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TNO report

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Review of dermal exposure determinants for the dermal Advanced REACH Tool (dART) model

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Glossary

Activity classes (AC) are groups of workplace activities that were systematically categorized according to the energy involved during an activity, the scale of the activity and the product-to-air interface, while considering inhalation exposure processes and exposure determinants. For this purpose, activities are defined as specific process steps with handling characteristics that differentiate them from other process steps

Availability gives an indication of the undried or unfixed amount of product available for direct emission & contact and transfer from contaminated objects. It is determined by the drying or hardening time of a product in relation to the time that passed from the moment surface contamination occurred, to the actual handling of the contaminated objects.

Deposition refers to the transport of liquid in the form of mist or spray aerosol from the air to the skin (in this model a worker's hands or gloves)

Direct emission & contact concerns the transport of (bulk) product onto a worker in the NF. For hand exposure, the model distinguishes between two basic forms: (1) large droplets or bulk product, e.g. splashes, spilling, reflected spray of large droplets (not to confuse with smaller aerosol droplets in sprays relevant for deposition), and (2) hand immersion

Exposed surface area (of a body part) describes the potential skin surface area, whether protected or unprotected, that is affected by a specified route of exposure. For hand exposure, it refers to the proportion or fraction of the total hand surface area that is affected by an activity, e.g. both hands (100% or factor 1), both hand palms (50% or factor 0.5) or one hand palm or less (25% or factor 0.25)

Far field (FF) is comprised by the remainder of the workspace (outside of the NF); therefore the area further away from the worker (>1m from the worker).

Hand immersion refers to activities where workers immerse their hands or part of their hands in a product during work. It is addressed as part of the direct emission & contact route and relevant for activities with open liquid surfaces and open reservoirs (AC2) and spreading (AC4).

Intensity of contamination describes the thickness of the layer of a product on a surface or object at the time of contamination.

Level of automation describes the degree of manual or automated work and the approximate distance between the worker and the emission source or contaminated surfaces. For this purpose, the dART model considers the relevance of hand immersion, direct handling of objects, short or long hand tools, use of (remote) control panels, etc

Maximum retention capacity refers to the maximum mass loading per surface area (e.g. mg/cm^2) that may occur on the skin or gloves during an activity. Theoretically, the mass of product left on the hands after both the hands are immersed in a product may be considered a maximum retention capacity.

Near field (NF) is the area centred on the worker.

Partial or full screens (also referred to as protective guards, excl. glove ports) is a new localized control category that is not identified in the ART model and defined as

(i) any screens that are fixed or mobile that is placed between the emission source and the worker's hands or body (not to be confused with enclosures or containment of sources), or (ii) protective screens or guards fitted on for example the handles of hand tools

Product is the material (e.g. liquid) or formulation under investigation which contains a chemical agent or substance of interest for the exposure assessment. The model estimates the product exposure for each route, followed by the aggregated hand exposure to the product and subsequently the substance itself (considering the weight fraction)

Proportional contamination refers to the proportion or fraction of the total surface area of an object or surface that is contaminated by a product

Substance is the chemical agent of interest that is generally carried in a product or formulation. In the model, the substance is calculated after estimation of the product exposure per route of exposure

Surfaces the dART model defines different surfaces in the workplace for different activity classes. Broadly speaking, a distinction is made between (i) hand-held tools and equipment, (ii) immersed objects or equipment, treated or coated objects/surfaces or objects contaminated by other means, and (iii) (remote) control panels and devices.

Surface texture (or donor surface type) refers to the type of surface from which a surface contaminant will be transferred through body-surface contacts. The surface texture is known to affect the transfer efficiency to the skin (e.g. hands) or clothing (e.g. gloves). This determinant is of particular importance during the handling of contaminated objects (AC3)

Transfer describes the transport of a substance through contact between a contaminated surface and the skin (Schneider et al., 1999).

