Ann. Occup. Hyg., Vol. 55, No. 6, pp. 578–590, 2011

doi:10.1093/annhyg/mer026

Assessment of dermal exposure to bitumen condensate among road paving and mastic crews with an observational method

MICHELA AGOSTINI[1], WOUTER FRANSMAN[1,2], FRANK DE VOCHT[1,3], BERNA VAN WENDEL DE JOODE[4] and HANS KROMHOUT[1]*

[1]Division of Environmental Epidemiology, Institute for Risk Assessment Sciences, University of Utrecht, Utrecht, The Netherlands; [2]Business Unit Quality and Safety, TNO Quality of Life, Zeist, The Netherlands; [3]Centre for Occupational and Environmental Health, School of Community Based Medicine, The University of Manchester, Manchester, UK; [4]Central American Institute for Studies on Toxic Substances (IRET), Universidad Nacional, Heredia, Costa Rica

Received 2 December 2010; in final form 10 February 2011; published online 19 May 2011

Objective: To assess dermal exposure to bitumen condensate among road pavers and indoor mastic workers in multiple crews using a semi-quantitative observational method [DeRmal Exposure Assessment Method (DREAM)].

Methods: Two skilled observers assessed dermal exposure to bitumen condensate among 85 asphalt workers from 12 crews from nine companies active within four European countries using the DREAM methodology, which produces an estimate of exposure expressed in dimensionless DREAM units. Both observers independently evaluated each crew member's job ($N = 14$ jobs) for road paving and mastic applications. Potential and actual dermal exposures were estimated for hands and for the rest of the body separately, taking into account the effect of protective clothing. To evaluate the reproducibility of the observational method intra-class correlation coefficients (ICCs) were estimated. The exposures in DREAM units were modelled using linear mixed models to estimate average relative scores for each job. Correlations between dermal exposure parameters were evaluated by estimating Pearson correlation coefficients.

Results: A total of 170 observations were completed by two observers independently ($n = 118$ and $n = 52$ for 59 road pavers and 26 mastic workers, respectively) in 11 days. The mean ICCs (for potential and actual exposure in DREAM units) varied between 0.74 and 0.80 with values for actual units being slightly higher. Geometric mean potential dermal exposure units of mastic workers were higher than for road pavers (factor 3 for hands and factor 4 for rest of the body). Differences for actual dermal exposure units were smaller for hands (factor 2) and larger for actual exposure units of rest of the body (factor 5). Differences in dermal exposure at the hands between jobs within a paving crew were much larger than between jobs within a mastic crew. Within paving crews, a consistent pattern for all exposure units emerged with 'screed man' and 'raker' as the two highest exposed jobs. Within mastic crews, 'driver dumper truck' and 'spreader of mastic' were scored as the two jobs with the highest exposure units. Potential and actual exposure units were highly correlated. Hands were more profoundly exposed than the rest of the body, with transfer from contaminated surface to the hands as the most important route.

Conclusions: DREAM observations were reproducible and showed a consistent dermal exposure pattern among the observed crews. The study provided a clear picture of dermal exposure among road pavers and indoor mastic workers, with the mastic workers being considerably more highly exposed. The most important route of exposure appeared to be transferred from contaminated surfaces to the hands.

*Author to whom correspondence should be addressed. Tel: + 31-30-253-9440; fax: +31-30-253-9499;
e-mail: h.kromhout@uu.nl

Keywords: asphalt industry; bitumen condensate; dermal exposure; DeRmal Exposure Assessment Method (DREAM); exposure assessment

INTRODUCTION

Bitumen is the residual product from distillation of crude oil and is mainly being used as paving material in the asphalt industry (road paving) and in roofing applications (Burstyn *et al.*, 2000a). Different types of asphalt-paving materials are produced according to the characteristics of the road surface. Mastic asphalt, which contains a higher than average bitumen content, is often used for paving indoors, in garages, and for industrial floors or in homes in Germany (Burstyn *et al.*, 2000b; EAPA and NAPA, 2009). Bitumen contains small quantities of complex mixtures of polycyclic aromatic hydrocarbons (PAHs) some of which are either known or suspected carcinogens (IARC, 2010).

Historically, assessment of occupational exposure to bitumen has primarily focused on exposure to bitumen via inhalation (Partanen and Boffetta 1994; Boffetta *et al.*, 2003a,b; Kauppinen *et al.*, 2003; Randem *et al.*, 2003; Schulte 2007). Detailed information on dermal exposures in the asphalt industry is lacking historically except for an early study on coal tar and bitumen from The Netherlands (Jongeneelen *et al.*, 1988). In recent years, new important and informative exposure studies in Europe (Sciarra *et al.*, 2003; Burstyn *et al.*, 2002, ; Väänänen *et al.*, 2005, 2006; Fustinoni *et al.*, 2010) and in the USA (McClean *et al.*, 2004a,b, 2007) have suggested that workers can also be exposed to bitumen by dermal contact resulting from machines (e.g. paving, rolling machines) or when the worker is in contact with contaminated surfaces (McClean *et al.*, 2004a). Furthermore, recent toxicological work in mice and humans suggests that skin contact with PAHs might be relevant to humans, especially in situation where co-exposures to solvents occur, because they facilitate passage of carcinogens through skin, resulting in higher levels of genetic damage in the target organs (Moen *et al.*, 1996; Lee and Talaska 1999; Lee *et al.*, 2000; Booth-Jones, 2002).

Dermal exposure to bitumen condensate has never been systematically assessed for epidemiological studies on the carcinogenicity of bitumen. A recent nested case–control study on lung cancer among asphalt workers was the first epidemiological study to address an association between dermal exposure to bitumen condensate and lung cancer (Olsson *et al.*, 2010). Given the lack of available dermal exposure measurement data, an observational field survey was conducted to provide semi-quantitative measures of dermal exposure intensity among road pavers and mastic asphalt workers for this study. A generic observational DeRmal Exposure Assessment Method (DREAM) was used (Van-Wendel-de-Joode *et al.*, 2003) which is based on a conceptual model for dermal exposure (Schneider *et al.*, 1999). The method comprises two parts, a multiple-choice questionnaire (including information on the probability and intensity of the main exposure routes and information on clothing layer for the worker performing the task and percentage of working time a task is performed) and an evaluation model. In the evaluation model, the values assigned to each answer in the questionnaire are used in an algorithm, which generates a numerical estimate for the dermal exposure level encountered by workers performing a certain task or job and are expressed in dimensionless 'DREAM units' (Van-Wendel-de-Joode *et al.*, 2005a). The reproducibility of the DREAM method has been tested in a variety of workplaces and shows (high) reproducible results for a broad range of tasks with dermal exposure to liquids, solids, as well as vapours (Van-Wendel-de-Joode *et al.*, 2005a). Its accuracy was tested by comparing the semi-quantitative DREAM units with (quantitative) measured dermal exposure in several occupational settings (Van-Wendel-de-Joode *et al.*, 2005b). The DREAM method appeared to enable semi-quantitative dermal exposure assessment in groups of workers with considerable contrast in dermal exposure levels (Van-Wendel-de-Joode *et al.*, 2005b).

