Ann. occup. Hyg., Vol. 47, No. 1, pp. 71–87, 2003

Published by Oxford University Press
DOI: 10.1093/annhyg/meg012

DREAM: A Method for Semi-quantitative Dermal Exposure Assessment

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Received 25 April 2002; in final form 2 October 2002

This paper describes a new method (DREAM) for structured, semi-quantitative dermal exposure assessment for chemical or biological agents that can be used in occupational hygiene or epidemiology. It is anticipated that DREAM could serve as an initial assessment of dermal exposure, amongst others, resulting in a ranking of tasks and subsequently jobs. DREAM consists of an inventory and evaluation part. Two examples of dermal exposure of workers of a car-construction company show that DREAM characterizes tasks and gives insight into exposure mechanisms, forming a basis for systematic exposure reduction. DREAM supplies estimates for exposure levels on the outside clothing layer as well as on skin, and provides insight into the distribution of dermal exposure over the body. Together with the ranking of tasks and people, this provides information for measurement strategies and helps to determine who, where and what to measure. In addition to dermal exposure assessment, the systematic description of dermal exposure pathways helps to prioritize and determine most adequate measurement strategies and methods. DREAM could be a promising approach for structured, semi-quantitative, dermal exposure assessment.

Keywords: dermal exposure; semi-quantitative methods; measurement strategy; exposure assessment

INTRODUCTION

Occupational hygiene has traditionally focused on inhalation exposures to chemical and biological agents, and a wide range of measurement methods and strategies have been developed for their assessment and interpretation (Schneider *et al.*, 2000). The assessment of dermal exposure remained a nascent field of scientific research for most of the twentieth century, although multiple fatalities due to dermal absorption have been described in literature from the 1880s onwards (Fenske, 2000). During the last decade, dermal exposure assessment has received more attention, as reflected through special topic meetings, research grants and special issues on dermal exposure assessment in scientific journals [e.g. a meeting of European investigators (Dost, 1995), and special issues of *International Journal of Occupational and Environmental Health* (April/June 2000) and *Annals of Occupational Hygiene* (October 2000)].

One of the results was the development of a conceptual model for dermal exposure assessment (Schneider *et al.*, 1999). This model systematically describes the transport of contaminant mass from exposure sources to the surface of the skin through three main exposure routes: emission, deposition and transfer. Emission involves mass transport of substances by direct release from a source onto skin or clothing, such as exposure by splashes, or immersion of hands into a liquid or powder (droplets and powder particles have an aerodynamic diameter of ≥100 μm).

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Deposition on skin or clothing describes mass transport from air. In this case, the contaminant mass (e.g. small particles with an aerodynamic diameter of <100 μm, such as vapours, mist) is first released into the air and subsequently deposited on skin or clothing. Transfer is defined as the transport of mass from contaminated surfaces onto skin or clothing, e.g. skin contact with surfaces or working tools that have been previously contaminated with an agent.

Schneider *et al.* (2000) proposed a measurement strategy for dermal exposure assessment based on a tiered approach in analogy with the European Committee for Standardization's standard EN 689 for assessing inhalation exposure (CEN, 1995). According to this approach, chemical substances used in the workplace and their toxicity are first identified. Secondly, factors such as tasks, work patterns and sources of dermal exposure are described. Thirdly, a structured semi-quantitative dermal exposure assessment should be performed. Finally, if dermal uptake of hazardous substances cannot be ruled out, a quantitative survey should be performed on the distribution and level of dermal exposure.

However, validated semi-quantitative dermal exposure assessment methods applicable at workplaces for a broad range of substances are practically non-existent, although a clear need exists for the development of such methods. Only some limited, isolated examples exist. For example, the general-purpose exposure assessment software package EASE supplies dermal exposure estimates. Nonetheless, the dermal exposure estimates by EASE seem imprecise (Hughson and Cherrie, 2001) and of limited use. Brouwer *et al.* (2001) developed a predictive model for assessing dermal exposure levels; however, their model is only applicable for spray painting. A model for exposure assessment to pesticides has also been developed (Dosemeci *et al.*, 2002).

The aim of our study was to develop a structured dermal exposure assessment method (DREAM) to assess and evaluate occupational dermal exposure to chemical agents semi-quantitatively, to be used in occupational hygiene and epidemiology in any given situation. It is anticipated that the method could serve as: (i) an initial assessment of dermal exposure levels of liquids and solids; (ii) a framework for measurement strategies [determining who, what and where to measure, and ranking of body parts, (groups of) workers and tasks]; or (iii) a basis for control measures.

In this paper, we describe the developed method. In addition, we illustrate DREAM by means of two examples of dermal exposure of workers of a car-construction company.

DREAM is based on a theoretical model for dermal exposure assessment (Schneider *et al.*, 1999) and a method for structured subjective assessment of airborne concentrations (Cherrie *et al.*, 1996). We chose the conceptual model of Schneider *et al.* (1999) because it is the only model available that provides a structured description of all processes involved in dermal exposure. It describes essential variables of dermal and surface contamination, and consistent use of such a model ensures that most relevant variables are taken into consideration in any given situation (Vermeulen *et al.*, 2000b). The method of Cherrie *et al.* (1996) was selected because validation of their approach carried out for 63 jobs, and involving five different agents, resulted in generally statistically significant correlations, ranging from 0.31 to 0.93 (Cherrie and Schneider, 1999). Also, validation of the dermal exposure assessment model for spray painting of Brouwer *et al.* (2001), based on the approach developed by Cherrie *et al.* (1996), showed reasonable rank correlation with the measured exposure ($r = 0.82$, $n = 19$).

METHODS

The inventory part

The dermal exposure assessment method, DREAM, consists of an inventory and an evaluation part. The inventory part comprises a hierarchically structured questionnaire with six modules: company, department, agent, job, task and exposure. The questionnaire is to be filled in by an occupational health professional, starting with the 'company' and finishing with the 'exposure' module after observing workers performing their tasks. However, when not feasible, information can be obtained by interviewing workers. The occupational health professional defines which activities the tasks comprise.

The modules address general information as well as possible dermal exposure determinants that were identified with the conceptual model of Schneider *et al.* (1999) and by evaluating literature. Because the number of determinants was large, the inventory part was programmed in MS-ACCESS to facilitate data collection.

Table 1 describes the information obtained in each module. In the 'company' module, general information on the company and the observer is obtained. In the 'department' module, the observer indicates whether exposure to chemical—or biological—substances is likely to occur, and completes questions on cleaning activities. In the 'agent' module, substances are defined for which dermal exposure is consequently assessed, and physical and chemical properties of substances are collected. In the 'job' module, job titles are defined and information on workers' hygiene is obtained. In the 'task' module, the observer defines tasks, and information is obtained on frequency and duration of task performance. In the sixth and last module, the 'exposure' module, questions are filled in for a worker,

Table 1. Summarizing the information obtained in the inventory part

Module	Data obtained on	Processes in conceptual model of Schneider *et al.* (1999)
1. Company	General information about company and observer	
2. Department	Chemical or biological agents that occur in work environment Cleaning activities at department	Source present (no/yes), surface contaminant layer present (no/yes) Decontamination of surface contaminant layer
3. Agent	Physical characteristics of substance for which dermal exposure is assessed, such as concentration of active ingredient in substance, physical state, boiling temperature, viscosity, formulation (powder, granules), dustiness, stickiness	Source strength, emission, evaporation, decontamination
4. Job	Hygienic behaviour Number of people with this job title	Decontamination of skin
5. Task	Percentage of time that task is performed Number of people performing task	Event per unit of time
6. Exposure to a substance assessed for a certain task	Probability and intensity of dermal exposure routes (per body part) Use of clothing (per body part) (covered versus uncovered body parts, clothing material, repeated use of clothing) Contamination of work environment	Emission, deposition, transfer Clothing barrier, contamination of clothing, redistribution

performing a particular task defined in the 'task' module and being exposed to a substance defined in the 'agent' module. Key items of the 'exposure' module are assessment of probability and intensity of three dermal exposure routes: emission, deposition and transfer.