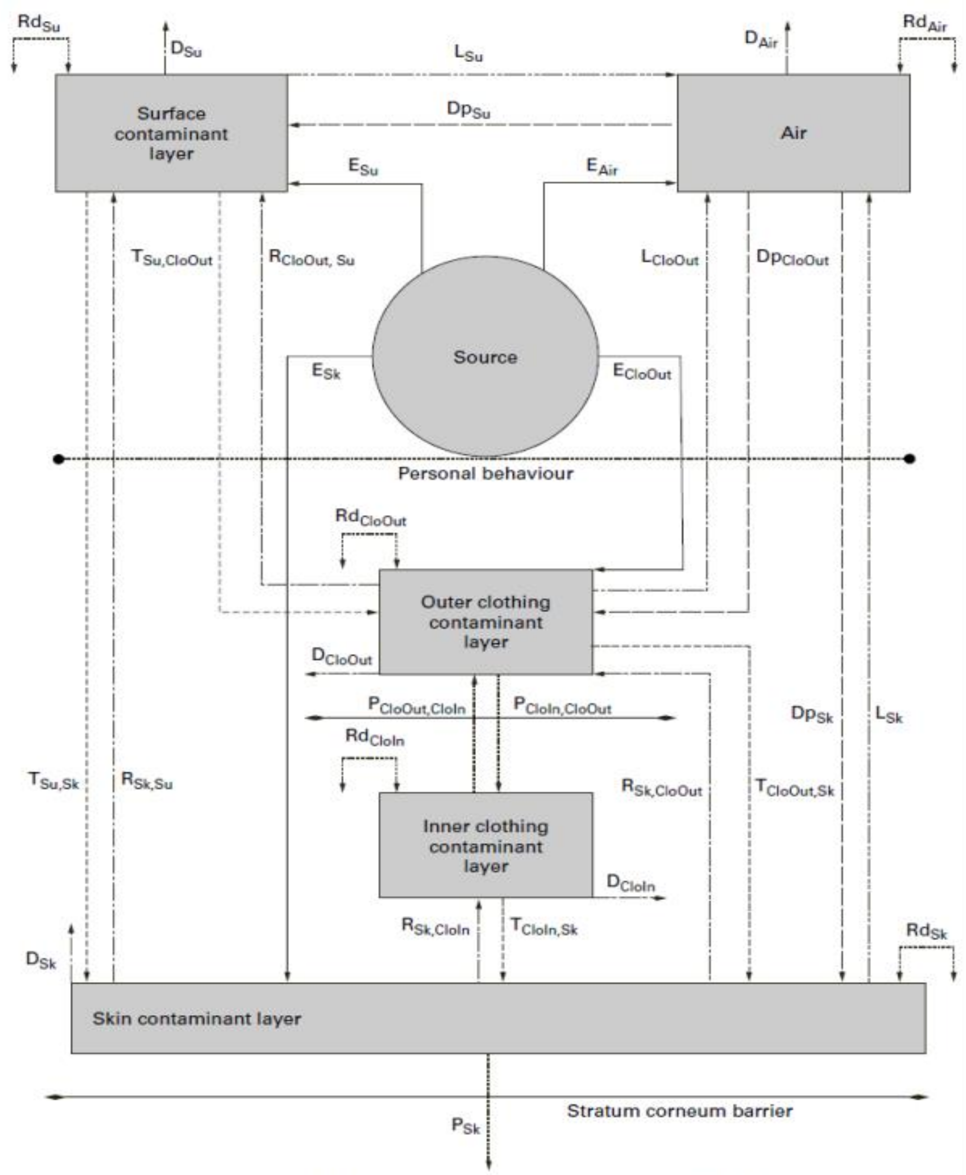
1 Introduction

The development of a dermal exposure model is a challenge because of the complexity of dermal exposure processes on one hand, and the scarcity of good quality and contextually-rich dermal exposure measurements. Dermal exposure modelling is further complicated by the difficulty of measuring dermal exposure due to the lack of standardised methods (CEN/TR 2006). For example, three types of sampling systems are typically used, i.e. interception methods, removal techniques and direct assessment (in situ detection). Despite these challenges, important advancements in dermal exposure modelling have been achieved since the start of the millennium, including the Bayesian Exposure Assessment Tool (BEAT) for biocides, the RISKOFDERM models (Van Hemmen et al. 2003) and structured semi-quantitative method to assess dermal exposure for chemical and biological agents, i.e. DREAM (Wendel de Joode 2005).

A great deal of fundamental work on the processes leading to dermal exposure variation has already been completed. The postulated conceptual model of Schneider *et al.* (1999) in combination with DREAM and other dermal models (e.g. RISKOFDERM) will form a solid basis for the development of a mechanistic dermal model. The source-receptor model of Schneider *et al.* describes the transport of contaminant mass from the source to the surface of the skin, and provides consistent terminology for dermal exposure processes. The conceptual model is comprised of distinct physical compartments (e.g. air, surfaces) that are connected by mass transport processes (see Figure below). The model include eight different mass transport processes, of which three major routes of dermal exposure can be derived, i.e. deposition from the air compartment, direct emission & contact from sources and transfer from surfaces. However, evidence on the effect of different exposure determinants and their relation to the different routes of dermal exposure is still incomplete (Marquart et al., 2003; Gorman Ng et al., 2012b) and will require additional expert opinion.