The main objective of the field survey was to assess dermal exposure to bitumen concentrate among road pavers and mastic workers in multiple crews within four European countries using the semi-quantitative observational method (DREAM).

MATERIALS AND METHODS

Workplace and DREAM exposure assessment method

Two skilled observers (F.dV. and W.F.) assessed dermal exposure to bitumen condensate among 85 male asphalt workers from 12 crews from nine companies active within four European countries (Denmark, France, Germany, and The Netherlands) using the DREAM methodology. The asphalt companies represented a subset of asphalt companies in these four countries involved in a large cohort study of asphalt workers (Burstyn *et al.*, 2003; Boffetta *et al.*, 2003a), for which a nested case–control study was conducted focussing primarily on the associations between inhalation exposure to bitumen fume and dermal exposure to bitumen condensate and lung cancer (Agostini *et al.*, 2010; Olsson *et al.*, 2010).

To assess variability of dermal exposure in DREAM units between different companies, at least two work sites (companies) were observed for each country, except for France (Table 1). The asphalt companies were engaged in two different types of asphalt-applications (road paving and indoor mastic asphalt flooring). The companies in Denmark, France, and The Netherlands were active in road paving and employed 59 observed asphalt workers from 9 crews, while all 26 observed mastic workers were from 3 crews from Germany (Table 1).

Both observers independently evaluated each crew member's job ($N = 14$ jobs) for road paving and indoor mastic applications. Seven distinct jobs were observed in the road paving crews: supervisor, transporter asphalt, operator paving machine, screed man, raker, (small) roller driver, and (large) roller driver. In addition, seven jobs were observed within the indoor mastic crews: supervisor, mastic tapper, driver dumper truck, carrier of buckets mastic, pourer of mastic on floor, spreader of mastic, and finisher mastic (sander). Details of road paving and indoor mastic asphalt applications have been described elsewhere (Burstyn *et al.*, 2003).

During the observations, the two observers completed a structured DREAM questionnaire for each distinct job performed within a crew. Jobs were scored at the workplace at the following nested levels:

- company and observer,
- application (road paving and indoor mastic asphalt flooring),
- agent (concentration),
- job (% of time job is performed),
- route of dermal exposure (emission, deposition, and transfer),
- protective clothing (e.g. gloves, coverall).

Information collected in the field phase was entered into the DREAM database and subsequently utilized as input for the DREAM semi-quantitative evaluation algorithm, which has been described elsewhere (Van-Wendel-de-Joode *et al.*, 2003). Briefly, the assigned scores are incorporated in an algorithm resulting in a semi-quantitative DREAM output score that consists of units for clothing contaminant layer exposure ('potential dermal exposure') and of units for skin contaminant layer exposure ('actual dermal

Table 1. Descriptive statistics by asphalt application and reliability of the DREAM exposure assessment method

Asphalt applications	N_{obs}	$N_{countries}$	$N_{company}$	$N_{workers}$	N_{crews}	N_{jobs}	K	DREAM exposure units	AM	GM	GSD	Min	Max	ICC_{ind}	ICC_{mean}
Road asphalt paving	118	3	6[a]	59	9	7	2	Potential dermal exposure hands	22.53	12.26	3.64	0.25	103	0.55	0.71
								Actual dermal exposure hands	20.92	10.58	3.77	0.25	103	0.57	0.73
								Potential dermal exposure body	10.68	4.83	4.38	0.06	51.9	0.48	0.65
								Actual dermal exposure body	2.53	0.77	6.62	0	16.1	0.63	0.77
Indoor mastic asphalt flooring	52	1	3	26	3	7	2	Potential dermal exposure hands	42.27	39.47	1.58	3.2	62.1	0.53	0.69
								Actual dermal exposure hands	31.98	25.11	2.21	2.89	62.1	0.85	0.92
								Potential dermal exposure body	23.69	20.85	1.84	2.22	38.93	0.35	0.52
								Actual dermal exposure body	4.9	3.7	2.58	0.14	10.6	0.30	0.46
Total	170	4	9	85	12	14	2	Potential dermal exposure hands	28.57	17.54	3.42	0.25	103.0	0.63	0.77
								Actual dermal exposure hands	24.3	13.79	3.5	0.25	103.0	0.65	0.79
								Potential dermal exposure body	14.66	7.55	4.23	0.06	51.9	0.58	0.74
								Actual dermal exposure body	3.25	1.24	6.1	0	16.1	0.66	0.80

N_{obs}, total number of observations; $N_{countries}$, total number of countries; $N_{company}$, total number of companies; $N_{workers}$, total number of workers; N_{crews}, total number of crews; N_{jobs}, total number of jobs; K, total number of observers; AM, arithmetic mean; GSD, geometric standard deviation; Min, minimum value; Max, maximum value; ICC_{ind}, intra-class coefficient individual; ICC_{mean}, intra-class coefficient mean.

[a]$N_{company} = 2$, $N_{company}$ 3, and $N_{company} = 1$ for Denmark, The Netherlands, and France, respectively.

exposure') for nine individual body parts (hands, fore arms, upper arms, head, torso front, torso back, lower body part, lower legs, and feet). The principal evaluation was at job level; so for each job, potential and actual dermal exposure units were estimated for hands and the rest of the body sites combined, separately, taking into account the effect of protective clothing and normal (work) clothing (Van-Wendel-de-Joode *et al.*, 2003). The DREAM method provides a categorical classification for total actual dermal exposure in seven ordinal exposure categories [0 = no exposure (unit = 0); 1 = very low exposure (DREAM units > 0 – 10); 2 = low exposure (DREAM units 10 – 30); 3 = moderate exposure (DREAM units 30 – 100); 4 = high exposure (DREAM units 100 – 300); 5 = very high exposure (units 300 – 1000); 6 = extremely high exposure (DREAM units > 1000)] (Van-Wendel-de-Joode *et al.*, 2003).

Statistical analyses

All statistical analyses were carried out in SAS version 9.2 (SAS 2003). The distribution of the DREAM dermal exposure units appeared to follow a log-normal distribution. All analyses were therefore performed on log-transformed values.

Descriptive statistics were calculated stratified by asphalt applications (crews) and job title. To evaluate the reproducibility of the observational method intraclass correlation coefficients (ICCs) were estimated based on the repeated data from the two observers as a measure of inter-observer agreement (SAS INTRACC procedure). The levels of agreement were graded as poor (<0.40), good (0.40–0.75), and excellent (≥0.75) (Landis and Koch, 1977).