The evaluation part

Figure 1 summarizes the evaluation model of DREAM. Each estimate presented in Fig. 1 is determined by a set of underlying variables. In total, 33 variables were included. For 26 of the included variables, the direction of the effect on dermal exposure (increasing versus decreasing exposure) has actually been described previously (see Appendix). Only for physical and chemical characteristics of substances (Driver *et al.*, 1989; Cinalli *et al.*, 1992; Popendorf *et al.*, 1995a; Kissel *et al.*, 1996; Llewellyn *et al.*, 1996; Mulhausen and Damiano, 1998; Garrod *et al.*, 1999; Preller and Schipper, 1999) and protective clothing (Branson and Sweeney, 1991; Thind *et al.*, 1991; Easter and Nigg, 1992; Popendorf *et al.*, 1995a,b; Roff, 1997; Garrod *et al.*, 1999, 2000, 2001; Preller and Schipper, 1999; Brouwer *et al.*, 2000c; Vermeulen *et al.*, 2000a; Creely and Cherrie, 2001) was information detailed enough to serve as a reference for semi-quantitative value assignment of determinants. Values of miscellaneous determinants were assigned by expert judgement, in accordance with the method for structured assessment of airborne concentrations by Cherrie *et al.* (1996). Cherrie *et al.* (1996) proposed to weigh effects of exposure determinants in equal steps on a logarithmic scale, because exposures generally follow a log-normal distribution. Assigned values of the variables included in the evaluation model are described in the appendix.

In the DREAM model, evaluation of exposure takes place at the task level, assessing both *potential dermal exposure* (Skin-$P_{TASK.BP}$) and *actual dermal exposure* estimates (Skin-$A_{TASK.BP}$) for nine different body parts (BPs): head, upper arms, lower arms, hands, torso front, torso back, lower body part, lower legs and feet. *Potential dermal exposure* concerns exposure on clothing and uncovered skin, whereas *actual dermal exposure* is defined as exposure on skin. In addition to estimates for each body part, total dermal exposure estimates are calculated (Skin-P_{TASK} and Skin-A_{TASK}).

The *potential exposure estimate* (Skin-P_{BP}) for a certain body part comprises the sum of dermal exposures due to three different exposure routes: emission (E_{BP}), transfer (T_{BP}) and deposition (D_{BP}) (see equation 1).

The exposure route estimates are the products of *probability* (P_{BP}) and *intensity* (I_{BP}) of each exposure route, assessed for each body part, and subsequently multiplied by estimates of 'intrinsic emission (E_I)' (equations 2–4). *Probability* is defined as the frequency of occurrence of the concerned exposure route, and divided into four categories. For 'emission' and 'deposition', these are: (i) unlikely (<1% of task duration); (ii) occasionally (1–10% of task duration); (iii) frequently (10–50% of task duration); and (iv) almost constantly (>50% of task duration). The categories are assigned values of 0, 1, 3 and 10, respectively. *Intensity* is defined as the assessed amount of agent on clothing and uncovered skin resulting from the exposure route. For 'emission' and

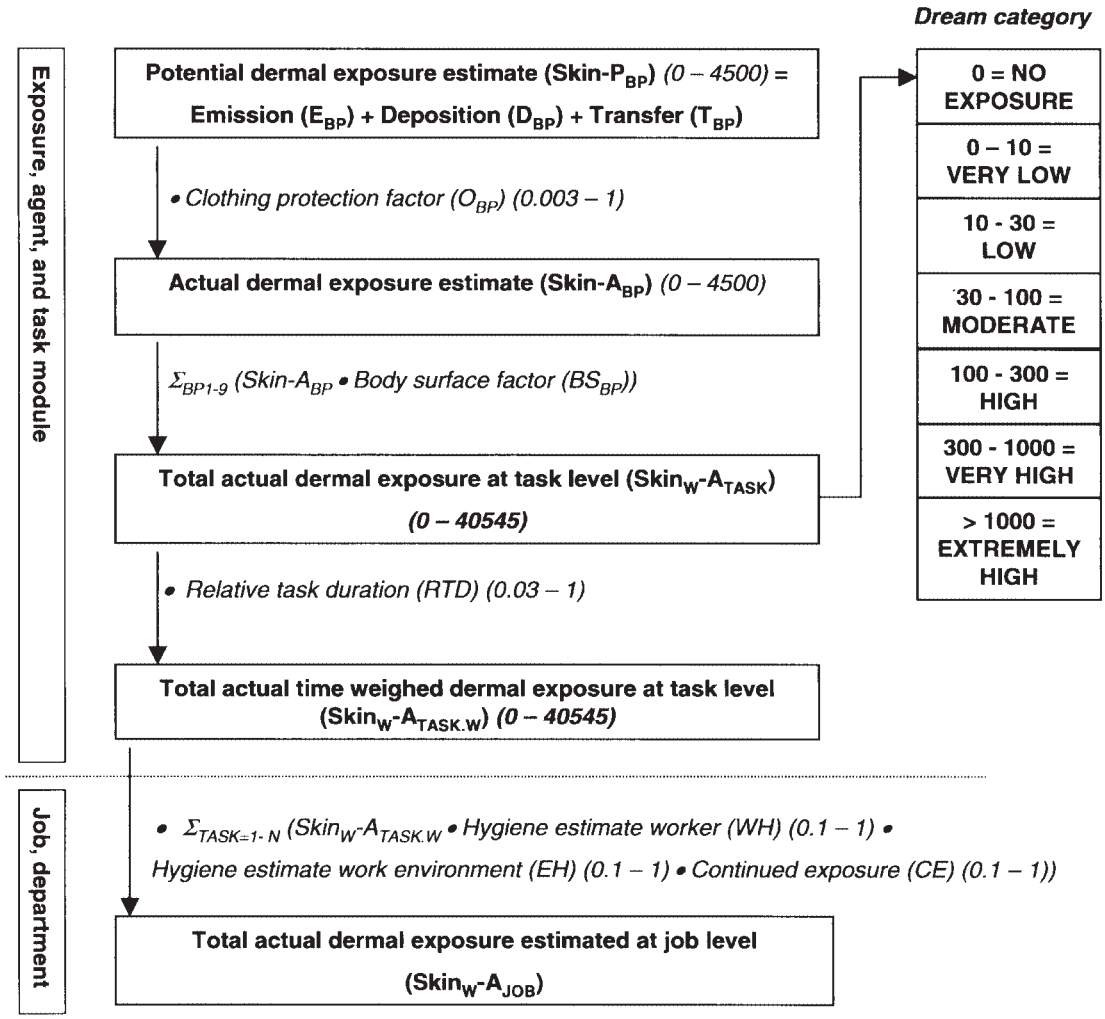

Fig. 1. Summary of the evaluation model of DREAM. Each estimate is determined by a set of underlying variables. The ranges of the estimates are in brackets.

'deposition', the following categories are indicated: (i) small amount (<10% of body part exposed); (ii) medium amount (10–50% of body part exposed); and (iii) large amount (>50% of body part exposed). Assigned values are 1, 3 and 10, respectively.

For 'transfer', *probability* is defined as contact frequency with surfaces such as floor, worktables, machines and working tools; the categories are the same as for emission and deposition. *Intensity* is defined as the contamination level of the contact surface of these surfaces. Intensity of contamination categories are: (i) not contaminated; (ii) possibly contaminated; (iii) <50% of contact surface is contaminated; and (iv) >50% of contact surface is contaminated, with assigned values of 0, 1, 3 and 10, respectively.

