste collectors the exposure modifiers for calculating exposure from one type of job description to another was derived by keeping the 'collector' as a reference. The data used for estimating the exposure modifiers were obtained for workers operating a 'low loaded' compactor vehicle for the collection of MH-BD-ND-waste kept in wheeled bins or containers. Within a job the exposure data were log-transformed and the exposure modifier (log-transformed) was estimated as the difference in the means between the two types of job descriptions under consideration. If a hypothesis of homogeneity in variance among the two job descriptions was accepted at a 5% level of statistical significance (Bartlett's test) the 95% confidence interval of the mean was estimated using the pooled variance. The estimated exposure modifiers (retransformed) are listed in Table 1. Keeping a 'low loaded' compactor vehicle as a reference, exposure modifiers were estimated likewise for calculating exposure from a 'low loaded' to a 'high loaded' vehicle. Data for the calculations were obtained for the 'collector' collecting MH-BD-ND-waste in wheeled bins or containers. The estimated modifiers are summarized in Table 2.

Table 1. Bioaerosol exposure during collection of MH-BD-ND waste kept in wheeled bins or containers. 'Low loaded' compactor vehicles were used. For a 'runner' the exposure is not affected by the type of truck and the listed data include samples (N = 1) obtained for 'runners' at 'high loaded' compactor trucks. Keeping the 'collector' as a reference the exposure modifiers (EM) for calculating bioaerosol exposure from one job description to another are included in the table. Note that the modifiers were derived from log-transformed data.

	Driver (N = 2)	Runner (N = 4)	Loader (N = 8)	Collector (N = 47)
Fungal spores (live and dead)				
Exposure (10^3 cells/m^3)	59[A]; 1.6[B]	71; 1.7	340; 2.0	240; 2.9
	(0.6-5100)[C]	(30-170)	(190-610)	(180-330)
EM	0.24	0.091	1.4	1
	(0.05-1.1)[C]	(0.03-0.3)	(0.3-1.6)	
Microorganisms (live and dead)				
Exposure (10^3 cells/m^3)	59; 1.6	120; 2.2	490; 1.9	330; 3.0
	(0.7-5100)	(33-410)	(290-820)	(240-460)
EM	0.18	0.35	1.5	1
	(0.04-0.8)	(0.1-1.0)	(0.7-3.3)	
Fungi (culturable)				
Exposure (10^3 cfu/m^3)	37; 2.0	25; 2.5	180; 1.9	87; 2.9
	(0.06-22000)	(6-100)	(100-300)	(66-110)
EM	0.42	0.29	2.0	1
	(0.09-1.9)	(0.01-0.8)	(0.9-4.4)	

A: Median; B: Geometric standard deviation (GSD); C: 95% confidence interval.

Table 2. Waste collectors' exposure to bioaerosols during the collection of MH-BD-ND waste in wheeled bins or containers. The exposure modifiers (EM) for calculating bioaerosol exposure from one type of compactor vehicle to another are given in the table. Note that the modifiers were derived from log-transformed data.

	'Low-loaded' compactor vehicle (N = 47)	'High-loaded' compactor vehicle (N = 21)
Fungal spores (live and dead)		
Exposure (10^3 cells/m^3)	240[A]; 2.9[B]	75; 2.5
	(180-330)[C]	(50-120)
EM	1	0.31
		(0.2-0.5)[C]
Microorganisms (live and dead)		
Exposure (10^3 cells/m^3)	330; 3.0	240; 2.0
	(240-460)	(170-330)
EM	1	0.71
		(0.4-1.2)
Fungi (culturable)		
Exposure (10^3 cfu/m^3)	87; 2.9	22; 2.8
	(64-120)	(14-35)
EM	1	0.25
		(0.1-0.4)

A: Median; B: Geometric standard deviation (GSD); C: 95% confidence interval.

Table 3. Pulmonary ventilation rate at different job descriptions during collecting household waste.

