

Variability of Task-based Dermal Exposure Measurements from a Variety of Workplaces

HANS KROMHOUT^{1*}, WOUTER FRANSMAN¹, ROEL VERMEULEN^{1,2}, MARTIN ROFF³ and JOOP J. VAN HEMMEN⁴

¹Environmental and Occupational Health Division, Institute for Risk Assessment Sciences, Utrecht University, Utrecht, The Netherlands; ²National Cancer Institute, Division of Cancer Epidemiology and Genetics, Occupational and Environmental Epidemiology Branch, Rockville, MD, USA; ³Health and Safety Laboratory, Broad Lane, Sheffield S3 7HQ, UK; ⁴TNO Nutrition and Food Research, Department of Chemical Exposure Assessment, PO Box 360, Zeist, The Netherlands

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Introduction: The RISKOFDERM project collected task-based estimates of potential dermal exposure from a wide range of industries and services from around Europe. A formal statistical analysis was carried out to explore the main components of variability in dermal exposure levels. The central research question was to what extent dermal exposure levels could be explained by generic grouping variables like 'exposure scenarios' and 'dermal exposure operation units' (DEOs) (grouping of scenarios on the basis of similarity in exposure patterns).

Methods: Mixed effect linear models were used to estimate variance components of potential dermal exposure for DEOs or scenarios and for factories, workers and time. In addition within- and between-worker variance components were estimated for single groups of workers performing a specific scenario in a specific location with potential dermal exposure to a specific agent.

Results: Variability in potential dermal exposure is very large. Differences in geometric mean potential dermal exposure can range over 3–5 orders of magnitude both for DEOs and scenarios. The range depends on how dermal exposure is expressed (amount or rate). Both DEOs and scenarios explain a considerable amount of variability, but large differences in dermal exposure still existed within DEOs and scenarios. In contrast, between-worker variability in mean potential dermal exposure is minimal for a given scenario carried out within a specific location with exposure to a particular agent. Temporal variability, however, is considerable, most likely due to the event-based nature of the dermal exposure process.

Conclusion: The classification of tasks in DEOs and scenarios has proven to be useful since large differences in average dermal exposure estimates exist between DEOs and between scenarios. However, large differences also exist between scenarios within a DEO and even within a scenario. These differences are governed by local conditions determined by the actual handling of the agent, the agent's physical and chemical properties, its intrinsic toxicity, control measures taken and training and attitude of workers. For the time being, actual dermal exposure measurements and a better understanding of actual determinants of dermal exposure seem to be a necessity in order to evaluate dermal exposure hazards properly.

Keywords: dermal exposure; tasks; variability; industry; hospitals

INTRODUCTION

Information on the variability of dermal exposure is relatively scarce. Recently, Kromhout and Vermeu-

len (2001) reported on variability in dermal exposures from a database comprising data from 20 surveys. Their median values of between-worker ($\sigma^2_B = 0.15$) and within-worker variability ($\sigma^2_W = 0.47$) were quite similar to what was reported earlier for respiratory exposure (Kromhout *et al.*, 1993).

The RISKOFDERM project, designed to provide an overview of dermal exposure in Europe, yielded

*Author to whom correspondence should be addressed.
Tel: +31-30-2539440; fax: +31-30-2539499; e-mail:
h.kromhout@iras.uu.nl

enough data to explore this matter further for task-based measurements (Rajan-Sithamparamadarajah *et al.*, 2004). In the RISKOFDERM project, exposure scenarios (made up of a series of activities) were grouped together into dermal exposure operations units (DEOs). The allocation of scenarios to DEOs was achieved on the basis of similarities of task and professional judgement (Rajan-Sithamparamadarajah *et al.*, 2004). The large variety of agents, workplaces

and methods used to estimate dermal exposure in this survey enabled us to study the relative importance of factors like DEOs, scenarios, factories, workers and time. Our statistical analyses of the RISKOFDERM database were aimed at providing insight into whether the DEO or scenario approach could be used as a generic method to predict and assess dermal exposures.

Table 1. Description of data structure estimates of potential dermal exposure of hands

| DEO | Scenario | No. of factories (<i>F</i>) | No. of workers (<i>K</i>) | No. of measurements (<i>N</i>) | Repeats |
|--|----------------------------|-------------------------------|-----------------------------|----------------------------------|--|
| 1. Handling objects | 106. Maintenance/servicing | 19 | 28 | 34 | 6 individuals ($n = 2$) |
| | 108. Loading | 8 | 15 | 28 | 5 individuals ($3 n = 2$; $1 n = 4$; $1 n = 8$) |
| | 110. Filling | 28 | 47 | 60 | 13 individuals ($n = 2$) |
| | 114. Mixing/diluting | 4 | 14 | 29 | 8 individuals ($7 n = 2$; $1 n = 9$) |
| 2. Manual dispersion | 202. Wiping | 3 | 9 | 30 | 7 individuals ($2 n = 3$; $3 n = 4$; $2 n = 5$) |
| 3. Manual dispersion with hand tools | 301. Pouring | 1 | 3 | 4 | 1 individual ($n = 2$) |
| | 302. Spreading material | 16 | 24 | 30 | 6 individuals ($n = 2$) |
| | 304. Rolling | 2 | 10 | 30 | 8 individuals ($3 n = 2$; $2 n = 3$; $1 n = 4$; $2 n = 6$) |
| 4. Spray dispersion | 305. Brushing | 4 | 13 | 24 | 11 individuals ($n = 2$) |
| | 402. Spray painting | 23 | 37 | 77 | 15 individuals ($8 n = 2$; $2 n = 4$; $1 n = 5$; $2 n = 6$; $2 n = 7$) |
| 5. Dip coating | 501. Galvanizing | 6 | 16 | 29 | 13 individuals ($n = 2$) |
| 6. Mechanical treatment of solids ^a | 606. Grinding | 5 | 15 | 29 | 14 individuals ($n = 2$) |

^aIn the analyses we kept this data set even though workers wore gloves for an unknown proportion of the time during the measurements.