The DREAM units were modelled using generalized linear mixed effects models (SAS PROC MIXED procedure) to estimate average relative scores [geometric mean (GM) levels] for each job in a paving and mastic crew. These models considered exposure concentrations as the dependent variable and job as fixed effect, while the variable 'observer' was incorporated as a random effect because we assumed individual observers to estimate a common mean exposure (with variance) and to originate from the same distribution. The models for each asphalt application (road paving and indoor mastic) had the following general form:

$$Y_{ij} = \ln(X_{ij}) = \mu_j + \sum_{j=1}^{j} \beta_j \times \text{job}_j + \bar{\omega}_i + \varepsilon_{ij}, \tag{1}$$

where Y_{ij} is the natural logarithm of X_{ij}. X_{ij} is the dermal exposure DREAM units for the *j*th job by the *i*th observer, μ_j represents the true unknown mean (logged) dermal exposure estimate; β_j is the regression coefficient for job_j representing the effect of the *j*th job; $\bar{\omega}_i$ is the random effect for the *i*th observer, and ε_{ij} is the random effect for residual variance.

GM dermal exposure units for different jobs were consequently estimated from the models by taking the exponent of the predicted betas for a specific job, taking into account the random observer component (Van-Wendel-de-Joode *et al.*, 2005a). In addition, the models estimated between-observer variance and whether observers' intercepts (ωi) differed from the overall intercept (μj). A multiplier (Mo) was estimated for each observer by calculating e^{ω^i} (Van-Wendel-de-Joode *et al.*, 2005a) to assess the effect of individual observers on the potential and actual dermal exposure units. The models were also run with random effects for observers only (unconditional models) resulting in estimates of between- and within-observer variability in DREAM scores. This enabled estimation of explained variance in the full models by comparing the resulting variance components, as follows:

$$\text{Explained variance} = \frac{\left(S^2_{\text{o(unconditional)}} + S^2_{\text{e(unconditional)}}\right) - \left(S^2_{\text{o}} + S^2_{\text{e}}\right)}{\left(S^2_{\text{o(unconditional)}} + S^2_{\text{e(unconditional)}}\right)} \times 100, \tag{2}$$

where $S^2_{\text{o(unconditional)}}$ = between observers variance in the unconditional model; $S^2_{\text{e(unconditional)}}$ = residual variance in the unconditional model with only observer as random effect; S^2_{o} = between observers variance in the (full) model; S^2_{e} = residual variance in the (full) model.

Correlations between dermal exposure parameters were evaluated by estimating Pearson correlation coefficients between the mean of the two observers for each asphalt application for potential and actual dermal exposure units.

Finally, the DREAM method allowed for insight into the relative importance of the different routes of dermal exposure. The potential exposures for hands and for body (Skin-P_{HA}, Skin-P_{BODY}, respectively) were estimated as the sum of the three major routes of dermal exposures: emission, deposition, and transfer following:

$$\text{Skin-}P_{\text{HA}} = E_{\text{HA}} + D_{\text{HA}} + T_{\text{HA}}, \quad (3)$$

$$\text{Skin-}P_{\text{BODY}} = E_{\text{BODY}} + D_{\text{BODY}} + T_{\text{BODY}}, \quad (4)$$

where E_{HA} is exposure for hands via emission, D_{HA} is exposure for hands through deposition, T_{HA} is exposure for hands through transfer, E_{BODY} is exposure for the rest of the body through emission, D_{BODY} is exposure for the rest of the body through deposition, and T_{BODY} is exposure for the rest of the body through transfer.

Actual dermal exposures units for hands and for the whole body (Skin-A_{BODY}, Skin-A_{BODY}, respectively) were calculated by multiplying potential exposure with the clothing protection factor for hands (O_{HA}) or other body parts (O_{BODY}) (Van-Wendel-de-Joode *et al.*, 2003).

RESULTS

In the summers of 2004, 2005, and 2006, a total of 170 observations were completed by two observers independently, ($n = 118$ and $n = 52$ for 59 road paving and 26 indoor mastic asphalt workers, respectively) in 11 days.

The mean ICCs (for potential and actual dermal exposure units) based on two observers varied between 0.74 and 0.80 with values for actual exposure being slightly higher (Table 1). Agreement varied between the two asphalt applications, ranging from good to excellent. For road paving workers, highest agreement was observed for actual dermal exposure of hands and rest of the body (0.73 and 0.77, respectively), while agreement for potential body was lowest (0.65). Highest agreement occurred for asphalt mastic crews, for actual and potential dermal exposure of hands (0.92 and 0.69, respectively), while lowest agreements were found for actual and potential exposure of rest of the body (0.46 and 0.52, respectively). The mean ICCs (for potential and actual dermal exposure units) for both observers did not improve over time. As the observers worked in the four countries successively, this means that no differences were seen between countries (results not shown).

Overall, hands were more profoundly exposed than the rest of the body (Table 1). GM potential dermal exposure units of mastic workers were higher than for road pavers (factor 3 for hands and factor 4 for rest of the body). Differences for actual exposure units were small for hands (factor 2) and somewhat larger for actual exposure units of rest of the body (factor 5) (Table 1).

Figure 1 shows that differences in dermal exposure on the hands between jobs within a paving crew were much larger than between jobs within an indoor mastic asphalt crew (factor 14–11 versus factor 2–8 for potential and actual dermal exposure, respectively). For potential exposure of the rest of the body, differences between jobs were also larger for road pavers than for mastic crews (factor 25 versus factor 3). A practically identical pattern was apparent for actual exposure of the rest of the body (factor 32 versus factor 4.5 for road pavers and indoor mastic workers, respectively).

Within paving crews, a consistent pattern for all exposure estimates emerged with ‘screed man’ and ‘raker’ as the two highest exposed jobs (Table 2). The ‘operator paving machine’ and ‘small roller driver’ (working in close vicinity of the paving machine) appeared to be exposed at an intermediate level, while the more distant job of ‘transporter asphalt’ was scored as lowest exposed (Table 2). Within mastic crews, ‘driver dumper truck’ and ‘spreader of mastic’ were scored as the two highest exposed jobs for all exposure measures (except for actual exposure at hands), followed by ‘carrier of buckets mastic’ who was scored as exposed at an intermediate level, and ‘supervisor mastic’, ‘finisher mastic’, and ‘pourer of mastic on floor’ comprised the lowest exposed jobs (Table 2). A different pattern appeared for actual dermal exposure of the hands, for which the supervisor mastic was scored as having the highest dermal exposure, followed by the finisher mastic, and with ‘tapper of mastic in buckets’ scored as lowest jobs.

In Table 3, model predictions of GMs for actual and potential dermal exposure units to bitumen condensate are presented by job stratified by application, taking into account the repeated observations and random differences between observers. Differences in observers’ dermal exposure units were relatively small but were largest for the road paving workers, with observers’ multipliers (M_{o}) of 1.10 and 0.91 for potential and 1.05 and 0.95 for actual dermal exposure units at the hands for, respectively, Observer 1 and Observer 2 (Table 3). Observers’ multipliers were of the same magnitude for the rest of the body units for paving workers, ranging from 0.88 to 1.14 and from 0.96 to 1.04 for potential and actual dermal exposure units, respectively, but in this case, Observer 1 was lower than Observer 2 (Table 3). For mastic crews, no differences in observers’ dermal exposure units were evident, except for potential dermal exposure units of rest of the body where M_{o} were 1.03 and 0.97, respectively.