Exposure due to emission is given more weight [exposure route factor for emission (ER_E) = 3] than exposure due to deposition (ER_D = 1) or transfer (ER_T = 1). This is because emission is defined as mass transport of substances by direct release from a source onto clothing and uncovered skin, whereas deposition and transfer result from indirect mass transport of substances after interference with air or surface compartments, where loss of mass is likely to occur. In addition, absolute mass being released due to emission is likely to be higher than due to transfer or deposition.

$$\text{Skin-}P_{BP} = E_{BP} + D_{BP} + T_{BP} \quad (1)$$

$$E_{BP} = P_{E.BP} \cdot I_{E.BP} \cdot E_I \cdot ER_E \quad (2)$$

$$D_{BP} = P_{D.BP} \cdot I_{D.BP} \cdot E_I \cdot ER_D \quad (3)$$

$$T_{BP} = P_{T.BP} \cdot I_{T.BP} \cdot E_I \cdot ER_T \quad (4)$$

Intrinsic emission (E_I) concerns physical and chemical characteristics of the substance, such as concentration of active ingredient in the substance,

physical state, boiling temperature, viscosity and dustiness. Solids, liquids and vapours have different formulae (equations 5–7). See Table A2 for information on values of the determinants included in each equation. For solids the intrinsic emission is calculated by multiplying 'physical state (*PS*) of agent', 'concentration (*C*)', 'formulation (*F*)', 'dustiness (*DU*)', and 'stickiness–wax–moist (*SS*)' estimates (see equation 5). For liquids intrinsic emission is the product of 'physical state (*PS*)', 'concentration (*C*)', 'evaporation (*EV*)', and 'viscosity (*V*)' estimates (equation 6), whilst for vapours intrinsic emission is the product of 'physical state (*PS*)' and 'concentration (*C*)' estimates (equation 7).

$$E_{\mathrm{I(SOLID)}} = PS \cdot C \cdot F \cdot DU \cdot SS \quad (5)$$

$$E_{\mathrm{I(LIQUIDS)}} = PS \cdot C \cdot EV \quad (6)$$

$$E_{\mathrm{I(VAPOURS)}} = PS \cdot C \quad (7)$$

The *actual dermal exposure* estimate for each body part is calculated by multiplying potential exposure with its clothing protection factor for hands (O_{HA}), or other body parts (O_{BP}) (equation 8). The clothing protection factor for hands and other body parts (equations 9 and 10) depend on the kind of material covering the skin (*M*) (woven, non-woven, non-permeable) and the protection factor of the clothing material (*PFM*), as well as the replacement frequency of clothing (*RF*) (Branson and Sweeney, 1991; Easter and Nigg, 1992; Popendorf *et al.*, 1995b; Preller and Schipper, 1999; Brouwer *et al.*, 2000c; Vermeulen *et al.*, 2000a; Creely and Cherrie, 2001; Garrod *et al.*, 2001). Table A3 supplies information on values of the variables included in the clothing protection factor. The protection of clothing is assumed to be less for hands ($PFM_{\mathrm{HA}} = 1$) than for other body parts ($PFM_{\mathrm{BP}} = 0.3$). Gloves will experience higher pressure and friction than clothing of other body parts, resulting in more abrasions and subsequently higher permeation or penetration.

In addition to material and frequency of replacement, the clothing protection factor of hands (O_{HA}) depends on: whether the gloves connect well to the clothing of arms (*GC*); percentage of task duration that the gloves are being worn (*GD*); use of a second pair of gloves under outer-gloves (*UG*) with its replacement frequency (*URF*); and use of a barrier cream (*BC*).

$$\text{Skin-}A_{\mathrm{BP}} = \text{Skin-}P_{\mathrm{BP}} \cdot O_{\mathrm{HA/BP}} \quad (8)$$

$$O_{\mathrm{HA}} = M \cdot PFM_{\mathrm{HA}} \cdot RF \cdot GC \cdot GD \cdot UG \cdot URF \cdot BC \quad (9)$$

$$O_{\mathrm{BP}} = M \cdot PFM_{\mathrm{BP}} \cdot RF \quad (10)$$

In addition to estimates for each body part, total potential (Skin-P_{TASK}) and actual dermal exposure (Skin-A_{TASK}) estimates can be calculated for a specific task by summing individual body part values (equations 11 and 12). Weighting of each of the nine body parts by its body surface factor (BS_{BP}) before summing it results in weighted total exposures ($\mathrm{Skin_W}$-P_{TASK}, $\mathrm{Skin_W}$-A_{TASK}) (equations 13 and 14). The body part factor is defined as the surface area of an individual body part (Van Rooij *et al.*, 1993; ECETOC, 2001) divided by the mean surface area of the nine body parts (see Table A1, item 8).

$$\text{Skin-}P_{\mathrm{TASK}} = \Sigma_{\mathrm{BP=1–9}}\text{Skin-}P_{BP} \quad (11)$$

$$\text{Skin-}A_{\mathrm{TASK}} = \Sigma_{\mathrm{BP=1–9}}\text{Skin-}A_{BP} \quad (12)$$

$$\mathrm{Skin_w}\text{-}P_{\mathrm{TASK}} = \Sigma_{\mathrm{BP=1–9}}(BS_{BP} \cdot \text{Skin-}P_{BP}) \quad (13)$$

$$\mathrm{Skin_w}\text{-}A_{\mathrm{TASK}} = \Sigma_{\mathrm{BP=1–9}}(BS_{BP} \cdot \text{Skin-}A_{BP}) \quad (14)$$

Multiplying total dermal exposure of a task by its relative task duration estimate (*RTD*) results in time-weighted estimates ($\mathrm{Skin_W}$-P_{TASKW}, $\mathrm{Skin_W}$-A_{TASKW}). Relative task duration is defined as the total time of task performance ('task frequency' times 'task duration', assessed per day, week, month or year) divided by total working time assessed on the same timescale). To be able to compare the contribution of several tasks with a dermal exposure estimate for a working day, or at job level, the time-weighted task estimates are summed and subsequently multiplied by the workers' hygiene estimate (*WH*), the hygiene estimate of work environment (*EH*) and the continued exposure estimate (*CE*) (see Fig. 1 and Table A4).

RESULTS

Example I

In a department of a truck factory, motor blocks are being produced. Workers experience dermal exposure to metalworking fluids when removing metal parts from milling machines. Our first example concerns a worker whose task consisted of removing connection rods (metal parts) from a milling machine. Subsequently, he cleaned the part of the machine where the rods were attached using compressed air, then put in new rods. The machine used a cooling agent, which was the substance for which exposure was being assessed.

Table A5 shows the evaluation estimates for the worker performing this task. When unloading the machine, dermal exposure due to emission from source to both hands and other body parts was observed. Frequently, small amounts of cooling agent were released when the worker unloaded the machine. This resulted in contact of the substance

with the (covered) skin. Emission to the hands was estimated to be higher than for other body parts. Dermal exposure due to transfer frequently occurred through contact with metal rods that were heavily contaminated with the cooling agent. This concerned especially the hands. As a consequence, the hands obtained almost the maximum exposure estimate for transfer. Use of compressed air to clean metal objects was considered to result in deposition of invisible amounts of agent on all body parts except the back of the torso. Exposure routes were multiplied by the 'intrinsic emission' estimate of 0.3. The cooling agent was a 10% water-based emulsion, resulting in a concentration estimate (C) of 0.3, while other determinants had values of 1 [$E_{I\,(LIQUIDS)} = PS \cdot C \cdot EV \cdot V = 1 \cdot 0.3 \cdot 1 \cdot 1$]. By summing exposure estimates of individual body parts, potential and actual total dermal exposures for this task were estimated to be 54 and 10.6, respectively, which, based on Fig. 1, are regarded as moderate and low exposure levels.