Dermal model development will also benefit from existing inhalation model methodologies, since the inhalation exposure processes account for at least one route (i.e. deposition) of dermal exposure. The Advanced REACH Tool (ART) (Tielemans et al. 2008; Fransman et al. 2011) is a source-receptor model similar to the model of Schneider - that may be considered as a suitable candidate to be extended to estimate dermal exposure. Briefly, the ART mechanistic model is based on a source receptor approach (Tielemans et al., 2008; Cherrie and Schneider 1999) by applying a two-compartment model (near-field and far-field) and nine independent principal modifying factors (MFs) (e.g. localized control) and their underlying determinants (e.g. fume cupboards). The model applies structured groups of occupational activities or ‘activity classes’ (Marquart et al., 2011), and includes three exposure types (vapours, mists and dusts). While the mechanistic model assigns multipliers that reflects the approximated exposure estimate, the model output is dimensionless and provides a relative score for a given exposure scenario. By calibrating the model with corresponding measurement data, a geometric mean (GM) exposure is predicted (Schinkel et al., 2011).

In order to derive maximum benefit from the already existing ART mechanistic model structure, a dermal exposure model was developed that, in the future, can be implemented as an extension of the ART model and the existing ART software platform.
This document provides information of the characterization of dermal exposure determinants in the context of a dermal ART (dART) model.



Overview of the conceptual model, compartments and rate constants. E=emission (——); Dp=deposition (——); L=resuspension or evaporation (—.—.—); T=transfer (- - -); R=removal (-·-·-); Rd=redistribution (·······); D=decontamination (-·-·-·-); P=penetration and permeation (——).

A conceptual model for dermal exposure, compartments and rate constants (Schneider et al., 1999)

2 Aim and scope

The main aim of this project is to develop a higher tier dermal exposure assessment tool for (regulatory) risk assessment based on a comprehensive mechanistic model calibrated with empirical exposure data. In the future, the models can be integrated into the ART software tool to enable an aggregate assessment of both inhalation and dermal exposure. This report will focus on the identification and quantification of dermal exposure determinants that underlie the principal modifying factors (MF) in the mechanistic model.

The current scope of the dART model is limited to hand exposure (820 cm^2 both hands) to low volatile liquids and solid-in-liquid formulations (≤10Pa) (but its applicability domain can be extended in the future). Low-volatile liquid products include powders dissolved in a (non-volatile) liquid matrix, or so-called solids-in-liquid products. The handling of surfaces contaminated with dried powder residues that originate from the application of solid-in-liquid products - and handled extended periods after application, is outside the scope of this model.

3 Characterization of principle modifying factors (MFs) and underlying determinants

ARTs activity classes (ACs) (Marquart et al., 2011) were evaluated to obtain insight in relevant dermal exposure processes. Each AC was profiled and assigned with relevant dermal routes, types of surfaces, forms of direct emission & contact and other distinctive characteristics (Table A). Three processes involved in mass transport associated with (potential) dermal exposure identified by Schneider et al (1999) are applied in the main algorithm of the mechanistic model, i.e. (1) deposition, (2) direct emission & contact and (3) transfer.

Deposition refers to the transport of liquid in the form of mist or spray aerosol from the air to a worker's hands or gloves. Aerosol physics explain numerous mechanisms of deposition and droplet motion in the air, amongst others the settling velocity (Stoke's friction law) and turbulent diffusion (Fick's law) (Hinds, 1999). Aerosol dispersion is incorporated in ART and considers indoor and outdoor locations, various room sizes, air exchange rates and different monodisperse aerosols (ranging from 0.3 to ˜100 µm) (Cherrie et al., 2011). The effect of settling velocities on different aerosol sizes are therefore considered in the ART dispersion component, although it is limited to a droplet size-integrated estimate. The dART model being a generic model, it is acknowledged that the determinants that affect deposition are only addressed insofar as they affect inhalation exposure as described by van Tongeren et. al. (2011) and Cherrie et. al. (2011).
Direct emission & contact concerns the transport of product onto a worker from sources in the NF of the worker. For hand exposure, the model distinguishes between two basic forms: (1) bulk product such as splashes and spilling, and large droplets (>100 μm) from overspray, reflected spray / backbouncing (not to confuse with smaller aerosols as described in the Deposition section), and (2) hand immersion. For this purpose, the direct emission includes the non-inhalable fraction of aerosols with high aerodynamic diameters (~ >100 µm aerodynamic diameter) where sedimentation is rapid and the trajectory of large droplets are mostly unaffected by general air movement. Because direct contact (hand immersion) is an event-based occurrence with different mechanisms of exposure compared to direct emission & contact, the model explicitly distinguishes between hand immersion activities (during open surface (AC2) and spreading (AC4) activities) and activities without hand-immersion (remainder of ACs).
Transfer describes the transport of a substance through contact between a contaminated surface and the skin (Schneider et al., 1999). Workplace scenarios generally involve a renewed surface loading of a product onto numerous surfaces in the workplace.