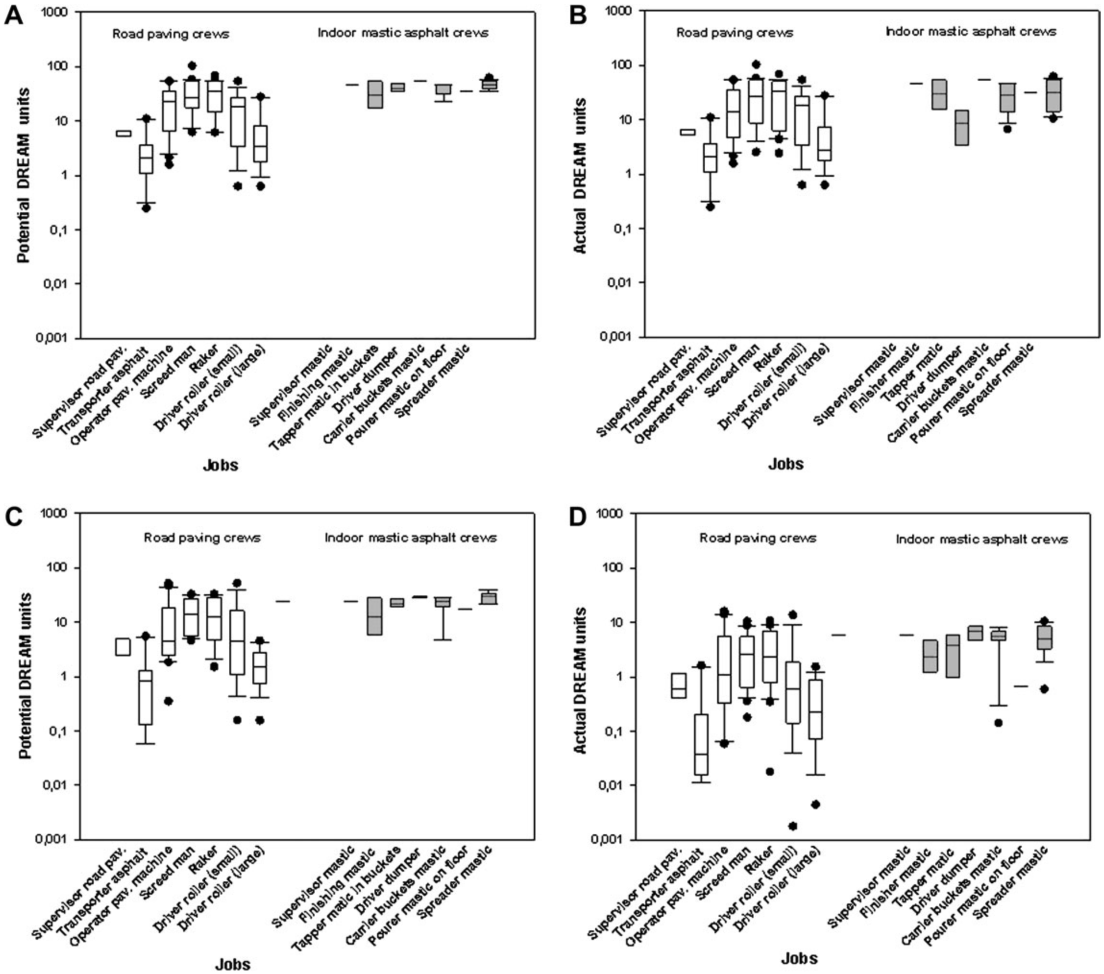

Fig. 1. (A and B) Range and average potential and actual dermal exposure hands in the paving and mastic asphalt crews by jobs (in DREAM units). (C and D) Range and average potential and actual dermal exposure at the body in the paving and mastic asphalt crews by jobs (in DREAM units) (road paving crews: 9 crews, 7 jobs, 59 workers, 118 observations; indoor mastic asphalt crews: 3 crews, 7 jobs, 26 workers, 52 observations).

For road paving applications, job explained 43% of the variability in potential dermal exposure of the hands and of the rest of the body. Job explained 32 and 30% of the variability in actual dermal exposure of hands and rest of the body, respectively (Table 3). For indoor mastic asphalt applications, job explained less variability (26 and 24%) in potential and actual dermal exposure of hands than observed for road paving. The explained variability in actual dermal exposure at the rest of the body was only 6%.

Pearson correlation coefficients between the average DREAM scores of the two observers for all observations and for road paving and indoor mastic asphalt applications separately are presented in Table 4. Potential and actual exposure units (at the hands and for the rest of the body) were overall highly correlated (r = 0.65–0.93). Within road asphalt paving crews, correlations were stronger (r = 0.78–0.97) than within indoor mastic asphalt crews (r = 0.20–0.85) (Table 4).

Figure 2A,B describes the pattern and routes of dermal exposure during road paving and indoor mastic asphalt applications. Comparison of potential dermal exposure of hands with rest of the body indicated that the hands were more profoundly exposed than the rest of the body, with transfer from contaminated surfaces as most important route (Figure 2A). Twenty-four per cent of workers wore gloves during road paving applications (3.4 and 20.3% workers

Table 2. Descriptive statistics for potential and actual dermal exposure (in DREAM units) to bitumen condensate by job