Figure 2a describes the exposure routes for three body parts and for the whole body (total dermal exposure) using a simplified conceptual model. The values presented in the clothing contaminant layer concern potential dermal exposure whereas values of the skin contaminant layer are actual dermal exposure estimates. Figure 2a elucidates how dermal exposure occurred, which is very helpful when designing intervention or measurement strategies. As can be seen, the importance of exposure routes differs between body parts. For the hands, transfer is considered to be the most important route, while for the front of the torso transfer is unimportant. Dermal exposure due to transfer contributed most to total dermal exposure. Therefore, control measures in this particular situation should aim at a reduction of contact of skin with contaminated surfaces.

Figure 3a gives an overview of the relative importance of exposure routes for all the nine body parts, potential as well as actual total dermal exposure estimates. Potential exposure of the hands was much higher (factor 10) than for any of the other body parts. The pattern for actual dermal exposure is different from that for potential exposure: the forearms have the highest actual exposure, while the hands have the highest potential dermal exposure. This can be explained by a difference in protective clothing: PVC gloves (resulting in a O_{HA} of 0.09) covered the hands, while the forearms were not covered since this worker wore a short-sleeved shirt.

Example II

At the same department, another worker performed a task that consisted of removing a motor block out of a metal working machine with help of a hoist and, subsequently, putting in the next motor block. The machine uses the same cooling-agent as described in the first example.

When unloading the machine, dermal exposure due to emission from source to hands or other body parts was considered unlikely. The distance between the worker and the motor block was about 2 m due to using the hoist. Consequently, cooling agent dripping from the wet motor block did not lead to contact with the (covered) skin. As a result, DREAM assigned emission estimates (E_{BP}) zero for all body parts. Dermal exposure to the hands due to transfer repeatedly occurred through contact with contaminated motor blocks when directing them towards a pallet, resulting in a transfer-estimate of $T_{HA} = 10$. Other body parts were not likely to be exposed due to transfer, since no contact was observed with surfaces contaminated with the cooling agent. Occasionally, when opening the metalworking machine shortly after it had finished its drilling process, a mist of cooling agent was released from the machine resulting in deposition estimates of 0.3 for all body parts. Clothing estimate for hands (O_{HA}) was 0.3, since the worker used woven gloves instead of PVC gloves as worn by the worker of the first example. Clothing estimates for other body parts were equal to those of the worker of the first example, except for the forearm that had a clothing estimate of 0.1 because the worker of the second example used long sleeves. Potential and actual total dermal exposures for this task were estimated to be 12.7 and 3.9, respectively, which are considered 'low' and 'very low' dermal exposures when consulting the DREAM exposure categories of Fig. 1.

Figure 2b shows exposure routes for three body parts and for total dermal exposure. The figure indicates that exposure routes differed less between body parts than they did in the first example; 'torso front' and 'lower body part' showed identical exposure patterns. Direct emission onto skin did not occur at all.

Figure 3b gives an overview of the exposure routes for all nine body parts; in addition, both potential and actual dermal exposure estimates are shown. Compared with the first example, potential dermal exposure estimates are less than half the amount, while the actual exposure estimates of the hands are almost identical. Figure 3b indicates that the total actual dermal exposure of this second example is almost entirely due to exposure of hands, whilst in the first example other body parts, such as the forearms, contributed significantly. The main exposure route is transfer of the cooling agent from contaminated surfaces; deposition contributed only slightly to the dermal exposure estimates.

DISCUSSION

We developed a semi-quantitative method for dermal exposure assessment (DREAM), in which we successfully implemented the conceptual model

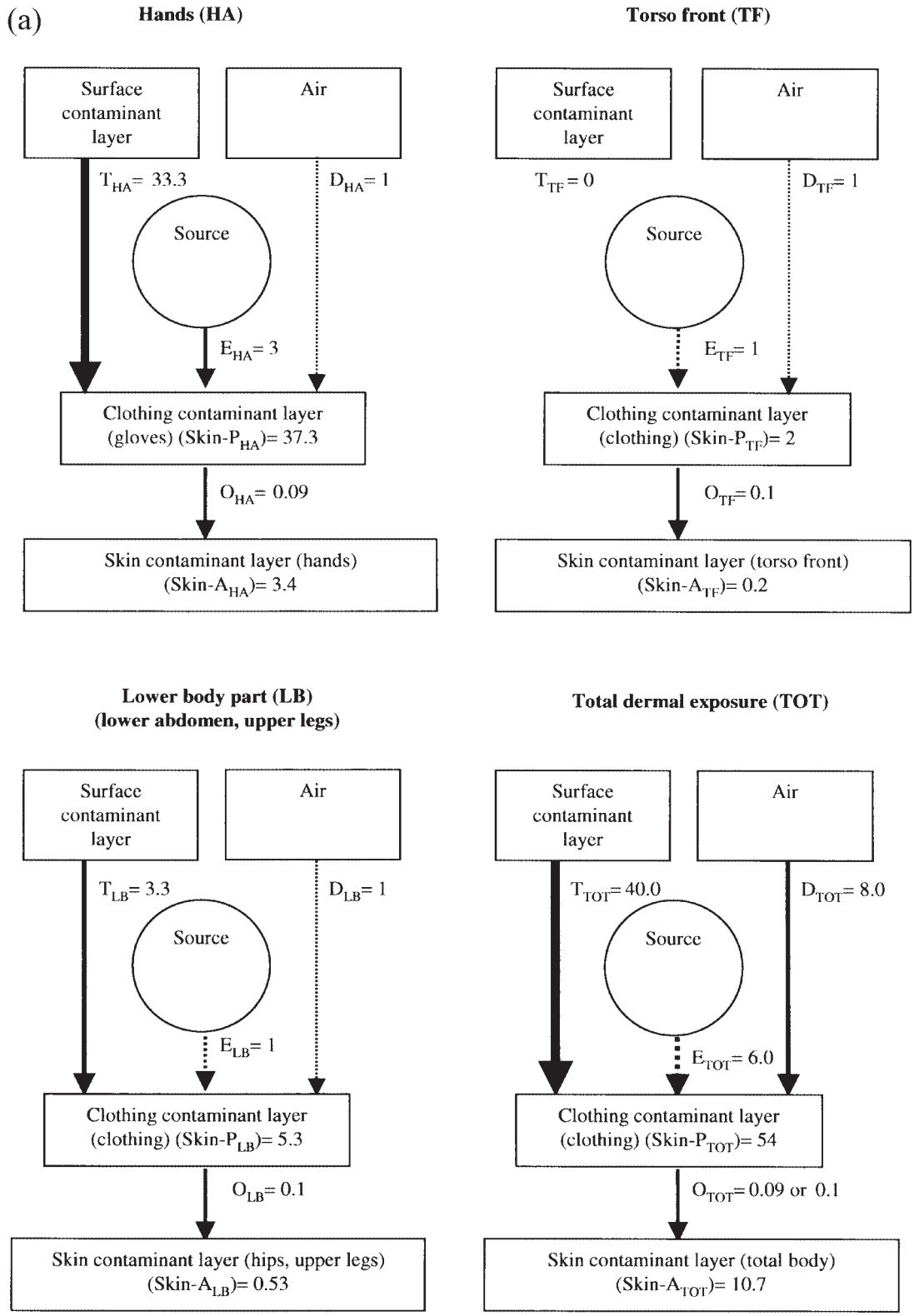

Fig. 2. (a) Example I: patterns of exposure routes for three body parts and for total skin exposure for a worker removing connection rods (metal parts) from a milling machine. E = emission, T = transfer, D = deposition, O = clothing protection factor.