For each activity (sub)class and principle modifying factor (MF) proposed for the dART model (Table 1), underlying determinants were identified and reviewed (see Figure below). The model structure and characterization of MFs was proposed by using an informal process of consensus between eight experts (in addition to two external experts) who participated in the consortium (HSL, TNO, TNO Triskelion, BAuA), in a similar fashion as described by Fransman et al. (2011). The overall model development adopted a process whereby the mechanistic model was refined during various iterations (McNally et al., 2018).

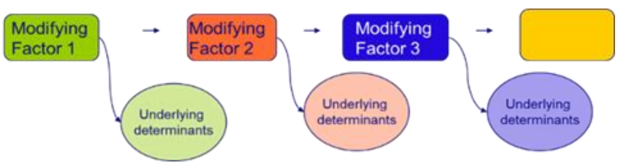


Figure: Structured approach applied for identifying modifying factors (MF) and their underlying determinants

A comprehensive review was conducted of peer-reviewed literature and other sources (e.g. unpublished internal and external reports). A distinction was made between (1) literature reviews and other relevant sources on dermal exposure determinants and modeling, (2) field studies and controlled workplace studies, and (3) experimental studies.
Literature reviews provided valuable information on the relevance of a broad scope of dermal exposure determinants (e.g. Marquart et al., 2003; EPA, 2011). In terms of field studies, and to avoid as much ambiguity as possible, several requirements are made of data included in the review. Firstly, only hand-specific data is used of low volatile liquids. For general trends, other body parts may be included in an evaluation, although this will be stated clearly. Secondly, data that aggregate different activity classes are not used. This is done to avoid the inherent uncertainty in estimating the contribution of each activity class to the reported exposure. Where sufficient contextual information was available, the data was coded according to known determinants of dermal exposure (to the product) and subsequently converted to the same metrics and corrected for the weight fraction (to a comparable total product application value in µg/min/cm²). This correction is done based on the assumption that the fraction of a substance in a formulation is linearly related to the concentration of the substance present in the liquid during use or application. Also, determinants are expressed as a rate for the specific product of interest, in order to incorporate time in their effect. In the interest of elucidating exposure weights, determinants are evaluated on three levels of specificity: single studies that varied one determinant (e.g. the same study testing different use rates), multiple studies with comparable design (e.g. direction of application among all tractor-mounted boom sprayers), and multiple studies with a different design (e.g. comparison between tractor-mounted boom sprayers and hand-held spraying equipment).

The resulting AC-specific datasets (Tables B1-B5 in Appendix), in addition to other relevant evidence on dermal exposure determinants in the published literature, were used to propose relevant underlying determinants to underpin each modifying factor (MF) of the respective ACs (Appendix). For example, experimental studies were also evaluated to obtain specific evidence on dermal determinants, in particular associated with specific dermal routes of exposure (e.g. Gorman NG et al., 2013; Gorman Ng et al., 2012b). Subsequently, determinants were parameterized and assigned with categories and their respective multipliers as summarized in Tables 4 and 5 (for each exposure route). The assigned multipliers are numeric values that represent typical values (median) of the expected distribution associated with a given exposure determinant. In some instances, suitable data could not be found for review in either field studies (Tables B1-B5) or experimental studies, while in other cases data was inadequate to extract conclusive evidence to underpin determinants. When this occurred, the findings were discussed amongst the consortia expert team to establish whether the determinant is included or excluded. If included, a suitable categorization and assignment of a relative effect value was proposed, often based on an extrapolation of evidence of the same determinant but with data relevant for a different AC.
In the Appendix, each principle modifying factor (MF) and their underlying determinants are described in more detail for each activity (sub) class.