Table 2. Description of data structure estimates of potential dermal exposure of body

| DEO | Scenario | No. of factories (<i>F</i>) | No. of workers (<i>K</i>) | No. of measurements (<i>N</i>) | Repeats |
|--------------------------------------|----------------------------|-------------------------------|-----------------------------|----------------------------------|--|
| 1. Handling objects | 106. Maintenance/servicing | 19 | 28 | 34 | 6 individuals ($n = 2$) |
| | 108. Loading | 4 | 7 | 10 | 3 individuals ($n = 2$) |
| | 110. Filling | 23 | 32 | 39 | 7 individuals ($n = 2$) |
| | 114. Mixing/diluting | 4 | 14 | 34 | 8 individuals ($7 n = 2$; $1 n = 14$) |
| 2. Manual dispersion | 202. Wiping | 3 | 9 | 30 | 7 individuals ($2 n = 3$; $3 n = 4$; $2 n = 5$) |
| 3. Manual dispersion with hand tools | 301. Pouring | 1 | 3 | 4 | 1 individual ($n = 2$) |
| | 302. Spreading material | 5 | 6 | 12 | 6 individuals ($n = 2$) |
| | 304. Rolling | 2 | 10 | 45 | 9 individuals ($2 n = 2$; $4 n = 3$; $1 n = 4$; $2 n = 12$) |
| 4. Spray dispersion | 402. Spray painting | 22 | 38 | 87 | 14 individuals ($7 n = 2$; $1 n = 3$; $1 n = 4$; $1 n = 7$; $1 n = 8$; $3 n = 9$) |
| 5. Dip coating | 501. Galvanizing | 9 | 43 | 56 | 13 individuals ($n = 2$) |
| 6. Mechanical treatment of solids | 602. Machining | 4 | 33 | 39 | 1 individual ($n = 7$) |
| | 606. Grinding | 5 | 15 | 29 | 14 individuals ($n = 2$) |

MATERIALS AND METHODS

Details of the exposure surveys conducted in five countries can be found elsewhere (Rajan-Sithamparamanadarajah *et al.*, 2004). The RISKOFDERM database was created by one of us (M.R.) and consists of 574 sets of individuals' dermal exposure samples. We analysed the following estimates of dermal exposure: total contamination of hands and body (mg formulation) and total contamination rate of hands and body (mg formulation/min). Dermal exposure expressed as total contamination (mg) is event-based and one assumes that area of contamination is constant. When dermal exposure is expressed as a rate it is assumed to take place continuously during the period of measurement.

After exclusion of samples collected under protective clothing we were left with 404 (70%) measurements of total potential dermal exposure of the hands and 419 (73%) measurements of total potential dermal exposure of the body. One series of hand measurements was collected from workers who wore leather or cotton gloves for an unknown period of time during the measurements. We decided not to exclude these measurements although potential exposure might have been underestimated.

We used SAS for Windows (version 8.2) to calculate descriptive statistics and variance components. Mixed effect linear models were estimated with the Mixed Procedure (Proc Mixed). In the mixed effect models the nested structure of the data was maintained, so we assumed that factories were nested in either a DEO or scenario, with workers nested in a factory. Repeated measurements on an individual worker were on different days or in some cases within a day. With only a few series of repeats collected both within a day and over more than 1 day available we could not justifiably estimate a within-day component of variance. Therefore, all repeats (collected either within a day or over several days) were treated similarly.

The actual model tested looks as follows for a DEO:

$$Y_{dfij} = \ln(X_{dfij}) = \mu_y + \alpha_d + \beta_{df} + \gamma_{dfi} + \epsilon_{dfij}$$

for $d = 1, \dots, 6$ DEOs; $f = 1, \dots, f_d$ factories in the d th DEO; $i = 1, \dots, k_{df}$ workers in the f th factory in the d th DEO; $j = 1, \dots, n_{dfi}$ measurements from the i th worker in the f th factory in the d th DEO. In this model, μ_y represents the true mean of the logged dermal exposure averaged over all strata, α_d is the random effect of the d th DEO, β_{df} is the random effect of the f th factory in the d th DEO, γ_{dfi} is the random effect of the i th worker in the f th factory in the d th DEO and ϵ_{dfij} is the random effect of the j th measurement effect of the i th worker in the f th factory in the d th DEO. The assumption is that α_d , β_{df} , γ_{dfi} and ϵ_{dfij} are each normally distributed and mutually independent, with

means of 0 and variances of σ_D^2 , σ_F^2 , σ_B^2 and σ_W^2 , respectively. The 'D', 'F', 'B' and 'W' subscripts are used to indicate that these variance components represent variation between DEO, between factory, between workers and within workers, respectively. The estimates of σ_D^2 , σ_F^2 , σ_B^2 and σ_W^2 are presented as $_dS_y^2$, $_fS_y^2$, $_bS_y^2$ and $_wS_y^2$, respectively. The 97.5 and 2.5 percentiles of the distributions (on the original scale) are also presented (Rappaport, 1991). They represent the fold ranges of variation of dermal exposure across DEOs, between factories, between persons and within persons, respectively. They are estimated as follows: $_D R_{0.95} = \exp^{(3.92, _dS_y)}$, $_F R_{0.95} = \exp^{(3.92, _fS_y)}$, $_B R_{0.95} = \exp^{(3.92, _bS_y)}$ and $_W R_{0.95} = \exp^{(3.92, _wS_y)}$.

A similar model was used in which DEO was replaced by scenario ($n = 12$).

A one-way random effects ANOVA model was used to estimate within- and between-worker variability for groups of workers defined by scenario and location. Criteria for these groups were similar to those described by Kromhout and Vermeulen (2001): at least two workers, with at least one with repeated measurements, at least four measurements in total and with at least 75% of observations >LOD.