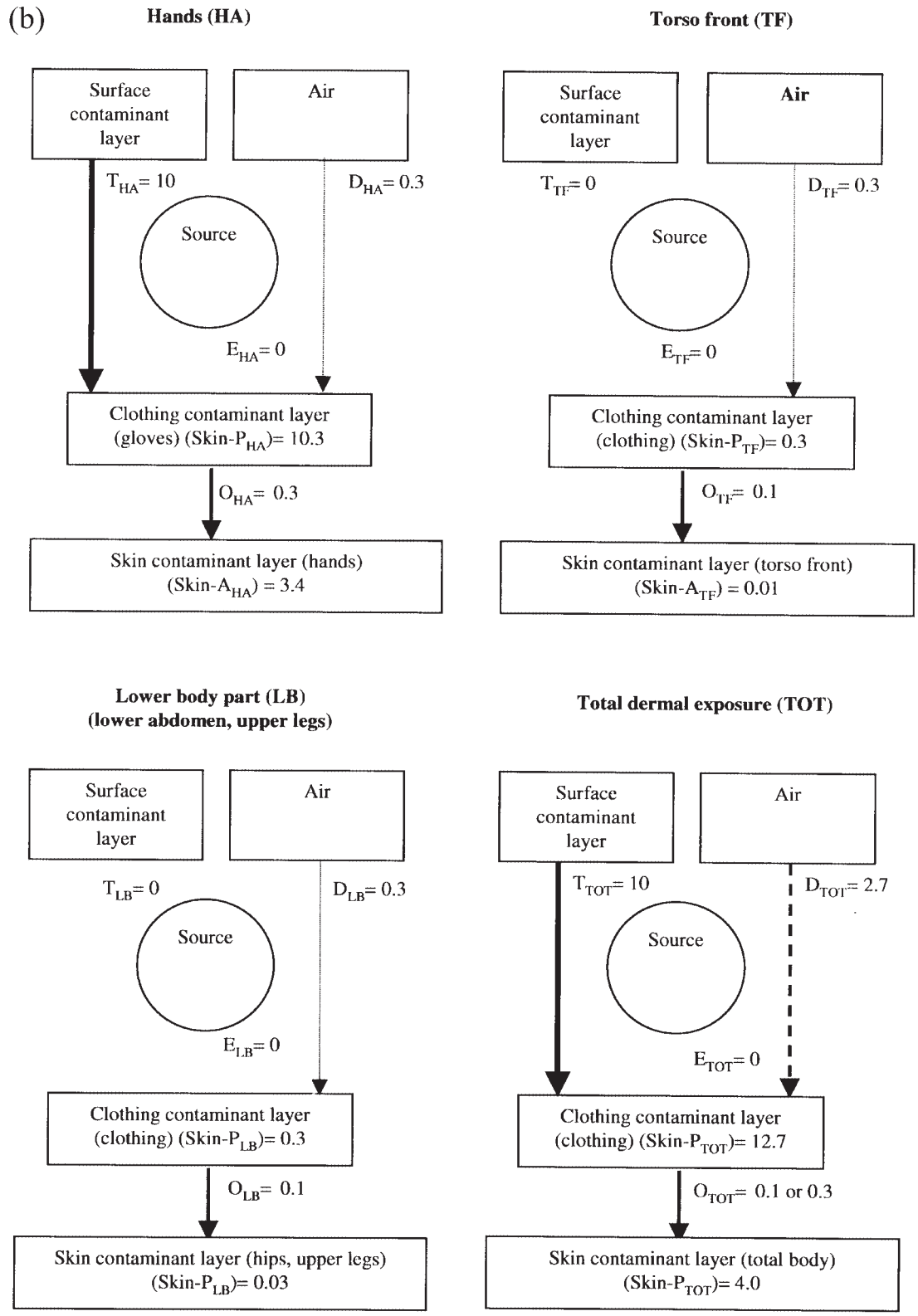

Fig. 2. (b) Example II: patterns of exposure routes for three body parts and for total skin exposure for a worker removing a motor block from a metal working machine with help of a hoist. E = emission, T = transfer, D = deposition, O = clothing protection factor.

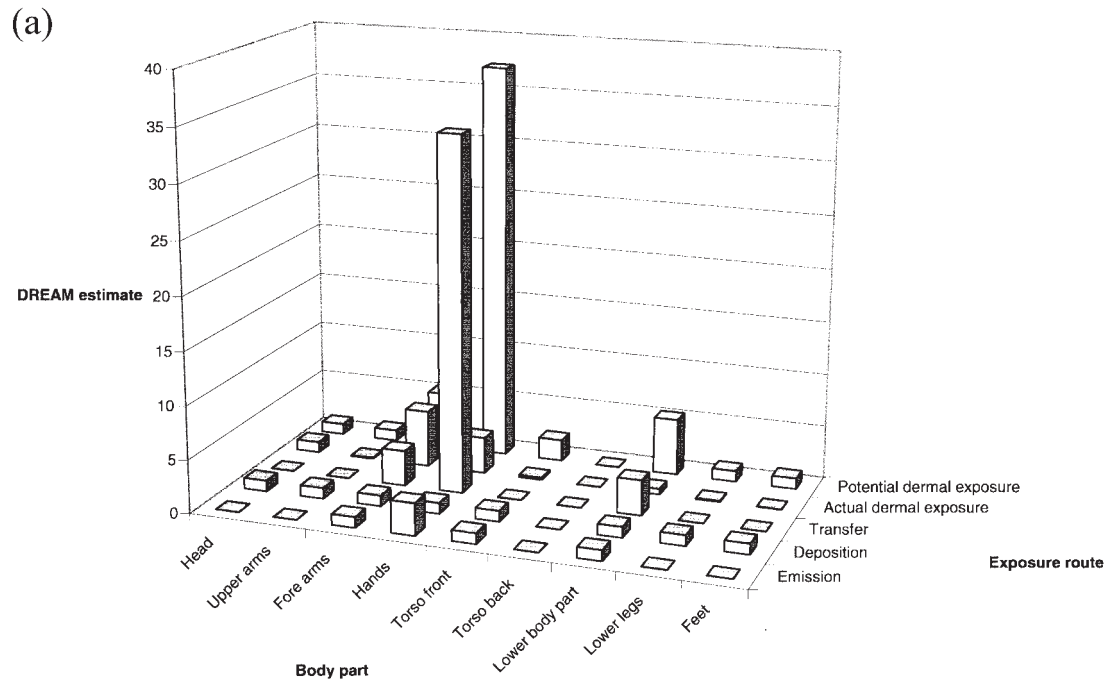

Fig. 3. (a) Example I: overview of exposure routes for each body part and total body exposures for a worker removing connection rods (metal parts) from a milling machine.