Job description	Pulmonary ventilation rate (l/min)
'driver'	20
'loader'	35
'runner'	45
'collector'	30

The bioaerosol exposure level for a matrix element with measurement data available was characterized in terms of the median (geometric mean) for culturable fungi, fungal spores, and total microorganisms (total counts of fungal spores and spherical bacteria), respectively. The data were log-transformed and the median was estimated as the retransformed mean of the log-transformed data. The 95% confidence interval for the mean was retransformed as an estimate of the 95% confidence interval for the median. Except for matrix element No. 1 the exposure level for a matrix element with less than 3 observations was estimated using exposure modifiers. Data from a comparable element were log-transformed and the estimated mean (including a 95% confidence interval) for the empty element was obtained using the log-transformed exposure modifier. The retransformed mean (including the 95% confidence interval) was the estimated median exposure level (including the 95% confidence interval).

Table 4. Bioaerosol exposure (M: median (geometric mean); GSD: geometric standard deviation; C.I.: 95% confidence interval for the median) during the collection of household waste. The notes (N1-N8) in the table are given in the text (results).

No	Type of vehicle	Collection unit	Type of waste	Job	N	Note	Culturable fungi $10^3 \times$ cfu/m^3			Fungal spores $10^3 \times$ cells/m^3			Total microorganisms $10^3 \times$ cells/m^3		
							M	GSD	C.I.	M	GSD	C.I.	M	GSD	C.I.
1	low loaded compactor vehicle	wheeled bins and containers	MHW-BDW-NDW[A]	driver	2	N1	37	2.0	20-73	59	1.6	32-98	59	1.6	32-110
2				runner	3	N2	25	2.5	6-100	71	1.7	30-170	120	2.2	30-410
3				loader	8	N1	180	1.9	100-300	340	2.0	190-610	490	1.9	290-820
4				collector	47	N1	87	2.9	66-110	240	2.9	180-330	330	3.0	240-460
5		bins without wheels	MHW-BDW-NDW	driver	0	N3	38	3.0	20-73	56	2.6	32-98	85	2.7	47-150
6				runner	1	N3	26	2.9	14-49	67	3.5	32-140	170	2.7	93-300
7				loader	0	N3	190	2.9	100-340	320	2.5	180-550	710	2.6	410-1200
8				collector	14	N1	91	3.3	46-180	230	1.5	180-290	480	1.6	360-650
9		sacks	MHW-BDW-NDW	driver	0	N3	19	2.8	11-33	31	3.4	16-60	35	3.7	18-72
10				runner	0	N3	13	2.8	8-22	37	4.2	17-80	69	3.7	34-140
11				loader	2	N3	92	2.7	55-160	180	3.3	94-330	290	3.6	150-580
12				collector	18	N1	45	2.4	29-71	130	5.0	57-280	200	6.2	81-490
13	high loaded compactor vehicle	wheeled bins and containers	MHW-BDW-NDW	driver	1	N3	9	2.8	5-16	18	3.7	11-31	42	2.7	25-70
14				runner	1	N2	25	2.5	6-100	71	1.7	30-170	120	2.2	30-410
15				loader	0	N3	45	2.8	27-75	110	2.7	64-170	350	2.6	210-570
16				collector	21	N1	22	2.8	14-35	75	2.5	50-120	240	2.0	170-330
17		bins without wheels	MHW-BDW-NDW	driver	0	N5	10	2.9	5-19	17	2.7	9-33	61	2.7	32-110
18				runner	0	N5	7	2.9	3-13	21	3.1	10-43	120	2.7	60-220
19				loader	0	N5	47	2.8	24-91	99	2.6	53-180	510	2.6	270-940
20				collector	0	N4	23	2.9	12-43	71	2.6	41-120	340	2.5	200-580
21		sacks	MHW-BDW-NDW	driver	0	N5	5	2.8	3-9	10	3.1	5-19	25	3.2	13-50
22				runner	0	N5	3	2.8	2-6	12	3.5	6-24	49	3.2	25-97
23				loader	0	N5	23	2.8	13-42	55	3.0	29-100	210	3.1	110-400
24				collector	0	N6	11	2.8	7-19	39	3.2	22-72	140	3.3	76-260
25	platform vehicle	sacks	MHW-BDW-NDW	driver	0	N3	15	2.7	8-28	56	2.9	28-110	74	3.1	36-150
26				runner	0	N3	10	2.7	6-17	67	3.8	30-150	140	3.1	70-280
27				loader	6	N1	29	2.9	9-90	490	2.3	200-1200	830	2.0	400-1700
28				collector	13	N1	36	2.1	23-55	230	3.3	110-470	420	3.5	200-890
29	low loaded compactor vehicle	sacks	paper and cardboard	collector	0	N7	4	2.4	2-8	39	1.7	27-57	150	1.9	92-240
30		bins without wheels	paper and cardboard	collector	0	N7	4	2.4	2-8	39	1.7	27-57	150	1.9	92-240
31		wheeled bins and ontainers	paper and cardboard	collector	10	N1	4	2.4	2-8	39	1.7	27-57	150	1.9	92-240
32	low loaded compactor vehicle	wheeled bins, sacks	garden	collector	12	N1	130	3.0	65-260	410	1.7	290-580	640	1.5	490-830
33	platform vehicle		paper/glas	collector	12	N1 N8	15	6.4	5-49	180 B	-	5-400 B	240 B	-	5-920 B