The classical ANOVA model for this analysis is as follows:

$$Y_{ij} = \ln(X_{ij}) = \mu_y + \beta_i + \epsilon_{ij}$$

for $i = 1, \dots, k$ workers and $j = 1, \dots, n_i$ measurements from the i th worker. In this model, μ_y represents the true mean of the logged dermal exposure averaged over all strata, β_i is the random effect of the i th worker and ϵ_{ij} is the random effect of the j th measurement effect of the i th worker. The assumption is that β_i and ϵ_{ij} are each normally distributed and mutually independent, with means of 0 and variances of σ_B^2 and σ_W^2 , respectively. The 'B' and 'W' subscripts are used to indicate that these variance components represent variation between-workers and within-workers, respectively. The estimates of σ_B^2 and σ_W^2 are presented as $_bS_y^2$ and $_wS_y^2$, respectively.

This analysis enabled a direct comparison with variance components estimated from the DERMDAT database (Kromhout and Vermeulen, 2001).

RESULTS

In Tables 1 and 2 descriptive statistics of the number of factories, workers and measurements are given for each of the scenarios of each DEO for dermal exposure estimates of the hands and body, respectively. In this table the number of individuals with repeated measurements is also given.

From Table 3a it can be seen that geometric mean levels of dermal exposure range over up to 4 orders of magnitude between DEOs when exposure is

Table 3. Descriptive statistics for potential dermal exposure of hands and body

| DEO | Scenario | N | Exposure (mg) | | | Exposure (mg/min) | | |
|---|----------------------------|-----------------|---------------|------|-------|-------------------|------|-------|
| | | | AM | GM | GSD | AM | GM | GSD |
| (a) For each DEO | | | | | | | | |
| <i>Hands</i> | | | | | | | | |
| All | | 404 | 3563 | 106 | 24.7 | 197 | 4 | 33.3 |
| 1. Handling objects | | 151 | 3930 | 90 | 29.2 | 138 | 9 | 21.5 |
| 2. Manual dispersion | | 30 | 20964 | 7890 | 13.3 | 1803 | 798 | 10.2 |
| 3. Manual dispersion with hand-held tools | | 88 | 486 | 104 | 9.9 | 10 | 2 | 9.1 |
| 4. Spray dispersion | | 77 | 2252 | 286 | 10.9 | 48 | 9 | 6.8 |
| 5. Dip coating | | 29 | 3 | 2 | 3.3 | 0.01 | 0.01 | 3.8 |
| 6. Mechanical treatment | | 29 | 30 | 16 | 3.3 | 0.25 | 0.12 | 3.6 |
| <i>Body</i> | | | | | | | | |
| All | | 419 | 3332 | 234 | 24.2 | 78 | 9 | 19.9 |
| 1. Handling objects | | 117 | 1942 | 16 | 31.1 | 51 | 2 | 30.1 |
| 2. Manual dispersion | | 30 | 3315 | 853 | 7.7 | 296 | 86 | 6.9 |
| 3. Manual dispersion with hand-held tools | | 61 | 7514 | 2602 | 9.0 | 142 | 77 | 4.1 |
| 4. Spray dispersion | | 87 | 4405 | 1003 | 6.6 | 63 | 26 | 4.2 |
| 5. Dip coating | | 56 ^a | 374 | 61 | 9.2 | 14 | 0.7 | 25.6 |
| 6. Mechanical treatment | | 68 | 3044 | 726 | 7.3 | 43 | 9 | 8.0 |
| (b) For each scenario within a DEO | | | | | | | | |
| <i>Hands</i> | | | | | | | | |
| All | All | 404 | 3562 | 106 | 24.7 | 197 | 4 | 33.3 |
| 1. Handling objects | | | | | | | | |
| | 106. Maintenance/servicing | 34 | 1063 | 71 | 10.5 | 73 | 19 | 6.2 |
| | 108. Loading | 28 | 3215 | 217 | 19.3 | 335 | 21 | 19.4 |
| | 110. Filling | 60 | 1433 | 153 | 10.2 | 51 | 12 | 7.0 |
| | 114. Mixing/diluting | 29 | 13 146 | 17 | 246.3 | 209 | 1 | 130.3 |
| 2. Manual dispersion | 202. Wiping | 30 | 20964 | 7890 | 13.3 | 1803 | 798 | 10.2 |
| 3. Manual dispersion with hand-held tools | 301. Pouring | 4 | 11.1 | 5 | 7.2 | 1 | 0.8 | 5.6 |
| | 302. Spreading material | 30 | 46 | 16 | 6.7 | 2 | 0.5 | 10.4 |
| | 304. Rolling | 30 | 1241 | 1036 | 1.9 | 25 | 18 | 2.3 |
| | 305. Brushing | 24 | 170 | 98 | 3.0 | 2 | 1 | 2.9 |
| 4. Spray dispersion | 402. Spray painting | 77 | 2252 | 286 | 10.9 | 48 | 9 | 6.8 |
| 5. Dip coating | 501. Galvanizing | 29 | 3 | 2 | 3.3 | 0.01 | 0.01 | 3.8 |
| 6. Mechanical treatment | 606. Grinding | 29 | 30 | 16 | 3.3 | 0.25 | 0.12 | 3.6 |
| <i>Body</i> | | | | | | | | |
| All | All | 419 | 3332 | 234 | 24.2 | 78 | 9 | 19.9 |
| 1. Handling objects | | | | | | | | |
| | 106. Maintenance/servicing | 34 | 1797 | 42 | 8.0 | 87 | 11 | 5.4 |
| | 108. Loading | 10 | 18 | 0.16 | 16.7 | 2 | 0.01 | 21.4 |
| | 110. Filling | 39 | 27 | 18 | 2.7 | 10 | 4 | 8.1 |
| | 114. Mixing/diluting | 34 | 4848 | 20 | 170.0 | 75 | 1 | 76.5 |
| 2. Manual dispersion | 202. Wiping | 30 | 3315 | 853 | 7.7 | 296 | 86 | 6.9 |
| 3. Manual dispersion with hand-held tools | | | | | | | | |
| | 301. Pouring | 4 | 43 | 39 | 1.7 | 6 | 6 | 1.7 |