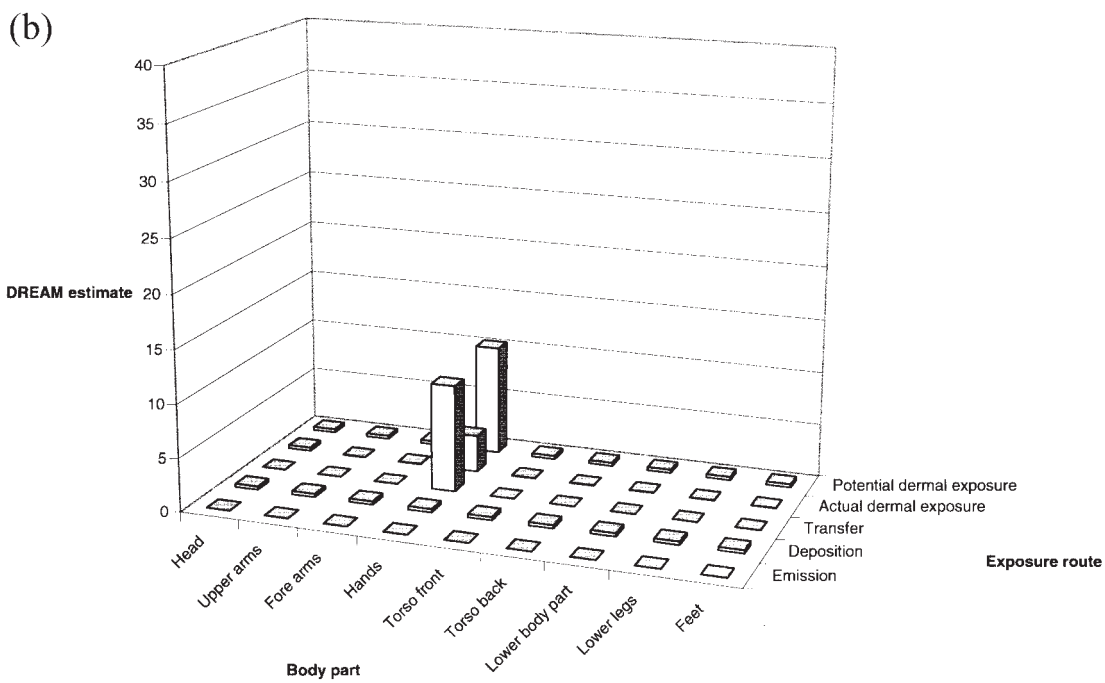

Fig. 3. (b) Example II: overview of exposure routes for each body part and total body exposures for a worker removing a motor block from a metal working machine with help of a hoist.

of Schneider *et al.* (1999) and assigned values to exposure variables according to an approach described by Cherrie *et al.* (1996). We have applied DREAM in two real working situations, characterized dermal exposure using DREAM and compared dermal exposure estimates provided by DREAM. An important advantage of DREAM is that the method documents decisions made by the investigator in a structured way.

DREAM has some limitations. First, since limited

knowledge on dermal exposure determinants is available, the values assigned to the model were principally assigned by educated assumptions, as in the method described by Cherrie *et al.* (1996) for structured subjective assessment of airborne concentrations.

Secondly, DREAM assesses exposure at a task level, with the observer determining which activities comprise tasks, and where a task begins and stops. To be able to compare DREAM estimates between different observers, they should define tasks beforehand. Nevertheless, the advantage of this approach is that it results in a flexible, general method that can be used for all dermal exposure characterization for all kinds of scenario. The observer makes the task inventory that suits him or her best, and decides the level of detail of the task definitions and consequently exposure estimates.

Thirdly, the method may be time-consuming due to the number of determinants (33 in total) it comprises. However, because of its hierarchical structure, it takes on average 15–30 min only to assess exposure for one person carrying out one task.

Despite its limitations, following the tiered approach for dermal exposure assessment described by Schneider *et al.* (2000), it becomes clear that DREAM fills a gap that exists for dermal exposure assessment methods and strategies, since it results in a systematic, semi-quantitative description of dermal exposure to chemical substances at workplaces. The DREAM estimates form an initial assessment of dermal exposure at task level, which allows the ranking of tasks, or (groups of) workers, by grouping them according to their DREAM estimate; for example, when aiming at hazard evaluation or control.

As was shown by the first and second examples, the systematic description of pathways according to the conceptual model of Schneider *et al.* (1999) characterizes tasks and gives insight into exposure mechanisms forming a bases for systematic exposure reduction. In view of the latter, DREAM also describes whether contamination of the working environment occurs during task performance.

DREAM supplies an estimate for exposure levels on the outside clothing layer as well as on skin, and gives insight in the distribution of dermal exposure over the body. Together with the ranking of tasks and (groups of) workers, this provides information for measurement strategies and helps to determine who, where and what to measure. In addition to dermal exposure assessment, the systematic description of dermal exposure pathways helps to prioritize and determine most adequate measurement strategies and methods. For example, if dermal exposure is mainly due to transfer of agent from contaminated surfaces, environmental sampling of the surfaces that come into contact with the (covered) skin will provide useful information. Information on which (groups of) workers and which body parts are being exposed helps to decide ‘who’ and ‘which body locations’ to measure. Tasks could also be ranked, after multiplying them by the average time of task performance. When interested in determining mean exposure levels for epidemiological purposes, ranking of these weighed estimates would be most appropriate, especially when estimating mean exposure levels at job title level.

In conclusion, DREAM may be a promising approach for the structured, semi-quantitative assessment of dermal exposure assessment in occupational hygiene, as well as in epidemiology. Its value will have to be proven by studying its reproducibility and validity.

Acknowledgements—The authors are grateful to Wim Braun for programming the MS-ACCESS database and thank John Cherrie for his valuable suggestions with regard to DREAM. We also would like to acknowledge Tim Meijster, Martijn Kerkman, Marc Lurvink, Simone Hilhorst and Wouter Fransman for their useful comments on the inventory part of DREAM. This work was financed by the Dutch Ministry of Social Affairs and Labour.

APPENDIX

Table A1. Exposure module—exposure routes: direct emission, transfer and deposition

Determinant	Category (assigned value)	Rationale	Literature		Process[a]
			S[b]	NS[c]	
1. Emission to clothing and uncovered skin; and immersion of skin into agent ($P_{E.BP}$)	Unlikely (<1% of task duration) (0) Occasionally (<10% of task duration) (1) Repeatedly (10–50% of task duration) (3) Almost constantly (≥50% of task duration) (10)	Increasing frequency of results in higher exposure levels	[1]		E
2. Intensity (= amount of agent) of emission ($I_{E.BP}$)	Small amount (<10 % of body part) (1) Medium amount (10–50% of body part) (3) Large amount (≥50% of body part) (10)	Increasing amount of agent results in higher exposure levels			E
3. Exposure route factors: emission (ER_E); deposition (ER_D) transfer (ER_T)	ER_E (3) ER_D (1) ER_T (1)	In our model emission starts at higher exposure levels than deposition and transfer			E
4. Probability of deposition on clothing and uncovered skin ($P_{D.BP}$)	Unlikely (<1% of task duration) (0) Occasionally (1–10% of task duration) (1) Repeatedly (10–50% of task duration) (3) Almost constantly (≥50% of task duration) (10)	Increasing frequency results in higher exposure levels	[1]		D
5. Intensity of deposition on clothing and uncovered skin ($I_{D.BP}$)	Small amount (<10 % of body part) (1) Medium amount (10–50% of body part) (3) Large amount (≥50% of body part) (10)	Increasing amount of agent results in higher exposure levels			D
6. Transfer to clothing and uncovered skin: Contact with surfaces, or tools, occurs ($P_{T.BP}$)	Unlikely (<1% of task duration) (0) Occasionally (1–10% of task duration) (1) Repeatedly (10–50% of task duration) (3) Almost constantly (≥50% of task duration) (10)	Increasing contact frequency results in higher exposure levels	[2–4]	[5]	T
7. Intensity of transfer: Contamination level of contact surface ($I_{T.BP}$)	Not contaminated (0) Possibly contaminated (1) < 50% of contact surface (3) ≥50% of contact surface (10)	Increasing contamination results in higher exposure levels	[2,6,7]		T
8. Body surface factor (BS_{BP})	Head (BS_HE) = 0.69 Upper arm (BS_UA) = 0.67 Forearm (BS_FA) = 0.53 Hands (BS_HA) = 0.47 Torso front (BS_TF) = 1.22 Torso back (BS_TB) = 1.22 Lower body part (BS_LB) = 2.43 Lower leg (BS_LL) = 1.15 Feet (BS_FE) = 0.63	The body part factor is defined as the surface area of an individual body part divided by the mean surface area of the nine body parts	[31,32]		

[a]According to Schneider *et al.* (2000). E = emission; D = deposition; T = transfer; S = source; R = removal; EV = evaporation; PC = penetration of clothing barrier; RC = redistribution to inner clothing contaminant layer; C = clothing barrier; DC = decontamination.

[b]Supporting.