A: Mixed household waste (MHW), bio-degradable waste (BDW) and non-degradable waste (NDW). B: Median and range (data were not log-normally distributed).

Table 5. Bioaerosol exposure in terms of inhaled dose per minute.

No	Type of vehicle	Collection unit	Type of waste	Job	V l/min	Culturable fungi cfu/min	Fungal spores cells/min	Total microorg. cells/min
1	low loaded compactor vehicle	wheeled bins and containers	MHW-BDW-NDW[A]	driver	20	740	1,200	1,200
2				runner	45	1,100	3,200	5,400
3				loader	35	6,300	12,000	17,000
4				collector	30	2,600	7,200	9,900
5		bins without wheels	MHW-BDW-NDW	driver	20	760	1,100	1,700
6				runner	45	1,200	3,000	7,700
7				loader	35	6,700	11,000	25,000
8				collector	30	2,700	6,900	14,000
9		sacks	MHW-BDW-NDW	driver	20	380	620	700
10				runner	45	590	1,700	3,100
11				loader	35	3,200	6,300	10,000
12				collector	30	1,400	3,900	6,000
13	high loaded compactor vehicle	wheeled bins and containers	MHW-BDW-NDW	driver	20	180	360	840
14				runner	45	1,100	3,200	5,400
15				loader	35	1,600	3,900	12,000
16				collector	30	660	2,300	7,200
17		bins without wheels	MHW-BDW-NDW	driver	20	200	340	1,200
18				runner	45	320	950	5,400
19				loader	35	1,600	3,500	18,000
20				collector	30	690	2,100	10,000
21		sacks	MHW-BDW-NDW	driver	20	100	200	500
22				runner	45	140	540	2,200
23				loader	35	800	1,900	7,400
24				collector	30	330	1,200	4,200
25	platform vehicle	sacks	MHW-BDW-NDW	driver	20	300	1,100	1,500
26				runner	45	450	3,000	6,300
27				loader	35	1,000	17,000	29,000
28				collector	30	1,100	6,900	13,000
29	low loaded compactor vehicle	sacks	paper and cardboard	collector	30	120	1,200	4,500
30		bins without wheels	paper and cardboard	collector	30	120	1,200	4,500
31		wheeled bins and containers	paper and cardboard	collector	30	120	1,200	4,500
32	low loaded compactor vehicle	wheeled bins, sacks	garden	collector	30	3,900	12,000	19,000
33	platform vehicle		paper/glas	operator	30	450	5,400	7,200

A: Mixed household waste (MHW), bio-degradable waste (BDW) and non-degradable waste (NDW).