A calibration of the dART model was performed that involved the conversion of dimensionless scores estimated in the dART mechanistic model to an exposure estimate, using hand exposure data. The overall dimensionless score calculated for exposure scenarios using the mechanistic model do not share the same length scale. To address this, a statistical calibration model was applied to scale and weight the three routes of exposure (deposition, direct emission & contact, transfer) using corresponding dermal exposure measurements (McNally et al., 2018). Various aspects associated with dermal exposure, such as removal processes, different sampling methodologies (e.g. cotton gloves, hand washing) and the use of protective gloves, were evaluated in the subsets of measurement data. The analysis of random effects in the model calibration provides some justification for the assumptions made in assigning the MFs and their underlying determinants.

3.1 Substance-related determinants

Weight fraction
Dermal exposure is generally assumed to correlate linearly with the weight fraction or percentage of a substance in a product (CEB, 2000), which corresponds with general findings in field studies, e.g. biocide spraying studies (Preller & Schipper, 1999).

Viscosity
For low volatile liquids, viscosity affects various dermal exposure processes along different routes of exposure. In addition to two viscosity categories defined in ART (like water, like oil), a high viscosity category is also included for dermal exposure relevant via other processes such as removal from surfaces and skin. Hence the proposal to also include highly viscous products (e.g. like honey, heavy oil, or ˜>1000 centipoise (cP)). In order to align the dART model with ART, and in the absence of evidence, we assume a typical situation where deposition, transfer and direct emission & contact from high viscosity products are set as equal to medium viscosity products (Table 4).

It is generally found that a highly viscous product results in a lower dermal exposure rate on the hands compared with low viscous liquids (Hughson et al., 2004; Gijsbers et al., 2004; Roff et al., 1997). The effect of viscosity is addressed as follows:

(i) Formation and transfer through direct emission & contact (E_e)

Little conclusive evidence is available to substantiate the effect of viscosity on the formation of different forms of direct emission (e.g. large droplets, splashes, spatter). Roff et al. (1997) observed that spirit-based liquids spatter and travel further through the air during brushing activities than water-based liquids, probably because spirit-based liquids tend to be flicked from a brush more easily as a spray than water – which remains in larger globules of foam. This effect resulted in a 3.7 higher dermal exposure when using spirit-based liquids. Similarly, for low volatile liquids, water-like products are expected to result in an increased formation of direct emissions compared with viscous (oil- or honey like) liquids, assigned with a factor 1 and 0.3 respectively.

(ii) Transfer from surfaces (E_t)

An experimental study by Gorman Ng et al. (2013) did not find any effects of viscosity on exposure by the transfer route, while increasing viscosity lead to lower exposures through the deposition route. Overall, the dART model assumes that viscosity has no significant effect on the transfer efficiency from surfaces to the hands. However, considering the effect of viscosity on the surface retention over time, it is assumed that an increased viscosity will have a slight overall increase in surface retention (reduced surface removal) and subsequent hand exposure through the transfer route.

(iii) Removal of a product from the skin or gloves

Viscosity can affect the removal of a product from the skin or gloves once a product reached the hands. Various experimental studies found that increasing viscosity (and stickiness) resulted in significant higher dermal exposure (Gorman NG et al., 2012; Cinalli et al., 1992). Assuming that hand immersion studies are indicative of the retention of substances on the skin (i.e. after skin loading via different routes), water-like substances has shown to result in a reduced film thickness on the hands (4.99^{-3} cm) compared to a range of different viscous oily substances (˜8.7^{-3} cm), suggesting a factor of ˜0.5 difference (EPA, 2011). This effect can be more significant, as indicated by the immersion studies by Gorman NG et al (2012) where a factor 0.11 difference was found for dermal loading of the index finger when immersed into respectively 20% and 87% glycerol solutions (2730 ug/cm^2 and 23760 µg/cm^2). Note that this effect of viscosity on skin retention is not included in the mechanistic model (except for hand immersions) but addressed simultaneously with the calibration with exposure data.

Availability
'Availability' gives an indication of the undried or unfixed amount of product available for direct emission & contact and transfer from contaminated objects. It is determined by, among others, the drying or hardening properties of a product. For most activities, it is assumed that a product will always be available due to an almost continuous renewed availability, e.g. continuous or repeated application of a product. Handling of contaminated objects (AC3) is an exception where a substantial period of time may pass (e.g. in drying rooms) prior to handling. Although evidence is limited, studies in auto body repair shops has indicated that skin exposure to isocyanates is common during tasks involving recently applied dried paints, such as wet sanding or compounding (Bello et al., 2007b; de Vries et al., 2012). These results suggest that substances in a product (such as free isocyanate species) can be present on dried but not fully cured surfaces.