[c]Not supporting. Numbered references are: [1] Lansink *et al.* (1998); [2] Brouwer *et al.* (1999); [3] Spencer *et al.* (1995); [4] Kissel *et al.* (1996); [5] Llewellyn *et al.* (1996); [6] Brouwer *et al.* (1992); [7] Brouwer *et al.* (2000a); [31] Marquart *et al.* (1994); [32] ECETOC (2001).

Table A2. Agent module—determinants for 'intrinsic emission' estimate

Determinant	Category (assigned value)	Rationale	Literature		Process
			S	NS	
9. Physical state (PS)	Solid (1) Liquid (1) Vapour–gaseous (0.3)	Experiments comparing solids and liquids show inconsistent results, therefore both have factor 1. Solids and liquids are supposed to result in higher exposure levels than vapours and gases	[5,8]		E
10. Concentration (C)	>90% active ingredient of interest (1) 1–90% active ingredient of interest (0.3) <1% active ingredient of interest (0.1)	Dermal exposure increases with concentration of active ingredient in substance	[9–12]	[5,13]	S
11. Evaporation (EV) (liquids): boiling temperature	<50°C (3) 50–150°C (1) >150°C (0.3)	Volatile liquids result in lower dermal exposure due to increased removal	[14]		EV
12. Viscosity (V) (liquids)	Low (like water) (1) Medium (like oil) (1.75) High (like resin/paste) (3)	Higher viscosity results in decreased removal from (covered) skin. Stickiness is expected to increase equally with viscosity	[15]		R
13. Formulation (F) (solids)	Powder/fine particles (3) Granules/grain/pellets/particles (1) Pack/bunch/bundle (0.3)	Adherence to skin varies inversely with particle size. Smaller particles result in higher emission, have increased transfer and have higher adherence to skin (decreased removal)	[4,16]		E, T, R
14. Dusty (DU) (solids)	No (1) Yes (3)	Dusty solids are emitted more easily from source than non-dusty solids			E
15. Stickiness/wax/moist (SS) (non-powder and non-dusty solids)	No (1) Yes (1.75)	Sticky, waxy and moist solids result in better attachment to skin and therefore in decreased removal from (covered) skin	[4]		R

Numbered references are: [4] Kissel *et al.* (1996); [5] Llewellyn *et al.* (1996); [8] Popendorf *et al.* (1995a); [9] Mulhausen and Damiano (1998); [10] US EPA (1987); [11] Preller and Schipper (1999); [12] Cherrie and Robertson (1995); [13] Van Wendel de Joode *et al.* (1996); [14] Garrod *et al.* (1999); [15] Cinalli *et al.* (1992); [16] Driver *et al.* (1989).

Table A3. Exposure module—determinants of 'clothing' estimate

Determinant	Category (assigned value)	Rational	Literature	Process
			S	
16. Glove or clothing material (M)	No gloves used/body part not covered (1) Woven clothing (0.3) Non-woven permeable (0.1) Non-woven impermeable (0.03)	Use of gloves (clothing) reduce(s) external dermal exposure	Glove use results in exposure reduction [17–23] with a factor of: 155 and 290 [17] or 20 [18]. Reduction of 90% (external measurements) versus 40% (based on bio-monitoring data) [19] Dermal exposure for wearing clothing is 20 times lower than for wearing minimal clothing [25]; Tyvek coverall has a 10% penetration rate [14]; 1.3–8% penetration of clothing [8] Efficiency of protective clothing 95% of exposure [19]; type, composition thickness etc. affect penetration through clothing [20,21]	PC
17. Protection factor (PFM)	PFMHA = 1 PFMBP = 0.3	Gloves experience higher pressure and friction than clothing of other body parts	Pressure and friction on gloves result in abrasions and subsequently higher permeation or penetration	PC
18. Replacement frequency (RF)	After having them used once (0.3) Daily (1) Weekly (3) Monthly (10)	Gloves (clothing) that are replaced frequently reduce exposure more than gloves (clothing) that are infrequently replaced	When workers change gloves every 4 weeks, no difference in internal exposure was found compared with not using gloves [24]	PC, RC
19. If non-woven gloves connect well to clothing of arms (GC)	No (3) Yes (1)	Gloves connecting well reduce exposure more than gloves that do not connect well		RC
20. If non-woven gloves are worn during (GD)	0–25% of task duration (10) 25–99% of task duration (3) 100% of task duration (1)	Gloves worn during total time of task performance reduce exposure more than gloves worn during part of the time		C, RC
21. A second pair of gloves is worn (UG) under outer gloves	No (1) Yes (0.3)	Use of a second pair of gloves may reduce exposure		PC
22. Replacement frequency of these inner gloves (URF)	After 1 time (1) Daily (3) Weekly / monthly (10)	Inner gloves only protect if frequently replaced; if not, they become a source of exposure		RC
23. Barrier cream used (BC)	No (1) Yes (0.3)	Use of barrier crème reduces exposure		CB

Numbered references are: [8] Popendorf *et al.* (1995a); [14] Garrod *et al.* (1999); [17] Popendorf *et al.* (1995b); [18] Garrod *et al.* (2001); [19] Brouwer *et al.* (2000c); [20] Branson and Sweeney (1991); [21] Easter and Nigg (1992); [22] Creely and Cherrie (2001); [23] Vermeulen *et al.* (2000a); [24] Thind *et al.* (1991); [25] Roff (1997).

Table A4. Task, job and department module—determinants for 'exposure duration' estimates, hygiene and continued exposure

Determinant	Category (assigned value)	Rational	Literature		Process
			S	NS	
Task module:					
24a. Relative task duration: relative time of task performance = (frequency · duration task)/total working time); categorical estimate (RTD_{CAT})	Daily 4–8 h/weekly >20 h/monthly >80 h/yearly >800 h (1) Daily 1–4 h/weekly 4–20 h/monthly 16–80 h/yearly 160–800 h (0.3) Daily 11–60 min/weekly 1–4 h/monthly 4–16 h/yearly 40–160 h (0.1) Daily <11 min/weekly 0–1 h/monthly 0–4 h/yearly 0–40 h (0.03)	Increasing task duration results in higher dermal exposure	[25–28]	[11,29]	E, D, T
24b. Relative task duration: relative time of task performance = (frequency · duration task)/total working time); absolute estimate (RTD_{ABS})	Total time of task performance divided by total working time				
Job module:					
25–26. Workers' hygiene factor (WH) determined by: hand-wash frequency (HWF) and wash efficiency (WE)	Hands not washed (1) Washed 2–10 times per shift with water (0.3) Washed 2–5 times per shift (scrub) soap or solvents (0.3) Washed >10 times per shift with water (0.1) Washed >5 times per shift with (scrub) soap or solvents (0.1)	Hand washing reduces exposure	Washing once, with water and soap, reduces exposure by 10–26%; washing twice reduces it by 46% [31]		DC
27–29. Continued exposure (CE) = working clothes immediately changed after work (EC1) · workers wash own working clothes (EC2) · workers immediately shower after work (EC3)	Working clothes are immediately changed after work: No (0.3) Yes (1) Workers responsible for washing own working clothes: No (1); Yes (3) Workers immediately shower after work: No (1); Yes (0.3)	Contaminated working clothes result in exposure after work; direct showering reduces continued exposure			T, DC
30–33. Hygiene estimate work environment (EH) = (hygiene floor (EH_{FL}) + hygiene work tables (EH_{WT}) + hygiene machines (EH_{MC})+ hygiene working tools (EH_{TO})/4	Hygiene estimates of floor, worktables, machines and working tools determined by cleaning frequency and cleaning efficiency. Daily cleaning wet, or dry and wet (0.1) Weekly cleaning wet, or dry and wet (0.3) Cleaning dry (1)	Higher cleaning frequency results in cleaner work environment Wet cleaning is more efficient than dry cleaing			DC

Numbered references are: [11] Preller and Schipper (1999); [25] Roff (1997); [26] Brouwer *et al.* (2000b); [27] Brouwer *et al.* (2001); [28] Lansink *et al.* (1998); [29] de Pater *et al.* (2000); [30] Marquart *et al.* (1994).