The job exposure matrix including the estimated exposure levels to bioaerosols is presented in Table 4. The estimated geometric standard deviations (GSD) are included in the table, and throughout all matrix elements GSD was at or below 3.2 for 92% of the elements. As indicated in the table the data require the following remarks: N1 - the median exposure was estimated from measurement data; N2 - the runners' exposure is not affected by the type of collection vehicle and the exposure was estimated as the median of data from matrix elements Nos. 2 and 14; N3 - using the exposure modifiers given in Table 1 the exposure level was calculated from measured data obtained for the collector; N4 - using the exposure modifiers listed in Table 2 the collectors' exposure was calculated from measurement data obtained for the collector at matrix element No. 8; N5 - using the exposure modifiers listed in Table 1 the exposure was calculated from the calculated exposure for the collector; N6 - using the exposure modifiers listed in Table 2 the exposure was calculated from measurement data for the collector at matrix element No. 12; N7 - the exposure level was assumed to be similar to the level of matrix element No. 31; N8 - this type of waste required no specific collection unit at the houses, i.e. the waste was kept in bundles, plastic bags etc.

The degrees of freedom was low (N-1 = 1) in estimating the confidence intervals of the medians for matrix element No. 1. Consequently, wide intervals were obtained (Table 1, 'driver'). As observed from Table 4 the estimated GSD's for matrix element No. 1 were comparable to the GSD's for all other matrix elements. Therefore the confidence intervals listed in Table 1 for matrix element No. 1 were not included in Table 4. For Table 4 the confidence intervals for matrix element No. 5 (fungi and fungal spores) and No. 17 (total microorganisms) were used for element No. 1. The elements Nos. 5 and 17 were used because of medians similar to element No. 1 and GSD's above element No. 1.

For application of exposure modifiers it is a basic assumption that they are unaffected from other governing parameters except for the parameter under consideration. To validate the performance of the exposure modifiers given in Table 1 the exposure level of the loader (Table 4: element No. 27) was estimated from the collector (Table 4: element No. 28). In terms of medians and 95% confidence intervals the estimated exposure levels for the loader were: fungi (culturable): 72×10^3 cfu/m^3 (95% confidence interval ranging from 40×10^3 to 130×10^3 cfu/m^3); fungal spores (live and dead): 320×10^3 cells/m^3 (95% confidence interval ranging from 170×10^3 to 600×10^3 cells/m^3); and total microorganisms (live and dead): 610×10^3 cells/m^3 (95% confidence interval ranging from 320×10^3 to 1200×10^3 cells/m^3). For all three parameters the calculated median exposure level was close to the level estimated from measurement data (see element No. 27, Table 3), and a calculated level was within the 95% confidence interval estimated for the element. For matrix element No. 11 two observations were available, and from the observations the estimated median exposure levels were 50×10^3 cfu/m^3 (culturable fungi), 700×10^3 cells/m^3 (fungal spores) and, 800×10^3 cells/m^3 (total microorganisms). For culturable fungi the exposure level was within the 95% confidence interval of the calculated exposure level, but for fungal spores and total microorganisms the estimated exposure levels were not within the confidence intervals of the calculated exposure levels.

As the inhaled amount of bioaerosols may be more important than the recorded air concentrations when considering health effects, each matrix element was also classified according to the inhaled dose per minute (Tab. 5). As an approximation the dose was calculated as the median exposure level (Tab. 4: air concentration) multiplied by the pulmonary ventilation rate (Tab. 3). The pulmonary ventilation rate (Tab. 3) was estimated from information on the physical work load and recordings of pulmonary ventilation rate during collection of waste [15]. It is noted that a dose listed in Table 5 is a rough estimate (see discussion) and a 95% confidence interval was not estimated.