Asphalt applications	Jobs	*n*	AM	GM	GSD	Min	Max	AM	GM	GSD	Min	Max
			Potential dermal exposure hands					Actual dermal exposure hands				
Road asphalt paving	Supervisor road paving	6	6.07	5.81	1.36	5.13	10.8	6.07	5.81	1.36	5.13	10.8
	Transporter asphalt	10	3.04	1.97	2.82	0.25	11.00	3.04	1.97	2.82	0.25	11.00
	Operator paving machine	22	24.51	16.20	2.92	1.58	54.08	22.14	13.01	3.18	1.58	54.08
	Screed man	24	34.39	26.78	2.16	6.3	103	32.65	21.82	2.89	2.55	103.00
	Raker	26	33.36	25.63	2.28	6.14	68.25	29.87	20.09	2.83	2.43	68.25
	Driver roller (small)	14	17.80	10.35	3.67	0.63	54.00	17.80	10.35	3.67	0.63	54.00
	Driver roller (large)	16	6.94	3.77	3.04	0.63	27.81	6.58	3.47	3.01	0.63	27.81
Indoor mastic asphalt flooring	Supervisor mastic	2	37.13	36.28	1.36	29.25	45.00	37.13	36.28	1.36	29.25	45.00
	Finishing mastic (sanding)	6	31.94	23.66	2.84	3.21	54.00	31.52	22.84	2.96	2.89	54.00
	Tapper mastic in buckets	4	41.15	40.53	1.22	34.26	51.08	8.92	7.02	2.29	3.43	15.32
	Driver dumper and tapping	6	54.81	54.81	1.00	54.81	54.81	54.81	54.81	1.00	54.81	54.81
	Carrier buckets mastic	14	38.8	37.41	1.34	22.44	45.68	29.18	24.34	1.96	6.73	45.68
	Pourer mastic on floor	2	26.66	25.56	1.51	19.07	34.26	24.00	23.00	1.51	17.16	30.83
	Spreader mastic	18	46.79	46.05	1.2	35.27	62.1	32.14	26.35	1.95	10.58	62.1
			Potential dermal exposure body					Actual dermal exposure body				
Road asphalt paving	Supervisor road paving	6	3.76	3.21	1.73	2.43	9.50	0.82	0.69	1.85	0.41	2.09
	Transporter asphalt	10	1.17	0.50	4.54	0.06	5.51	0.24	0.06	5.07	0.01	1.62
	Operator paving machine	22	12.26	5.98	3.51	0.35	51.90	3.67	1.10	5.99	0.06	16.10
	Screed man	24	15.71	12.64	2.02	4.58	32.94	3.40	1.95	3.29	0.18	10.54
	Raker	26	15.57	10.52	2.73	1.52	33.11	3.66	1.92	4.25	0.02	10.90
	Driver roller (small)	14	10.38	3.95	5.10	0.16	51.90	1.92	0.50	8.50	0	13.76
	Driver roller (large)	16	1.85	1.38	2.41	0.16	4.57	0.44	0.19	5.03	0	1.54
Indoor mastic asphalt flooring	Supervisor mastic	2	16.15	13.90	2.21	7.93	24.36	3.76	3.21	2.27	1.80	5.73
	Finishing mastic (sanding)	6	15.10	10.83	2.69	2.22	28.82	2.65	1.96	2.7	0.33	4.75
	Tapper mastic in buckets	4	22.29	22.06	1.18	18.82	26.81	3.57	2.52	3.05	0.54	5.97
	Driver dumper and tapping	6	28.61	28.61	1.02	28.2	29.03	6.63	6.44	1.30	4.64	8.62
	Carrier buckets mastic	14	21.41	18.83	1.86	4.79	27.89	5.26	3.75	3.30	0.14	8.14
	Pourer mastic on floor	2	11.21	9.39	2.38	5.09	17.33	1.82	1.42	2.82	0.68	2.95
	Spreader mastic	18	29.23	28.51	1.26	21.31	38.93	5.56	4.61	2.05	0.60	10.60

n, total number of observations; AM, arithmetic mean; GSD, geometric standard deviation; Min, minimum value; Max, maximum value.

wore cotton gloves and latex disposable gloves, respectively), but type and effectiveness were such that protection was scored as minimal in the DREAM method (O_{HA} = 0.9, see Figure 2A). The main route of exposure for the rest of the body appeared to be deposition exposure. Clothing and protective clothing eliminated 80% of the dermal exposure (O_{BODY} = 0.2).

For dermal exposure during mastic activities, the patterns were basically similar to those for paving. Transfer was the most important route of exposure to the hands, but a considerable contribution through deposition was also noted for mastic operations (Figure 2B). Emissions were estimated to be higher for mastic workers than for paving workers mainly due to being closer to the source (e.g. short hand tools versus rakes of the paving workers) and therefore with a higher probability of direct contact with source material and a higher emission of the harder type of bitumen used in mastic asphalt versus paving applications. Seventy-three per cent of mastic workers used woven gloves (23.0 and 50.0% workers wore cotton gloves and latex disposable gloves, respectively) and type and effectiveness were such that higher protection was assigned (O_{HA} = 0.7) compared to road pavers. The effectiveness of (protective) clothing for the rest of the body was similar to those of the road-paving worker (O_{BODY} = 0.2).

Overall, despite the fact that dermal protection was scored more effective for mastic workers compared to road pavers, actual dermal exposure of the hands and the rest of the body was higher for mastic workers

Table 3. Model predictions of GM of potential and actual dermal exposure (in DREAM units) to bitumen condensate by job stratified by road asphalt paving and indoor asphalt mastic application

		Potential dermal exposure hands			Actual dermal exposure hands		Potential dermal exposure body		Actual dermal exposure body	
Asphalt applications	Jobs	*n*	β	GM (95% CI)	β	GM (95% CI)	β	GM (95% CI)	β	GM (95% CI)
Road asphalt paving	Supervisor road paving	6	1.76	5.81 (2.22–6.4)	1.76	5.81 (2.38–14.16)	1.17	3.21 (1.25–8.26)	−0.38	0.69 (0.19–2.47)
	Transporter asphalt	10	0.66	1.97 (1.03–3.76)	0.68	1.97 (0.98–3.95)	−0.7	0.50 (0.23–1.06)	−2.78	0.06 (0.02–0.17)
	Operator paving machine	22	2.78	16.19 (10.13–25.90)	2.56	13.01 (8.02–21.12)	1.79	5.98 (3.42–10.48)	0.09	1.10 (0.56–2.17)
	Screed man	24	3.29	26.78 (17.00–42.19)	3.08	21.82 (13.69–34.7)	2.53	12.64 (7.34–21.78)	0.67	1.95 (1.02–3.75)
	Raker	26	3.24	25.63 (16.49–39.86)	3.00	20.09 (31.5–12.81)	2.35	10.52 (6.19–17.87)	0.65	1.92 (1.02–3.60)
	Driver roller (small)	14	2.34	10.35 (5.90–18.16)	2.34	10.35 (5.71–18.78)	1.37	3.95 (2.04–7.66)	−0.69	0.50 (0.22–1.17)
	Driver roller (large)	16	1.33	3.77 (2.22–6.42)	1.24	3.48 (1.99–6.08)	0.32	1.38 (0.73–2.58)	−1.64	0.19 (0.09–0.43)
			M_o (95% CI)			M_o (95% CI)		M_o (95% CI)		M_o (95% CI)
		O1 =	1.10 (0.84–1.44)			O1 = 1.05 (0.86–1.28)		O1 = 0.88 (0.61–1.25)		O1 = 0.96 (0.80–1.17)
		O2 =	0.91 (0.69–1.19)			O2 = 0.95 (0.78–1.16)		O2 = 1.14 (0.80–1.63)		O2 = 1.04 (0.85–1.24)
			Variance component (unconditional)			Variance component (unconditional)		Variance component (unconditional)		Variance component (unconditional)
			S_o^2 = 0.03 (0.02			S_o^2 = 0.01 (0.01)		S_o^2 = 0.05 (0.03)		S_o^2 = 0.01 (0.00)
			S_e^2 = 0.93 (1.66)			S_e^2 = 1.18 (1.76)		S_e^2 = 1.21 (2.16)		S_e^2 = 2.48 (3.57)