Dilution
The handling of contaminated objects (AC3) often includes the removal of product using diluent (e.g. water, solvent) or materials (e.g. cloth, paper) to clean contaminated equipment. In the absence of data, dilution is introduced as a determinant to account for a reduced hand exposure, assuming that for example running water or solvent will result in product in a diluted form. Although no specific evidence is available for the dilution effect, its relevance is evident in practice (e.g. cleaning of tools, Delgado et al., 2004).

3.2 Control measures

Localized and dispersion controls were evaluated by considering the existing control measures proposed in ART which was derived from an Exposure Control Efficacy Library (ECEL) and an expert elicitation process (Fransman et al., 2008). All ART determinants related to the control of air emission (localized controls) and dispersion (e.g. downflow systems, worker enclosures) are adopted from ART for the deposition route (see Fransman et al., 2011).

Containment
ARTs containment categories are applied to incorporate the effect of containment on the deposition route, with multipliers between 0.1 and 0.001. To extend containment types for dermal exposure, fixed or mobile screens or protective guards on hand tools (without glove ports) between source and hands are included. This new addition in the list of controls may not reduce air emissions (and not defined in ART), but is expected to considerably reduce direct emissions. In contrast, where screens or enclosures are fitted with glove bags or glove ports - it is assumed reasonable that exposure from any direct emissions are completely eliminated (factor 0) for all activity classes.

Local exhaust ventilations (LEV) systems

The effect of LEV on air emission is addressed in ART (Fransman et al., 2011) and adopted for the deposition route (multipliers ranging from 0.5 to 0.01). These multipliers are based on studies focusing on control efficiency of LEV on inhalation exposure (Fransman et al., 2008).
Very little data is available on the effect of LEV on hand exposure during the application of low volatile liquids. Local exhaust ventilations (LEV) systems are generally not designed to capture direct emissions. An exception is spraying activities (AC1) associated with larger droplets from overspray, which is addressed separately. For example, capture velocities of LEV can be effective enough to extract (or displace) course droplets, and it is assumed that receiving- and fixed LEV systems can extract course droplets away from the hands (0.3) – although less effective compared to fine aerosols. Movable hoods and other LEV systems are expected to reduce direct emissions less effectively (0.7). Canopy hoods, fume cupboards and laminar flow booths may require the worker to use their hands between the source and the extraction hood – and are therefore assumed to be ineffective to mitigate hand exposure (factor 1).

Other controls
A vast number of controls such as administrative controls can be applied to reduce dermal exposures. Where appropriate, these controls are included as determinants in the model (e.g. curing/drying time before commencing with work). Other determinants such as specialized surface cleaning methods (such as vacuuming prior to handling) are not specifically addressed and it is advised that the relevant ‘surface contamination level’ (at the time of handling) is applied in such cases. In cases where automated processes are introduced in the workplace (which will imply a new activity and exposure scenario), the dART model requires the assessment of the new activity.
Hand protection such as gloves is not applied in the mechanistic model, but included in the exposure estimates where a model user can apply their own preferred (regulatory) glove protection values. A brief review is provided in the Appendix (section 18).

3.3 Activity-specific determinants

Level of automation
The level of automation is defined as the degree of manual or automated work and the approximate distance between the worker and the emission source or contaminated surfaces. The model therefore considers the relevance of hand immersion, direct handling of objects, short or long hand tools, use of additional accessories and the use of control panels. This parameter provides information on the probability of direct emission & contacts in the NF.

Available field studies generally provide limited contextual information on the actual method or technique applied, e.g. the tools and equipment used. For surface spraying (AC1.1), the effect of tool length on hand exposure is often contradictive, but generally a 2 to 3 fold lower hand and body exposure is found when using lances compared to spray pistols (Machado Neto et al., 1997; Nuyttens et al. 2009). As for spreading applications (AC4), short tools also appear to result in higher exposure rates than long tools. In a lacquer spreading study (KRIOH 2002), short tools show a markedly higher exposure rate than long tools (3.24 vs 0.24 µg/min/cm² respectively). However, this relationship is not always supported (Gijsbers et al., 2004; Erikksson et al., 2004), which could be explained by excessive spattering during rolling activities using extended handles and the fact that longer tools are often used in an upward direction.