Table A5. Calculation of variables of example I: a worker removing connection rods (metal parts) from a milling machine

Variable	Name	Formula	In example
Emission to: head, upper arms, forearms, hands, torso front, torso back, lower body part, lower legs, feet	E_{BP}	$E_{BP} = ER_E \cdot P_{E.BP} \cdot I_{E.BP} \cdot E_I$	$E_{HE} = 3 \cdot 0 \cdot 0 \cdot 0.3 = 0$ $E_{UA} = 3 \cdot 0 \cdot 0 \cdot 0.3 = 0$ $E_{FA} = 3 \cdot 1 \cdot 1 \cdot 0.3 = 1$ $E_{HA} = 3 \cdot 3 \cdot 1 \cdot 0.3 = 3$ $E_{TF} = 3 \cdot 1 \cdot 1 \cdot 0.3 = 1$ $E_{TB} = 3 \cdot 0 \cdot 0 \cdot 0.3 = 0$ $E_{LB} = 3 \cdot 1 \cdot 1 \cdot 0.3 = 1$ $E_{LL} = 3 \cdot 0 \cdot 0 \cdot 0.3 = 0$ $E_{FE} = 3 \cdot 0 \cdot 0 \cdot 0.3 = 0$
Total emission	E_{TOT}	$E_{TOT} = \Sigma_{BP=1-9} E_{BP}$	6
Deposition on head, upper arms, forearms, hands, torso front, torso back, lower body part, lower legs, feet	D_{BP}	$D_{BP} = ER_D \cdot P_{D.BP} \cdot I_{D.BP} \cdot Dp_{BP}{}^a \cdot E_I$	$D_{HE} = 1 \cdot 3 \cdot 1 \cdot 1 \cdot 0.3 = 1$ $D_{UA} = 1 \cdot 3 \cdot 1 \cdot 1 \cdot 0.3 = 1$ $D_{FA} = 1 \cdot 3 \cdot 1 \cdot 1 \cdot 0.3 = 1$ $D_{HA} = 1 \cdot 3 \cdot 1 \cdot 1 \cdot 0.3 = 1$ $D_{TF} = 1 \cdot 3 \cdot 1 \cdot 1 \cdot 0.3 = 1$ $D_{TB} = 1 \cdot 3 \cdot 1 \cdot 0 \cdot 0.3 = 0$ $D_{LB} = 1 \cdot 3 \cdot 1 \cdot 1 \cdot 0.3 = 1$ $D_{LL} = 1 \cdot 3 \cdot 1 \cdot 1 \cdot 0.3 = 1$ $D_{FE} = 1 \cdot 3 \cdot 1 \cdot 1 \cdot 0.3 = 1$
Total deposition	D_{TOT}	$D_{TOT} = \Sigma_{BP=1-9} D_{BP}$	8
Transfer to head, upper arms, forearms, hands, torso front, torso back, lower body part, lower legs, feet	T_{BP}	$T_{BP} = ER_T \cdot P_{T.BP} \cdot I_{T.BP} \cdot Tr_{BP}{}^b \cdot E_I$	$T_{HE} = 1 \cdot 10 \cdot 0 \cdot 0.3 = 0$ $T_{UA} = 1 \cdot 10 \cdot 0 \cdot 0.3 = 0$ $T_{FA} = 1 \cdot 10 \cdot 1 \cdot 0.3 = 3.3$ $T_{HA} = 1 \cdot 10 \cdot 10 \cdot 0.3 = 33.3$ $T_{TF} = 1 \cdot 10 \cdot 0 \cdot 0.3 = 0$ $T_{TB} = 1 \cdot 10 \cdot 0 \cdot 0.3 = 0$ $T_{LB} = 1 \cdot 10 \cdot 1 \cdot 0.3 = 3.3$ $T_{LL} = 1 \cdot 10 \cdot 0 \cdot 0.3 = 0$ $T_{FE} = 1 \cdot 10 \cdot 0 \cdot 0.3 = 0$
Total transfer	T_{TOT}	$T_{TOT} = \Sigma_{BP=1-9} T_{BP}$	39.9
Potential skin exposure per body part	Skin-P_{BP}	Skin-$P_{BP} = E_{BP} + D_{BP} + T_{BP}$	Skin-$P_{HE} = 0 + 1 + 0 = 1$ Skin-$P_{UA} = 0 + 1 + 0 = 1$ Skin-$P_{FA} = 1 + 1 + 3.3 = 5.3$ Skin-$P_{HA} = 3 + 1 + 33.3 = 37.3$ Skin-$P_{TF} = 1 + 1 + 0 = 2$ Skin-$P_{TB} = 0 + 0 + 0 = 0$ Skin-$P_{LB} = 1 + 1 + 3.3 = 5.3$ Skin-$P_{LL} = 0 + 1 + 0 = 1$ Skin-$P_{FE} = 0 + 1 + 0 = 1$
Total potential skin exposure	Skin-P_{TASK}	Skin-$P_{TASK} = \Sigma_{BP=1-9}$Skin-$P_{BP}$	53.9
Intrinsic emission	E_I	$E_I = PS \cdot C \cdot EV \cdot V$	$E_I = 1 \cdot 0.3 \cdot 1 \cdot 1 = 0.3$
Clothing factor hands	O_{HA}	$P_{HA} = M \cdot PFM_{HA} \cdot GC \cdot GD \cdot RF \cdot UG \cdot URF \cdot BC$	$CL_{HA} = 0.03 \cdot 3 \cdot 1 \cdot 1 \cdot 1 \cdot 1 \cdot 1 = 0.09$
Clothing factor other body parts	O_{BP}	$P_{TASK.BP} = M \cdot PFM_{BP} \cdot RF$ or $P_{JOB.BP} = M \cdot PFM_{BP} \cdot RF$ (lowest value)	$CL_{HE} = 1 \cdot 1 = 1$ $CL_{UA} = 0.1 \cdot 1 = 0.1$ $CL_{FA} = 1 \cdot 1 = 1$ $CL_{TF} = 0.1 \cdot 1 = 0.1$ $CL_{TB} = 0.1 \cdot 1 = 0.1$ $CL_{LB} = 0.1 \cdot 1 = 0.1$ $CL_{LL} = 0.1 \cdot 1 = 0.1$ $CL_{FE} = 0.03 \cdot 1 = 0.09$
Actual skin exposure for each body part	Skin-A_{BP}	Skin-A_{BP} = Skin-$P_{BP} \cdot O_{BP}$	Skin-$A_{HE} = 1 \cdot 1 = 1$ Skin-$A_{UA} = 1 \cdot 0.1 = 0.1$ Skin-$A_{FA} = 5.3 \cdot 1 = 5.3$ Skin-$A_{HA} = 37.3 \cdot 0.09 \cdot 1 = 3.4$ Skin-$A_{TF} = 2 \cdot 0.1 = 0.2$ Skin-$A_{TB} = 0 \cdot 0.1 = 0$ Skin-$A_{LB} = 5.3 \cdot 0.1 = 0.53$ Skin-$A_{LL} = 1 \cdot 0.1 = 0.1$ Skin-$A_{FE} = 1 \cdot 0.03 = 0.03$
Total actual skin exposure	Skin-A_{TASK}	Skin-$A_{TASK} = \Sigma_{BP=1-9}$Skin-$A_{BP}$	10.6

[a]Whether deposition to the specific body part occurs ($Dp_{BP} = 1$) or does not occur ($Dp_{BP} = 0$).
[b]Whether the specific body part has contact with the surface ($Tr_{BP} = 1$) or does not have contact ($Tr_{BP} = 0$).

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