Table 3. *Continued*

Asphalt applications	Jobs	Potential dermal exposure hands			Actual dermal exposure hands		Potential dermal exposure body		Actual dermal exposure body	
		n	β	GM (95% CI)	β	GM (95% CI)	β	GM (95% CI)	β	GM (95% CI)
Indoor mastic asphalt flooring	Supervisor mastic	2	3.59	36.28 (20.23–65.05)	3.59	36.28 (13.49–97.56)	2.63	13.90 (6.58–29.36)	1.17	3.21 (0.87–11.89)
	Finishing mastic (sanding)	6	3.16	23.66 (16.89–33.15)	3.13	22.84 (12.90–40.44)	2.38	10.83 (6.97–16.83)	0.67	1.96 (0.92–4.17)
	Tapper mastic in buckets	4	3.70	40.52 (26.82–61.24)	1.95	7.02 (3.49–14.13)	3.11	22.06 (12.93–37.34)	0.92	2.52 (1.00–6.37)
	Driver dumper and tapping	6	4.00	54.81 (39.12–76.78)	4.00	54.81 (30.96–97.03)	3.36	28.61 (18.41–44.46)	1.86	6.44 (3.02–13.73)
	Carrier buckets mastic	14	3.62	37.41 (30.00–46.65)	3.19	24.34 (16.75–35.37)	2.93	18.83 (13.94–25.42)	1.32	3.75 (2.29–6.16)
	Pourer mastic on floor	2	3.24	25.56 (14.25–45.83)	3.13	23.00 (8.55–61.86)	2.24	9.39 (4.45–19.84)	0.35	1.42 (0.38–5.26)
	Spreader mastic	18	3.83	46.05 (37.91–55.95)	3.27	26.35 (18.94–36.63)	3.35	28.51 (21.77–37.34)	1.53	4.61 (2.98–7.14)
			M_o (95% CI)			M_o (95% CI)		M_o (95% CI)		M_o (95% CI)
		O1 =	1 (. . . – . . .)[a]			O1 = 1 (. . . – . . .)[a]		O1 = 1.03 (0.90–1.19)		O1 = 1 (. . . – . . .)[a]
		O2 =	1 (. . . – . . .)[a]			O2 = 1 (. . .– . . .)[a]		O2 = 0.97 (0.84–1.11)		O2 = 1 (. . . – . . .)[a]
			Variance component (Unconditional)			Variance component (Unconditional)		Variance component (Unconditional)		Variance component (Unconditional)
		S_o^2 =	0.00 (0.00)			S_o^2 = 0.00 (0.00)		S_o^2 = 0.01 (0.002)		S_o^2 = 0.00 (0.00)
		S_e^2 =	0.16 (0.21)			S_e^2 = 0.48 (0.63)		S_e^2 = 0.27 (0.37)		S_e^2 = 0.84 (0.89)

n, number of observations by task; β, regression coefficient estimate; GM, standard deviation; M_o, predicted multipliers for each observer (random effect) in DREAM units; (95% CI), 95% confidence interval; O1, observer F.dV.; O2, observer W.F.

[a]Confidence intervals were not estimable; S_o^2: between observers variance; S_e^2: residual variance; in parentheses variance units in the unconditional model with only observer as random effect.

Table 4. Pearson correlation coefficients between potential and actual dermal exposure to bitumen condensate (mean of two observers) for road paving, indoor mastic asphalt applications, and overall

Asphalt applications		Pw_{HA}	Pw_{BODY}	Aw_{HA}	Aw_{BODY}
Road asphalt paving	Pw_{HA}	1	0.92**	0.97**	0.84**
	Pw_{BODY}		1	0.90**	0.88**
	Aw_{HA}			1	0.78**
	Aw_{BODY}				1
Indoor mastic asphalt flooring		Pw_{HA}	Pw_{BODY}	Aw_{HA}	Aw_{BODY}
	Pw_{HA}	1	0.85**	0.65*	0.64*
	Pw_{BODY}		1	0.31	0.82**
	Aw_{HA}			1	0.20
	Aw_{BODY}				1
Total		Pw_{HA}	Pw_{BODY}	Aw_{HA}	Aw_{BODY}
	Pw_{HA}	1	0.93**	0.87**	0.82**
	Pw_{BODY}		1	0.74**	0.88**
	Aw_{HA}			1	0.65**
	Aw_{BODY}				1

Pw_{HA}, potential hands time weighed for the mean of the two observers; Pw_{BODY}, potential body time weighed for the mean of the two observers; Aw_{HA}, actual hands time weighed for the mean of the two observers; Aw_{BODY}, actual body time weighed for the mean of the two observers; *<0.001; **<0.0001.

because of the large differences between potential exposure between mastic and paving workers (42.3 versus 22.5 and 23.7 versus 10.7 for potential exposure of the hands and rest of the body, respectively).

DISCUSSION AND CONCLUSION

This study semi-quantitatively assessed dermal exposure to bitumen condensate among asphalt workers (road paving and indoor mastic crews) in four European countries between 2004 and 2006 and studied the reproducibility of the DREAM method. This is to our knowledge the first study assessing dermal exposure to bitumen condensate by means of an observational method (DREAM).

The mean ICCs (for potential and actual dermal exposure units) for two observers was excellent, ranging from 0.74 to 0.80 with values for actual exposure being slightly higher (0.79 and 0.80 for actual exposure at hands and for rest of the body, respectively). The reliability was similar to what was reported in a study by Van-Wendel-de-Joode *et al.* (2005a) on dermal exposure to liquids, solids, and vapours, which reported ICCs ranging 0.68–0.83 for actual and 0.79–0.87 for potential dermal exposure units.

The results from this study indicate that potential dermal exposures (GMs) for mastic workers were significantly higher than for paving workers (factor 3 for hands and factor 4 for rest of the body). Differences for actual exposure were smaller for hands (factor 2) and are most likely related to the fact that the majority of mastic workers (73.0%) protected their hands better (compared to only the 24.5% use of gloves in pavers workers).

Several studies explicitly addressed dermal exposure during paving applications (McClean *et al.*, 2004a; Fustinoni *et al.*, 2010), although using a different methodology compared to our study. Nevertheless, the DREAM observations from this study appeared to corroborate the measured exposures by McClean *et al.* (2004a) on bitumen condensate exposure in the asphalt industry suggesting that screed men and rakers had the highest dermal exposure of the hands, while the 'paver operators' and 'roller drivers' were exposed to levels that were a Factor 4–5 lower. To date, no dermal exposure studies during mastic asphalt applications have been conducted and therefore, we cannot compare the mastic results to any other study.

DREAM was able to detect differences in dermal exposures between jobs for potential as well as actual dermal exposure. Underlying factors like the use of protective clothing are reflected in the exposure in DREAM units. The results from this study indicate that the actual job carried out within a crew, and whether or not protective clothing was used, were significant determinants of exposure for paving and mastic crews. This is consistent with an exposure measurement study conducted in the USA, which demonstrated that asphalt applications, and jobs are significant predictors of bitumen condensate exposures (McClean *et al.*, 2004a).