Table 3. Continued

| DEO | Scenario | N | Exposure (mg) | | | Exposure (mg/min) | | |
|-------------------------|-------------------------|-----------------|---------------|------|-----|-------------------|-----|------|
| | | | AM | GM | GSD | AM | GM | GSD |
| 4. Spray dispersion | 302. Spreading material | 12 | 193 | 110 | 3.5 | 18 | 12 | 2.7 |
| | 304. Rolling | 45 | 10 129 | 8794 | 1.7 | 187 | 158 | 1.8 |
| | 402. Spray painting | 87 | 4405 | 1003 | 6.6 | 63 | 26 | 4.2 |
| 5. Dip coating | 501. Galvanizing | 56 ^a | 374 | 61 | 9.2 | 14 | 0.7 | 25.6 |
| 6. Mechanical treatment | 602. Machining | 39 | 4842 | 1318 | 9.3 | 70 | 21 | 7.9 |
| | 606. Grinding | 29 | 3044 | 326 | 3.5 | 6 | 3 | 3.9 |

^aDue to missing sampling duration information only 55 observations could be used when estimates were based on mg/min.

Table 4. Variance components for potential dermal exposure for grouping by DEO and by scenario

| Variance component | Hands | | | | | Body | | | | |
|--------------------|-------|---------------------|------------------------|-------------------------|----------------------------|------------------|---------------------|------------------------|-------------------------|----------------------------|
| | N | S ² (mg) | R _{0.95} (mg) | S ² (mg/min) | R _{0.95} (mg/min) | N | S ² (mg) | R _{0.95} (mg) | S ² (mg/min) | R _{0.95} (mg/min) |
| <i>Model I</i> | | | | | | | | | | |
| DEO | 6 | 4.7 (41.6%) | 4863 | 13.4 (69.2%) | 1 704 085 | 6 | 2.4 (30.0%) | 445 | 2.9 (30.2%) | 773 |
| Factory | 72 | 4.2 (37.4%) | 3107 | 3.3 (16.9%) | 1200 | 59 | 3.5 (43.8%) | 1583 | 4.6 (47.9%) | 4305 |
| Subject | 179 | 0.9 (8.3%) | 44 | 1.2 (6.1%) | 71 | 188 | 0.9 (11.8%) | 45 | 0.9 (8.9%) | 37 |
| Error | | 1.4 (12.7%) | 108 | 1.5 (7.8%) | 125 | | 1.2 (14.4%) | 69 | 1.2 (13.0%) | 78 |
| Total | 404 | 11.3 (100%) | 516 513 | 19.4 (100%) | 31 000 518 | 419 ^a | 8.1 (100%) | 68 274 | 9.5 (100%) | 179 207 |
| <i>Model II</i> | | | | | | | | | | |
| Scenario | 12 | 3.7 (39.6%) | 1816 | 8.2 (63.0%) | 74 651 | 12 | 5.9 (58.1%) | 13 355 | 4.3 (45.2%) | 3289 |
| Factory | 72 | 3.8 (41.3%) | 2135 | 3.0 (23.2%) | 906 | 59 | 2.4 (23.3%) | 409 | 3.3 (34.7%) | 1210 |
| Subject | 179 | 0.6 (6.8%) | 22 | 0.5 (4.1%) | 17 | 188 | 0.7 (6.5%) | 24 | 0.7 (7.2%) | 25 |
| Error | | 1.1 (12.4%) | 67 | 1.3 (9.8%) | 83 | | 1.2 (12.1%) | 77 | 1.2 (12.9%) | 76 |
| Total | 404 | 9.3 (100%) | 152 086 | 13.1 (100%) | 1 384 467 | 419 ^a | 10.1 (100%) | 258 689 | 9.5 (100%) | 171 334 |

^aDue to missing sampling duration information only 418 observations could be used when estimates were based on mg/min.

expressed in milligrams. When the same exposure is expressed as a rate (mg/min) the order of magnitude difference increases to 3–5. Differences in geometric mean levels between scenarios were of the same order of magnitude as for DEOs when considering exposure of the hands, but the differences were larger for scenarios when considering the differences in exposure of the body (Table 3b).

This enormous variability in levels of dermal exposures is also reflected in the estimates of the variance components presented in Table 4. Task-based dermal exposure can vary by up to a factor of 500 000 for potential dermal exposure of the hands (mg) or even to 30 000 000 when expressed as a rate (mg/min). For exposure of the body the variability is less at, respectively, 70 000 and 180 000 for mass and rate. The estimates are somewhat different when dermal exposure is modelled with scenario instead of DEO, but are of the same order of magnitude when considering exposure of the hands and somewhat larger when considering exposure of the body. Both DEOs and scenarios explain a considerable amount

of variability in dermal exposure estimates. The relative contribution of DEOs was 42 and 69%, respectively, for amount and rate of dermal exposure of the hands, while for the body this was considerably lower at 30% for both dermal exposure estimates. When classified by scenario the relative contributions were 40 and 63%, respectively, for amount and rate of exposure of the hands and 58 and 45%, respectively, for the body. Factories contributed between 17 and 48% of the total variability and day-to-day variability in task-based dermal exposure estimates accounted for between 8 and 14%. Remarkably, the variability in mean individual levels was least important in most instances (between 4 and 12%) (Table 4).