Also during dipping operations (AC2.1), the proximity of the worker to the source (baths and objects) indicates gradual decrease in hand exposure when data is

grouped in far (0.19 µg/min/cm²), medium (1.29 µg/min/cm²), and close distances (2.61 µg/min/cm²) (HSL FS/PR/01/98).
In general, it is reasonable to assume that direct emissions (e.g. spatter, splashes) will be reduced when using long or extended tool handles or control panels in the NF. For transfer, a reasonable assumption is that the frequency of hand contacts will be less with smaller single-grip tools without accessories (AC1.1), or when handling tools instead of handling an object directly (AC2.1). For automated activities, the frequency of contacts with remote control panels and devices is best determined by a specification of frequency of use (e.g. categorizations such as infrequent or repeated use).
The type of equipment used is often closely related to the scale of an activity and may affect the level of automation. This is of particular importance during transfer activities, in particular top-loading (AC6.2). Gilbert et al (1999) compared the pouring of 10 L and 2L of product, both from a 10 L container, and found that the full container caused the worker much more trouble, reflected in an exposure rate difference of 16.4 vs 0.5 µg/min/cm². A study by Glass et al. (2009) tested three different containers: 5L, 10L and 20L. While the former two resulted in comparable dermal exposure (1.4 and 1.8 µg/min/cm²), the 20L container showed an increased exposure rate (7.6 µg/min/cm²). In the same study, the smallest containers (1 litre) resulted in hand contamination of <0.01 ml in 100% of the cases, while for the largest container (10 litre) only 72% of the hand contaminations were <0.01 ml. However, using many small containers does not per definition result in less hand exposure than using a single large container. Although based on experimental (controlled workplace) data, it appears appropriate to assume that a correlation exists between container size (and use of single or multiple containers) and dermal exposure via hand contacts during top-loading.

Hand immersion and maximum retention capacity
Hand immersion is relevant for activities with open liquid surfaces and open reservoirs (AC2) and spreading (AC4). Besides significantly higher hand exposure rates that have been reported during sponge cleaning operations (Hughson et al., 2004; TNO 2003) compared with non-hand immersion applications, hand immersion involves a different process where loading of the product on the hands is abrupt and immediate. Though less representative in practice, experimental studies indicated that during non-hand immersions (performed by rubbing of cloth saturated with liquid over the front and back of hands), hand exposure was roughly a factor of 0.5, 0.1 and 0.3 less compared to hand immersions in respectively water, mineral oil and a combination of water and oily products (EPA, 2011). An approximate 3 fold increase in skin loading (ranging from 2 to 10 fold considering products ranging from water-like to oily) can therefore be expected during immersion of the hands compared to non-immersion skin contact associated with a relatively high skin loading (e.g. 1 mg/cm^2, or 1.15^{-3} film thickness).

In order to estimate dermal exposure during the immersion of hands in a product, the dART model assumes that the maximum loading of the product on the hands is instantly reached. For this purpose, the mechanistic model applies a hand immersion factor that provides an indicative / relative multiplier for instant maximum loading on the hands (see Appendix, section 2.2.1). While the factor proposed for hand immersion is merely an indicative (and relative score) for instant maximum loading on the hands in the mechanistic model, the effect of hand immersion during an activity (as a function of time) was further evaluated considering hand immersion activities during the model calibration (McNally et al., 2018). For example, for the scenario 'car washing', complete saturation of the hands (hand immersion) was assumed, with measurements treated as right censored in the calibration (i.e. where the true exposure was greater than that measured). Therefore the calibration provides an exposure model resulting in a linear relation between relative scores and dermal loading on the hands. In theory this could result in unrealistic high dermal exposure estimates – which is corrected for by using a maximum retention capacity (Table 6).

A maximum retention capacity is proposed that takes account of the maximum amount (cut-off value) of product mass loading on the hands. Studies indicate a retention of ˜5 mg/cm^2 for water, ˜6 mg/cm^2 for light oils and ˜10 mg/cm^2 for mineral oil, considering the estimated film thickness and density of the product. To our knowledge, no maximum retention capacity values are available from experimental studies for more viscous products. Unpublished data from HSL indicate a retention of approximately 4 ml of water-like substances on both hands, and this value will be applied for low volatile liquids (irrespective of viscosity & density) until more evidence becomes available.