DISCUSSION

A basic task in assessing exposure for epidemiology is to assign exposure during a given period to a group of individuals who are characterized by some shared set of parameters governing the exposure. Exposure is usually assessed for a subsample only, using the results of measurements and modelling. Thus, a typical exposure assessment task is: (A) *a priori* definition of a group with some shared set of governing parameters, (B) definition and sampling of a subsample, (C) assessing the exposure of the subsample from the results of measurements, and (D) extrapolating from the sample to the whole group [16]. Step D is usually done by attributing the mean exposure of the subgroup to the whole group. An exposure scenario can be very complex including many governing parameters; unfortunately, there is no general method for selecting the governing parameters, and almost every epidemiological study includes its own set of governing parameters. For the present study type of collection vehicle, type of collection unit at the households, type of waste, and the waste collectors' job description were selected as governing parameters.

Several factors influence whether a JEM can provide useful exposure assessments. An important factor is the ratio of the variance between matrix elements to the variance within a matrix element. If the matrix elements are sufficiently detailed, the exposure profiles are more likely to be more homogeneous within matrix elements and heterogeneous between matrix elements; the cruder and less specific the matrix elements, the more likely the opposite pattern is to occur [17]. Rappaport [14] defined a homogeneously exposed group as a group in which 95% of the individual mean exposures lie within a factor of 2.

Assuming a log-normal distribution of the exposure (between persons) the definition requires GSD to be at or below 1.2. The definition of a uniformly exposed group is arbitrary and a factor of 2 is rather restrictive. For this study a GSD at or below 3.2 was observed for most of the matrix elements indicating that 95% of the individual exposures are expected to lie within a range of approx. 0.1 - 10 times the group mean. Although a GSD of 3.2 may be considered high it is noted that this level of variability is not uncommon for occupational settings [14].

The approach of exposure modifiers is well known [16] for the assessment of exposure to air pollutants. The aim of any method for assessing exposure should be to maximize the validity of the particular measurement variable chosen, where the validity is defined as the ability of the variable to reflect the true exposure. Considering the exposure level estimated from measurement data as 'true' it was observed that a calculated exposure level was close to the 'true' level. A calculated level was contained by the 95% confidence interval of the 'true' level. However, the exposure level estimated from two observations was not within the 95% confidence interval for all three parameters (fungi, fungal spores, total microorganisms) under consideration. It is recognized that few data were available for the validation and the JEM should not be considered fully validated.

As observed from equation No. 2 (in the appendix) it is far from easy to estimate the dose of bioaerosols inhaled by a waste collector. For the estimation time resolved data are required for the pulmonary ventilation rate and for the inhalable bioaerosol concentration. For this study only a rough estimate was available for the pulmonary ventilation rate. Closed-face field monitors were used for sampling of bioaerosols and time-weighted average concentrations were obtained. It is noted that the monitors did not meet the requirements for sampling inhalable aerosols [18]. As a first approximation the inhaled dose of bioaerosols per minute was estimated as the concentration times the pulmonary ventilation rate. By comparing Table 4 and 5 it is evident that the dose only changes the ranking for a few of the matrix elements.

Although the exposure matrix has not yet been fully validated, it should be recalled that the matrix, unlike several job-exposure matrices, was based on extensive bioaerosol exposure measurements at defined work conditions using personal sampling techniques. Moreover, when linked to questionnaire data, the listed levels of bioaerosol exposure provided some evidence of a relationship between exposure and prevalence proportion of nausea and diarrhoea or symptoms related to bronchitis [4, 7], indicating a potential usefulness of the employed JEM approach.

The present paper describes a first attempt to establish a JEM for waste collectors with a preliminary focus on a few bioaerosol exposure parameters, i.e. culturable fungi, counts of fungal spores, and total counts of microorganisms. In future research the JEM may include additional measured parameters, e.g. endotoxin, counts of spherical and rod shaped bacteria, viable counts of *A. fumigatus* etc. Recently, principal component analysis demonstrated that the variation between independent measurements of bioaerosol exposure was best accounted for by two parameters: total count of fungal spores and rod shaped bacteria [11]. The three parameters were not correlated, and establishment of a JEM for these parameters may provide new information on dose-response relationship for different health outcomes among waste collectors. For the statistical approach future research may include application of generalized linear models. Such an approach would have the advantage of relative stable predictions over matrix elements and more precise estimates of the variance.