This was confirmed when between- and within-individual variability in potential dermal exposure was estimated for groups of workers performing a specific scenario within a specific location (factory) (Table 5 and Fig. 1). Between-worker variability was minimal, with individual mean dermal exposure estimates lying on average within a 4-fold range. Within-individual variability outweighed the

Table 5. Median and interquartile range results of one-way random effects ANOVA for groups defined by scenario and factory for dermal exposure of body and hands

| Measure | No. of groups | bS_y^2 (IQ range) | $bR_{0.95}$ (IQ range) | wS_y^2 (IQ range) | $wR_{0.95}$ (IQ range) |
|----------------|---------------|---------------------|------------------------|---------------------|------------------------|
| Hands (mg) | 30 | 0.108 (0.359) | 3.6 (9.5) | 0.522 (0.793) | 17.0 (43.5) |
| Hands (mg/min) | 30 | 0.000 (0.425) | 1.0 (11.9) | 0.578 (0.973) | 19.9 (60.2) |
| Body (mg) | 22 | 0.000 (0.093) | 1.0 (2.3) | 0.835 (1.712) | 36.5 (235.7) |
| Body (mg/min) | 22 | 0.001 (0.356) | 1.1 (9.4) | 0.796 (1.557) | 33.1 (177.4) |

bS_y^2 , between-worker variability; $bR_{0.95}$, fold range of individual workers' mean dermal exposure estimates; wS_y^2 , within-worker variability; $wR_{0.95}$, fold range of worker's individual dermal exposure estimates.

between-individual component, with estimates lying on average within a 40-fold range.

DISCUSSION AND CONCLUSIONS

This industry-wide survey of workers performing tasks defined by scenarios within DEOs has shown the enormous range in potential dermal exposure of hands and body one could encounter in industry and services for a variety of chemical compounds. Classifications of tasks by DEO or by scenario both explained considerable amounts of encountered variability in dermal exposure, even though the schemes were only based on similarities in route of exposure patterns (Schneider *et al.*, 1999). However, the analyses of variance also showed that within DEOs, and even within scenarios, large differences in dermal exposure estimates (up to a factor of between 400 and 4500 depending on the dermal exposure estimate used) exist. This will not be a surprise, when one takes into account that different agents (and formulations) with different inherent risks were monitored while being worked with under very different conditions. Comparing 'mixing/diluting' a highly toxic chemical such as cyclophosphamide with 'mixing/diluting' a disinfectant containing potassium will show large differences in amounts and rates of potential dermal exposures caused by control measures in place (semi-closed systems in the case of cyclophosphamide versus an open system in the case of the disinfectant), the volume of substance handled and workers behaviour and training. In addition, some variability will have been caused by differences in monitoring techniques applied.

Monitored scenarios within a specific situation with exposure to a specific agent showed hardly any between-worker variability, indicating that definition and description of tasks making up a scenario was successful. The resulting average potential exposure estimates for a specific scenario varied minimally between workers carrying out the same tasks with the same formulation in the same location ($bS_y^2 = 0.00-0.11$). On the other hand, the temporal (within-worker) component was much larger ($wS_y^2 = 0.52-0.80$) and actually rather close to the results presented by Kromhout and Vermeulen (2001) for 'full-shift' dermal exposure measurements in their DERMDAT

database ($wS_y^2 = 0.33-0.79$). This analysis once again shows that potential dermal exposure has a large temporal component, even when measurement time is restricted to the duration of specific tasks. Event-based processes that might or might not happen during a particular measurement apparently govern dermal exposure. Of course, the way dermal exposure is often assessed (e.g. only a relatively small part of the potentially exposed surface is measured) also plays a role. This can be seen from the fact that the temporal (within-worker) component was larger for dermal exposure estimates of the body than for dermal exposure estimates of the hands. In almost all cases, total skin area of both hands was actually monitored either by a surrogate skin method, like gloves, or by removal techniques, like hand washing. Body estimates, in contrast, were most often based on pads measurements where non-uniformity of dermal exposure will increase the (temporal) variability when extrapolation to the total body area takes place.

Given the relatively small sample sizes for the scenarios monitored within a specific situation with exposure to a specific agent the estimated variance components should be treated with caution, even though the results seem to corroborate the results for the within-worker component of variance presented by Kromhout and Vermeulen (2001), where the median number of workers was similar and number of samples per group somewhat higher (8 versus 6). Restricting the analyses in the RISKOFDERM database to the groups with larger sample sizes with at least three workers with at least two repeats showed similar total variability, but somewhat larger median temporal variability and consequently lower between-worker variability. This is most likely again due to the event-based nature of dermal exposure. More samples will increase the likelihood of (high) exposure and consequently increase the temporal variability.

In conclusion, the RISKOFDERM project has convincingly shown that a wide variety of potential dermal exposure levels exist in industry and services. The classification of tasks in generic DEOs and scenarios has proven to be useful since large differences in average dermal exposure estimates are present between DEOs and between scenarios.