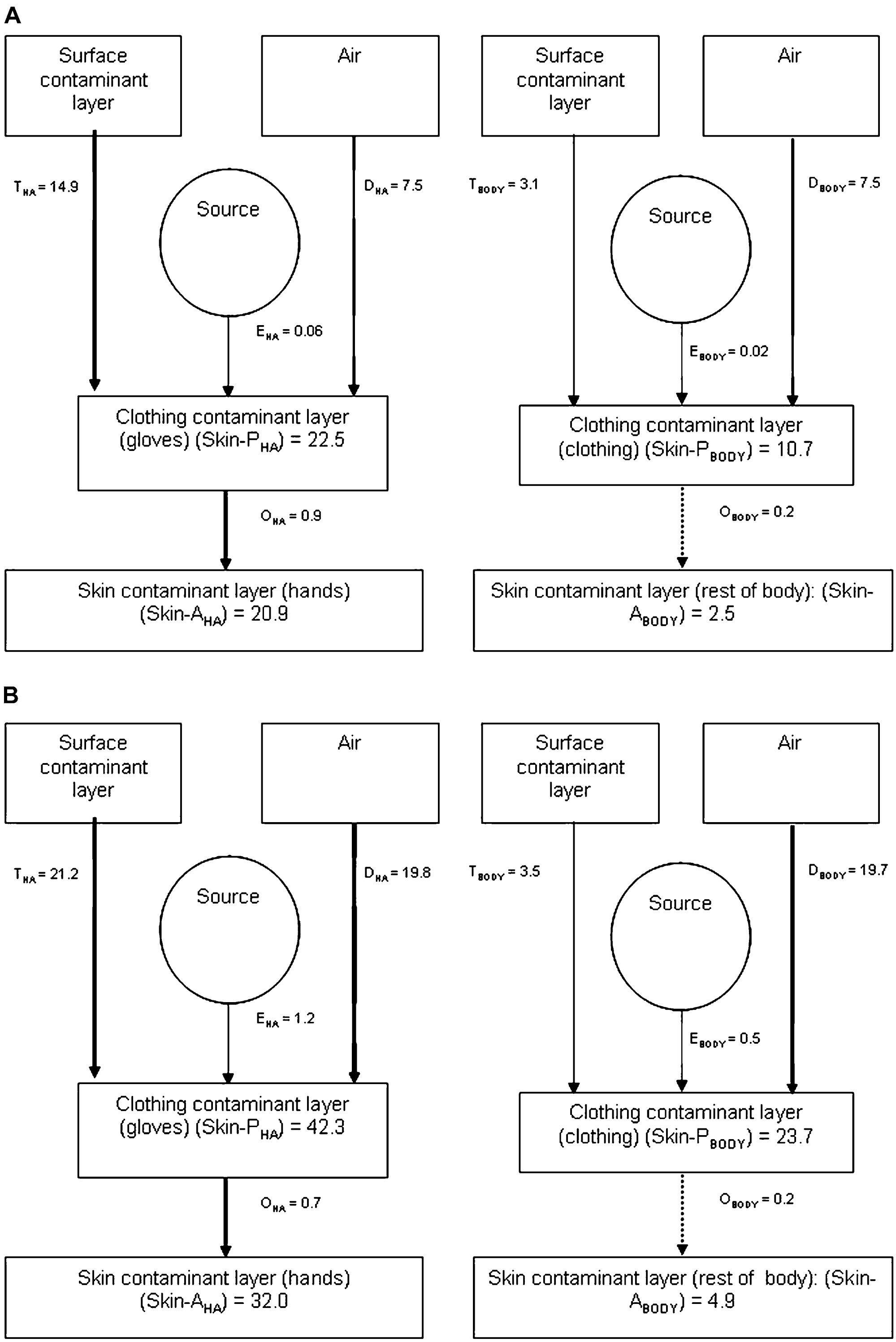

Fig. 2. (A) Exposure patterns for dermal exposure to bitumen condensate for hands and for rest of the body exposure for a road-paving worker. (B) Exposure patterns for dermal exposure to bitumen condensate for hands and for rest of the body exposure for an indoor mastic asphalt worker.

The empirical models developed for road pavers performed better in explaining total variability (43% of explained variance) than the models for the mastic workers (6–26%). This may be explained in part by the fact that the differences between jobs within a paving crew were much larger than within a mastic crew.

In this study, clear insight was gained in the relative importance of the different routes of exposure suggesting that transfer from contaminated surfaces was the most important route. This provides guidance for controlling dermal exposure in this industry. For all jobs, the hands were more profoundly exposed than the rest of the body. These findings are in agreement with other dermal exposure measurement studies among pavers and roofers (Jongeneelen *et al.*, 1988; Riala *et al.*, 1998; Sciarra *et al.*, 2003).

Potential and actual total dermal exposures for paving and mastic crews were estimated to be in the low DREAM category (Van-Wendel-de-Joode *et al.*, 2003). The hot-mix applications observed here are most likely the main reasons for this. Similar to the study by Van-Wendel-de-Joode *et al.* (2005a), actual dermal exposure of the body was considerably lower than potential dermal exposure, showing a clear effect of protective and regular clothing that on average lowered dermal exposure by 80%. For the hands, this was not the case because only a few workers wore gloves and used them adequately. Use of gloves was more common among mastic workers than paving workers, which at a group level led to higher protection (30 versus 10% protection).

By observing work practices of asphalt workers in the field, valuable information was gathered about specific asphalt applications and the resulting dermal exposure to bitumen condensate. This study not only indicates that skilled observers can perform the survey in a reliable way, it also showed that dermal exposure varies among jobs within a crew, but also between individuals due to differences in use of (protective) clothing. The DREAM method enabled the analysis of intensity and variability within and between different asphalt applications. The study provided valuable data that together with results from six dermal exposure measurement surveys (Jongeneelen *et al.*, 1988; McClean *et al.*, 2004a,b, Cirla *et al.*, 2005; Väänänen *et al.*, 2005, 2006; McClean *et al.*, 2007) formed the basis for the dermal exposure assessment and assignment in the NCC study on lung cancer among European Asphalt workers (Agostini *et al.*, 2010; Olsson *et al.*, 2010).

FUNDING

The study was partially supported by CONCAWE, European Bitumen Association (Eurobitume), European Asphalt Paving Association, National Asphalt Pavement Association, the Berufsgenossenschaftlichen Forschungsinstitut für Arbeitsmedizin, through an unrestricted grant to the International Agency for Research on Cancer.

Acknowledgements—We thank the Scientific Advisory Committee and the Liaison Committee for useful advices and support. We are grateful to Harry Roos, Monika Rauf Heimsoth, Helle Fabiansen, and Isabelle Chanas for enabling the observations of the asphalt crews in the field. In addition the cooperation of the observed crew members was highly appreciated.

Competing interest declaration—The authors declare they have no competing financial interests.

REFERENCES

Agostini M, Ferro G, Olsson A *et al.* (2010) Exposure assessment for a nested case control study of lung cancer among European asphalt workers. Ann Occup Hyg; 54: 813–23.

Boffetta P, Burstyn I, Partanen T *et al.* (2003a) Cancer mortality among European asphalt workers: an international epidemiological study. I. Results of the analysis based on job titles. Am J Ind Med; 43: 18–27.