CONCLUSION

A four dimensional JEM on bioaerosols was constructed for waste collectors. The governing parameters for the matrix were: type of waste, type of collection unit at the households, type of collection vehicle, and the waste collectors' job description. It is concluded that this approach allows exposure of subgroups of waste collectors to be estimated on the basis of easily obtained data on the governing parameters.

Acknowledgement

The present study is part of the 1993-98 research programme Waste Collection and Recycling, which is supported jointly by the Danish Ministry of the Environment and the Ministry of Labour.

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APPENDIX

Within and between worker variance

Suppose a matrix element of N workers has been defined and their exposure to bioaerosols is to be characterized. The temporal resolution will be one work shift. For worker i in the cohort the concentration as a function of time during shift j is $C_{ij}(t)$. The time-weighted average concentration, E_{ij}, experienced by the worker for the shift $[t_a, t_b]$ is

$$E_{ij} = \frac{1}{t_a - t_b} \int_{t_b}^{t_a} C_{ij}(t)dt \qquad (1)$$

If $C_{ij}(t)$ is the inhalable fraction of the bioaerosols and the pulmonary ventilation rate for worker i is $V_{ij}(t)$ the inhaled time-weighted average dose per minute, D_{ij}, during shift j is given by

$$D_{ij} = \frac{1}{t_a - t_b} \int_{t_b}^{t_a} C_{ij}(t) \times V_{ij}(t)dt \qquad (2)$$

Consider a period of m shifts ($j = 1,2,...,m$). The shift-integrated mean concentration for worker i is [2]

$$\mu_i = \frac{1}{m} \sum_{j=1}^{m} E_{ij} \qquad (3)$$

For the cohort the shift-integrated mean exposure is

$$\mu = \frac{1}{N} \sum_{i=1}^{N} \mu_i \qquad (4)$$

The within-worker i variance (day-to-day variance for worker i) is

$$\sigma_{wi}^2 = \frac{1}{m-1} \sum_{j=1}^{m} (E_{ij} - \mu_i)^2 \qquad (5)$$

The average within-worker variance is

$$\sigma_{w*}^2 = \frac{1}{N} \sum_{i=1}^{N} \sigma_{wi}^2 \qquad (6)$$

The between-worker variance is

$$\sigma_B^2 = \frac{1}{N-1} \sum_{i=1}^{N} (\mu_i - \mu)^2 \qquad (7)$$

Usually only a subsample of all E_{ij} is available for the estimation of μ. Consider the situation where n out of the N workers have been sampled on r out of m shifts, and that sampling was random and symmetric. E_{ij} is assumed to be known without error. For this two-stage sampling the group mean, μ, is estimated as

$$\hat{\mu} = \frac{1}{nr} \sum_{i=1}^{n} \sum_{j=1}^{r} E_{ij} \qquad (8)$$

The variance of the estimator [1] is

$$Var(\hat{\mu}) = \frac{1}{n}\left(\frac{1}{r} - \frac{1}{m}\right)\sigma_{w*}^2 + \left(\frac{1}{n} - \frac{1}{N}\right)\sigma_B^2 \qquad (9)$$

and an unbiased estimator is [1]

$$Var(\hat{\mu}) = \frac{1}{n}\left(\frac{1}{r} - \frac{1}{m}\right)\hat{\sigma}_{w*}^2 + \left(\frac{1}{n} - \frac{1}{N}\right)\hat{\sigma}_B^2 \qquad (10)$$

$$\hat{\sigma}_B^2 = \frac{1}{n-1} \sum_{i=1}^{n} (\hat{\mu}_i - \hat{\mu})^2 \qquad (11)$$

$$\hat{\sigma}_{w*}^2 = \frac{1}{n(r-1)} \sum_{i=1}^{n} \sum_{j=1}^{r} (E_{ij} - \hat{\mu}_j)^2 \qquad (12)$$

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