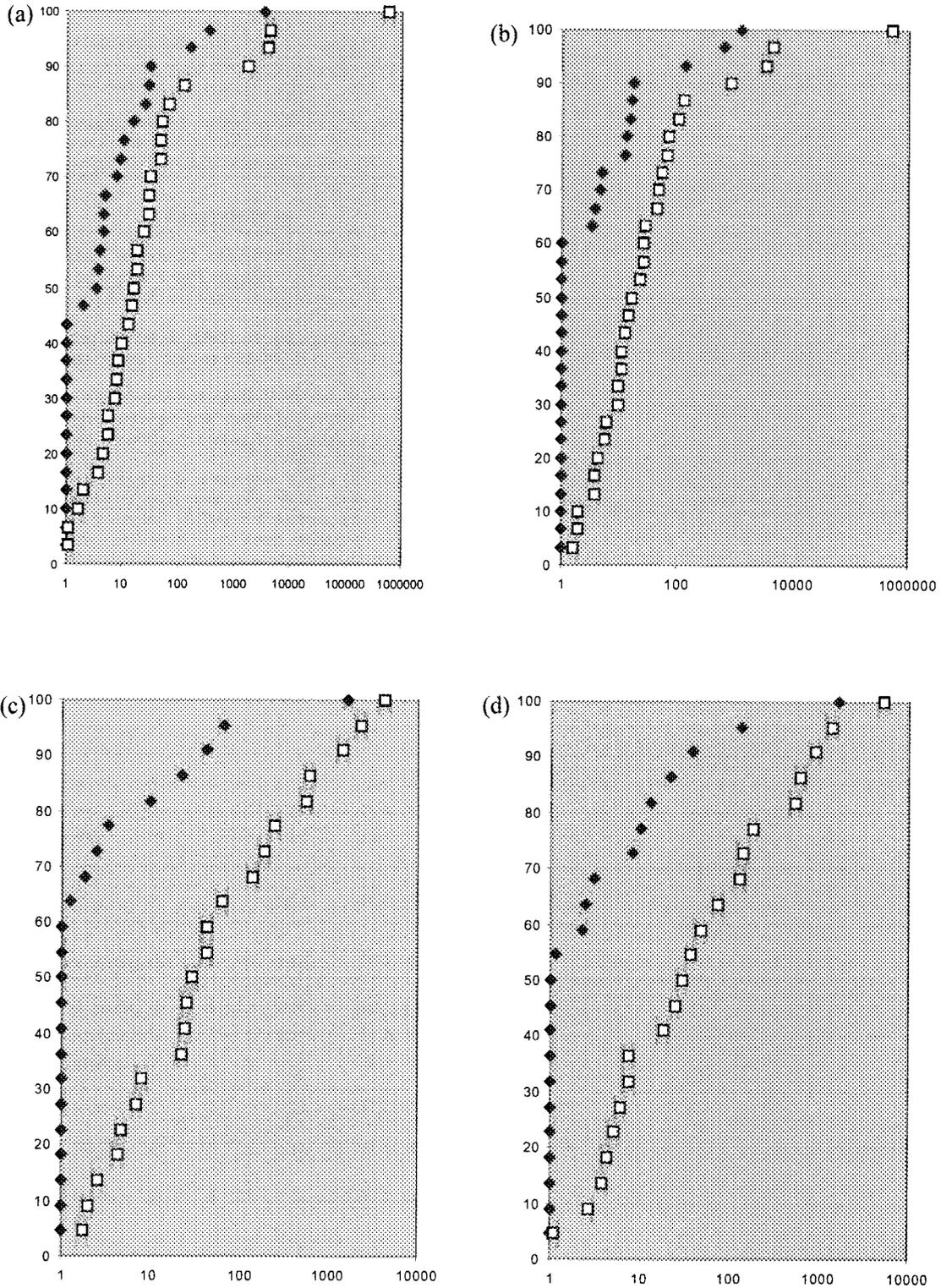


Fig. 1. (a) Cumulative distributions of ${}_B R_{0.95}$ (diamonds) and ${}_W R_{0.95}$ (squares) for potential dermal exposure of the hands (mg) for all 30 groups of workers based on scenario and location. (b) Cumulative distributions of ${}_B R_{0.95}$ (diamonds) and ${}_W R_{0.95}$ (squares) for potential dermal exposure of the hands (mg/min) for all 30 groups of workers based on scenario and location. (c) Cumulative distributions of ${}_B R_{0.95}$ (diamonds) and ${}_W R_{0.95}$ (squares) for potential dermal exposure of the body (mg) for all 22 groups of workers based on scenario and location. (d) Cumulative distributions of ${}_B R_{0.95}$ (diamonds) and ${}_W R_{0.95}$ (squares) for potential dermal exposure of the hands (mg/min) for all 22 groups of workers based on scenario and location

However, the DEO/scenario classification should only be seen as a first cut of the cake. Large differences do exist between scenarios within a DEO and even within a scenario. These differences are governed by local conditions determined by the actual handling of the agent, its intrinsic toxicity, control measures taken and training and attitude of workers. All these factors are not covered in the classification scheme, but will determine the potential exposure and, via actual exposure, the health risks involved. Further analyses and modelling of the RISKOFDERM database are underway and will hopefully unravel actual objective determinants of dermal exposure and yield predictive models like the recent model for spray painting (Brouwer *et al.*, 2001).

In our opinion, it will not be possible to estimate exposure for a local exposure situation solely on the generic exposure scenario involved. Additional measurements of dermal exposure and concomitant collection of detailed descriptive information will be a necessity to evaluate potential dermal exposure. In addition, from a public health perspective and for epidemiological purposes, estimates of actual dermal exposure and eventually uptake will be a requirement to safeguard the working population from the negative health effects of dermal exposure to chemicals (Vermeulen *et al.*, 2002).

APPENDIX

Tables A1 and A2 show the characteristics of hand and body exposure respectively.

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Table A1. Characteristics of hand exposure for 30 groups (based on scenario and factory)