Boffetta P, Burstyn I, Partanen T *et al.* (2003b) Cancer mortality among European asphalt workers: an international epidemiological study. II. Exposure to bitumen fume and other agents. Am J Ind Med; 43: 28–39.

Booth-Jones AD. (2002) Evaluating the effectiveness of a hand-washing intervention on dermal contamination of polycyclic aromatic hydrocarbons, DNA adducts, and 1-hydroxypyrene levels in automotive mechanic trainees. Cincinnati, OH: Dissertation Department of Environmental Health of the College of Medicine, University of Cincinnati.

Burstyn I, Boffetta P, Kauppinen T *et al.* (2003) Estimating exposures in the asphalt industry for an international epidemiological cohort study of cancer risk. Am J Ind Med; 43: 3–17.

Burstyn I, Ferrari P, Wegh H *et al.* (2002) Characterizing worker exposure to bitumen during hot mix paving and asphalt mixing operations. Am Ind Hyg Assoc J; 63(3): 293–9.

Burstyn I, Kromhout H, Boffetta P. (2000a) A literature review of levels and determinants of exposure to potential carcinogens and other agents in the road construction industry. Am Ind Hyg Assoc J; 61: 715–26.

Burstyn I, Kromhout H, Kauppinen T *et al.* (2000b) Statistical modelling of the determinants of historical exposure to bitumen and polycyclic aromatic hydrocarbons among paving workers. Ann Occup Hyg; 44: 43–56.

Cirla PE, Martinotti I, Zito E *et al.* (2005) Assessment of exposure to organic aromatic compounds and PAH in asphalt industry: the PPTP-POPA Study results. G Ital Med Lav Ergon; 27: 303–7.

EAPA and NAPA. (2009) The asphalt paving industry: a global perspective. 1st edn. (global series 101), Brussels, Belgium: National Asphalt Pavement Associations and European Asphalt Pavement Associations.

Fustinoni S, Campo L, Cirla EP *et al*. (2010) Dermal exposure to polycyclic aromatic hydrocarbons in asphalt workers. Occup Environ Med; 67: 456–63.

IARC. (2010) Some non-heterocyclic polycyclic aromatic hydrocarbons and some related industrial exposure. IARC Monogr Eval Carcinog Risk Hum; 92: 143–229.

Jongeneelen FJ, Scheepers PT, Groenendijk A *et al*. (1988) Airborne concentrations, skin contamination, and urinary metabolite excretion of polycyclic aromatic hydrocarbons among paving workers exposed to coal tar derived road tars. Am Ind Hyg Assoc J; 49(12): 600–7.

Kauppinen T, Heikkilä P, Partanen T *et al*. (2003) Mortality and cancer incidence of workers in Finnish Road Paving Companies. Am J Ind Med; 43: 49–57.

Landis JR, Koch GG. (1977) The measurements of observer agreement for categorical data. Biometrics; 33: 159–74.

Lee JH, Roh JH, Burks D *et al*. (2000) Skin cleaning with kerosene facilitates passage of carcinogens to the lungs of animals treated with used gasoline engine oil. Appl Occup Environ Hyg; 15: 362–9.

Lee JH, Talaska G. (1999) Effects of kerosene cleaning on the formation of DNA adducts in the skin and lung tissues of mice dermally exposed to used gasoline engine oil. J Toxicol Environ Health A; 56: 463–70.

McClean MD, Rinehart RD, Ngo L *et al*. (2004a) Inhalation and dermal exposure among asphalt paving workers. Ann Occup Hyg; 48: 663–71.

McClean MD, Rinehart RD, Ngo L *et al*. (2004b) Urinary 1-hydroxypyrene and polycyclic aromatic hydrocarbon exposure among asphalt paving workers. Ann Occup Hyg; 48: 565–78.

McClean MD, Rinehart RD, Sapkota A *et al*. (2007) Dermal exposure and urinary 1-hydroxypyrene among asphalt roofing workers. J Occup Environ Hyg; 4 (Suppl 1): 118–26.

Moen BE, Nilsson R, Nordlinder R *et al*. (1996) Assessment of exposure to polycyclic aromatic hydrocarbons in engine rooms by measurement of urinary 1- hydroxypyrene. Occup Environ Med; 53: 692–6.

Olsson A, Kromhout H, Agostini M *et al*. (2010) A case-control study of lung cancer nested in a cohort of European asphalt workers. Environ Health Perspect; 118: 1418–24.

Partanen T, Boffetta P. (1994) Cancer risk in asphalt workers and roofers: review and meta-analysis of epidemiologic studies. Am J Ind Med; 26: 721–40.

Randem BG, Langård S, Dale I *et al*. (2003) Cancer incidence among male Norwegian asphalt workers. Am J Ind Med; 43: 88–95.

Riala R, Heikkilä P, Kanerva L. (1998) A questionnaire study of road pavers and roofer's work related skin symptoms and bitumen exposure. Report. Int J Dermatol; 37: 27–30.

SAS. (2003) SAS version 9.1. Cary, NC. SAS Institute Inc.

Schneider T, Vermeulen R, Brower DH *et al*. (1999) Conceptual model for assessment of Dermal exposure. Occup Environ Med; 56: 765–73.

Schulte PA. (2007) Gaps in scientific knowledge about the carcinogenic potential of asphalt/bitumen fumes. J Occup Environ Hyg; 4: 3–5.

Sciarra G, Aprea C, Cenni A *et al*. (2003) Relazione dell'indagine igienistico-tossicologica per la valutazione dell'espozione a cancerogeni (idrocarburi policiclici aromatici e benzene) per gli addetti alla produzione di asfalti di bitumen e per gli addetti alla pavimentazione stradale con asfalti di bitumen. Memoria presentata al convegno ''I carcerogeni : la definizione dell'esposizione in ambiente di vita e lavoro''. Siena, Italia, 24-26 Settembre.

Väänänen V, Elovaara E, Nykyri E *et al*. (2006) Road pavers' occupational exposure to asphalt containing waste plastic and tall oil pitch. J Environ Monit; 8: 89–99.

Väänänen V, Hämeilä M, Kalliokoski P *et al*. (2005) Dermal exposure to polycyclic aromatic hydrocarbons among road pavers. Ann Occup Hyg; 49: 167–78.

Van-Wendel-de-Joode B, Brouwer H D, Vermeulen R *et al*. (2003) DREAM: a method for semi-quantitative dermal exposure assessment. Ann Occup Hyg; 47: 71–87.

Van-Wendel-de-Joode B, Van Hemmen JJ, Meijster T *et al*. (2005a) Reliability of a semi-quantitative method for dermal exposure assessment (DREAM). J Expo Anal Environ Epidemiol; 15: 111–20.

Van-Wendel-de-Joode B, Vermeulen R, Van Hemmen JJ. (2005b) Accuracy of a semi-quantitative method for Dermal Exposure Assessment (DREAM). Occup Environ Med; 62: 623–32.