| Scenario | Factory | K | N | Exposure (mg) | | | | Exposure (mg/min) | | | | Product (agent) |
|-----------------------------|---------|---|----|---------------|-------------|----------|-------------|-------------------|-------------|----------|-------------|--|
| | | | | wS^2_y | $wR_{0.95}$ | bS^2_y | $bR_{0.95}$ | wS^2_y | $wR_{0.95}$ | bS^2_y | $bR_{0.95}$ | |
| 106. Maintenance/ servicing | 51 | 3 | 4 | 0.29 | 8.2 | 0.00 | 1.0 | 0.12 | 3.9 | 0.00 | 1.0 | Washing water (cyclophosphamide) |
| 106. Maintenance/ servicing | 72 | 3 | 4 | 0.00 | 1.1 | 0.74 | 29.3 | 0.37 | 10.7 | 0.50 | 16.1 | Paint (aluminium) |
| 108. Loading (liquids) | 14 | 4 | 6 | 4.47 | 3986.5 | 0.00 | 1.0 | 4.29 | 3354.5 | 0.00 | 1.0 | Butyldiglycol (2-(2-butoxyethoxy) ethanol) |
| 110. Filling | 2 | 2 | 4 | 0.31 | 8.8 | 0.79 | 32.3 | 0.21 | 5.9 | 0.53 | 17.2 | Butyldiglycol (2-(2-butoxyethoxy) ethanol) |
| 110. Filling | 3 | 2 | 4 | 0.47 | 14.6 | 1.69 | 162.7 | 0.33 | 9.5 | 1.58 | 137.4 | Paint cleaner (2-(2-butoxyethoxy) ethanol) |
| 110. Filling | 5 | 3 | 4 | 1.51 | 123.9 | 0.16 | 4.9 | 1.41 | 105.8 | 0.00 | 1.0 | Paint (2-(2-butoxyethoxy) ethanol) |
| 110. Filling | 72 | 3 | 4 | 0.00 | 1.0 | 2.26 | 364.3 | 0.03 | 2.0 | 2.74 | 658.1 | Paint (aluminium) |
| 114. Mixing/ diluting | 47 | 5 | 9 | 4.53 | 4214.8 | 4.31 | 3419.0 | 4.58 | 4398.3 | 3.33 | 1272.8 | Disinfectant (potassium) |
| 114. Mixing/ diluting | 49 | 4 | 7 | 0.25 | 7.2 | 0.28 | 8.0 | 0.72 | 27.7 | 0.00 | 1.0 | Disinfectant (potassium) |
| 202. Wiping | 47 | 3 | 6 | 11.45 | 575147.5 | 0.00 | 1.0 | 11.30 | 528703.5 | 0.00 | 1.0 | Disinfectant (potassium) |
| 202. Wiping | 48 | 3 | 12 | 0.19 | 5.6 | 0.14 | 4.4 | 0.19 | 5.5 | 0.12 | 3.8 | Disinfectant (potassium) |
| 202. Wiping | 49 | 3 | 12 | 0.66 | 24.2 | 0.03 | 2.0 | 0.64 | 22.9 | 0.00 | 1.0 | Disinfectant (potassium) |
| 301. Pouring | 51 | 3 | 4 | 3.61 | 1725.1 | 0.32 | 9.3 | 2.97 | 859.7 | 0.00 | 1.0 | Urine (cyclophosphamide) |
| 302. Spreading material | 18 | 2 | 4 | 0.12 | 3.8 | 0.00 | 1.0 | 0.12 | 3.8 | 0.00 | 1.0 | Paint (2-(2-butoxyethoxy) ethanol) |
| 304. Rolling | 53 | 4 | 15 | 0.19 | 5.6 | 0.00 | 1.0 | 0.37 | 11.0 | 0.00 | 1.0 | Resin (styrene) |
| 304. Rolling | 54 | 6 | 15 | 0.55 | 18.4 | 0.00 | 1.0 | 0.42 | 12.8 | 0.00 | 1.0 | Resin (styrene) |
| 305. Brushing | 9 | 7 | 14 | 1.02 | 52.3 | 0.49 | 15.7 | 1.14 | 66.2 | 0.42 | 12.9 | Paint (2-(2-butoxyethoxy) ethanol) |
| 305. Brushing | 11 | 3 | 5 | 0.54 | 18.1 | 0.12 | 3.9 | 0.52 | 16.8 | 0.00 | 1.0 | Paint (2-(2-butoxyethoxy) ethanol) |
| 402. Spray painting | 44 | 2 | 8 | 0.74 | 29.3 | 0.15 | 4.5 | 0.70 | 26.7 | 0.15 | 4.6 | Dry powder paint (titanium) |
| 402. Spray painting | 50 | 4 | 24 | 0.99 | 49.1 | 0.00 | 1.0 | 1.06 | 56.3 | 0.00 | 1.0 | Paint (copper) |
| 402. Spray painting | 72 | 3 | 4 | 0.77 | 31.2 | 0.67 | 25.0 | 1.17 | 69.8 | 0.48 | 15.1 | Paint (aluminium) |
| 501. Galvanizing | 27 | 2 | 4 | 0.03 | 2.0 | 0.00 | 1.0 | 0.03 | 1.9 | 0.00 | 1.0 | Galvanizing liquids (nickel) |
| 501. Galvanizing | 36 | 2 | 4 | 0.97 | 47.2 | 0.00 | 1.0 | 0.97 | 47.7 | 0.00 | 1.0 | Galvanizing liquids (nickel) |
| 501. Galvanizing | 37 | 2 | 4 | 0.50 | 16.0 | 0.00 | 1.0 | 0.47 | 14.6 | 0.00 | 1.0 | Galvanizing liquids (nickel) |
| 501. Galvanizing | 38 | 5 | 10 | 1.14 | 65.4 | 0.00 | 1.0 | 1.57 | 134.9 | 0.00 | 1.0 | Galvanizing liquids (nickel) |
| 501. Galvanizing | 40 | 2 | 4 | 0.02 | 1.6 | 0.10 | 3.4 | 0.01 | 1.6 | 0.09 | 3.3 | Galvanizing liquids (nickel) |
| 606. Grinding | 32 | 5 | 9 | 0.34 | 10.0 | 0.36 | 10.5 | 0.95 | 45.4 | 0.45 | 14.0 | Steel (chromium) |
| 606. Grinding | 35 | 4 | 8 | 0.15 | 4.5 | 0.12 | 3.8 | 0.14 | 4.3 | 0.17 | 5.0 | Steel (chromium) |
| 606. Grinding | 39 | 2 | 4 | 0.75 | 29.5 | 0.00 | 1.0 | 0.70 | 26.3 | 0.00 | 1.0 | Steel (chromium) |
| 606. Grinding | 41 | 3 | 6 | 0.42 | 12.8 | 0.00 | 1.0 | 0.33 | 9.6 | 0.00 | 1.0 | Steel (chromium) |

K, number of workers; N, total number of measurements; wS^2_y , within-worker variability; $wR_{0.95}$, fold range of worker's individual dermal exposure estimates; bS^2_y , between-worker variability; $bR_{0.95}$, fold range in individual workers' mean dermal exposure estimates.

Table A2. Characteristics of body exposure for 22 groups (based on scenario and factory)

| Scenario | Factory | K | N | Exposure (mg) | | | Exposure (mg/min) | | | | Product (agent) | |
|--------------------------------|---------|---|----|---------------|-------------|----------|-------------------|----------|-------------|----------|-----------------|---|
| | | | | wS^2_y | $wR_{0.95}$ | bS^2_y | $bR_{0.95}$ | wS^2_y | $wR_{0.95}$ | bS^2_y | | $bR_{0.95}$ |
| 106. Maintenance/ servicing | 51 | 3 | 4 | 3.91 | 2333.9 | 0.00 | 1.0 | 3.40 | 1373.7 | 0.00 | 1.0 | Washing water (cyclophosphamide) |
| 106. Maintenance/ servicing | 72 | 3 | 4 | 0.93 | 44.0 | 0.00 | 1.0 | 0.21 | 6.0 | 0.43 | 13.1 | Paint (aluminium) |
| 108. Loading (liquids) | 14 | 4 | 6 | 0.93 | 43.7 | 1.15 | 66.5 | 0.84 | 36.5 | 1.56 | 133.6 | Butyldiglycol (2-(2- butoxyethoxy) ethanol) |
| 110. Filling | 72 | 3 | 4 | 0.02 | 1.8 | 0.02 | 1.8 | 0.00 | 1.1 | 0.29 | 8.4 | Paint (aluminium) |
| 114. Mixing/ diluting | 47 | 5 | 9 | 3.45 | 1453.4 | 0.00 | 1.0 | 3.00 | 891.0 | 0.00 | 1.0 | Disinfectant (potassium) |
| 114. Mixing/ diluting | 49 | 4 | 7 | 1.96 | 242.8 | 0.00 | 1.0 | 1.59 | 140.1 | 0.00 | 1.0 | Disinfectant (potassium) |
| 202. Wiping | 47 | 3 | 6 | 2.68 | 612.2 | 0.00 | 1.0 | 2.57 | 536.0 | 0.00 | 1.0 | Disinfectant (potassium) |
| 202. Wiping | 48 | 3 | 12 | 4.55 | 4267.1 | 0.09 | 3.3 | 4.78 | 5284.7 | 0.00 | 1.0 | Disinfectant (potassium) |
| 202. Wiping | 49 | 3 | 12 | 2.60 | 554.4 | 0.63 | 22.2 | 2.69 | 622.9 | 0.36 | 10.4 | Disinfectant (potassium) |
| 301. Pouring | 51 | 3 | 4 | 0.25 | 7.1 | 0.00 | 1.0 | 0.27 | 7.7 | 0.00 | 1.0 | Urine (cyclophosphamide) |
| 302. Spreading material | 18 | 2 | 4 | 0.06 | 2.6 | 3.57 | 1653.7 | 0.06 | 2.6 | 3.57 | 1653.7 | Paint (2-(2- butoxyethoxy) ethanol) |
| 304. Rolling | 54 | 6 | 15 | 0.63 | 22.6 | 0.00 | 1.0 | 0.56 | 18.7 | 0.08 | 3.0 | Resin (styrene) |
| 402. Spray painting | 72 | 3 | 4 | 0.03 | 2.0 | 0.05 | 2.5 | 0.12 | 3.9 | 0.04 | 2.2 | Paint (aluminium) |
| 501. Galvanizing | 36 | 2 | 4 | 0.67 | 24.7 | 0.00 | 1.0 | 0.67 | 24.8 | 0.00 | 1.0 | Galvanizing liquids (nickel) |
| 501. Galvanizing | 37 | 2 | 4 | 1.58 | 137.4 | 0.91 | 42.5 | 1.53 | 127.1 | 0.87 | 38.6 | Galvanizing liquids (nickel) |
| 501. Galvanizing | 38 | 5 | 10 | 0.68 | 25.1 | 0.00 | 1.0 | 0.97 | 47.2 | 0.00 | 1.0 | Galvanizing liquids (nickel) |
| 501. Galvanizing | 40 | 2 | 4 | 0.14 | 4.4 | 0.00 | 1.0 | 0.14 | 4.3 | 0.00 | 1.0 | Galvanizing liquids (nickel) |
| 606. Grinding | 32 | 5 | 9 | 0.74 | 29.3 | 0.35 | 10.0 | 0.75 | 29.8 | 0.63 | 22.4 | Steel (chromium) |
| 606. Grinding | 35 | 4 | 8 | 0.28 | 7.9 | 0.00 | 1.3 | 0.26 | 7.4 | 0.05 | 2.5 | Steel (chromium) |
| 606. Grinding | 39 | 2 | 4 | 1.13 | 64.1 | 0.00 | 1.0 | 1.21 | 74.1 | 0.00 | 1.0 | Steel (chromium) |
| 606. Grinding | 41 | 3 | 6 | 0.16 | 4.8 | 0.00 | 1.0 | 0.17 | 5.0 | 0.00 | 1.1 | Steel (chromium) |

K, number of workers; N, total number of measurements; wS^2_y , within-worker variability; $wR_{0.95}$, fold range of worker's individual dermal exposure estimates; bS^2_y , between-worker variability; $bR_{0.95}$, fold range in individual workers' mean dermal exposure estimates.