Scale of activity

For surface spraying (AC1.1), most studies reviewed did not find a significant relationship between use rate and hand exposure (Llewellyn et al., 1996; de Cock et al. 2002; Bjugstad et al. 1996). An exception is a lance spraying experiment (Wicke et al., 1999) that found that a doubled use rate corresponds with an exposure of 1.5 times higher when using injector nozzles, but this finding was not consistent for all nozzle types. During foam spraying, a use rate of 5.5 L/min and 1.5 L/min corresponded with a decrease in exposure rate by a factor of 2.7 (TNO, 2003). It is possible that a correlation between use rate and hand exposure is obfuscated by other variables, such as the type of spraying equipment or orientation.

The effect of scale on hand exposure during spreading activities (AC4) seems more pronounced than in spraying. For example, high and low scale applications (22.6 m²/h and 7.8 m²/h) are associated with corresponding hand exposure rates of 60.6 µg/min/cm² and 4.2 µg/min/cm² respectively (Garrod et al., 2000; Gijsbers et al., 2004). Similarly, data on top loading activities (AC6.2) show that increasing use rates (<10 L/min, 10-100 L/min and >100 L/min) are correlated with increasing exposure rates (5.44, 12.12 and 22.70 µg/min/cm² respectively) (Gijsbers et al., 2004).

Similar to ART, open surface areas are considered indicative of the scale of activities related to open liquid surfaces and open reservoirs (AC2). Overall, the largest scale categories of different ACs (use rate, open surface area, contaminated surface area; scale of application) are allocated with an increased potential for direct emissions (splashes, spattering, dripping and run-off onto the hands). These multipliers are modest in effect considering the combined contribution of other routes such as deposition.

Direction of application and orientation of work

Upward hand-held spraying shows a marked increase in whole body exposure (Llewellyn et al. 1996; Berger-Preiß et al. 2005; Koch et al., 2012), and for example a twofold increase in dermal exposure for wall spraying versus floor spraying of biocides and up to 125 times increased exposure during overhead airless spraying of antifouling products (Koch et al., 2012).

Considering hand exposure, hand-held spraying on low crop (broccoli) and high crop (maize) showed exposure rates of 86 and 319 µg/min/cm², a factor 3.7 difference (Hughes et al. 2008). Comparing tractor-mounted boom spraying operations on high versus low crop, hand exposure rates in open and closed cabins showed 3 fold and 7 fold differences respectively (Vercruysse, 2000). Aggregated data for hand-held spraying pistols, lances, and knapsack sprayers revealed relative factors of 1: 1.3: 20 for downward, level and all/upward direction categories respectively. It was concluded that no distinction can be made between downward and level spraying directions. By omitting extreme outliers from the dataset and considering the ART multipliers adopted for the deposition route, a modest effect of upward (all direction) spraying is allocated for hand exposure (factor 3) through direct emissions such as large droplets from overspray and dripping. A new category is proposed named ‘exclusively overhead work’ (not in ART) that is assigned with a factor of 10 in direct emissions.

For spreading activities, brushing and rolling applications beneath a boat show an above average hand exposure rate of 60.6 µg/min/cm² (Garrod et al., 2000) compared to brushing performed in a level orientation (Gijsbers et al., 2004; Roff

1997). Using sponges in level orientations has also been found to result in somewhat higher exposure rates (2790 µg/min/cm²) compared to downward applications (2073 µg/min/cm²) (Hughson et al., 2004). In all instances, however, a comparison is difficult because of various contributing factors such as tool length and product viscosity.
During dipping activities, a slight increase in (protected) hand exposure has been reported for level work (i.e. with a dipping bath positioned at workbench height) compared to downward orientations (Mäkinen et al., 2004; Roff et al., 2004). However, inconclusive evidence is available to merit a difference in hand exposure for downward and level oriented work. In terms of more automated processes, dipping activities may be performed with overhead lifting devices above shoulder height and is included in the model as well.

Other specific determinants
Various specific determinants are included in the respective ACs, e.g. spray technique, surface shape, tool speed and rotation, agitation level, restricted workspaces, product type and donor surface type. In terms of spray technique, high-volume low pressure (HVLP) are associated with a high transfer efficiency onto surfaces of about 65%, whereas conventional air atomized spray painting guns are far less efficient (25-35%). The overspray concentration per unit of film thickness on the surface was found to be a factor 2 significantly higher for gravity-feed conventional (pneumatic) spray guns compared to HVLP spraying operations (Heitbrink et al., 1994). These studies do not only indicate reduced aerosol concentrations during use of low pressure spray techniques such as HVLP guns, but they also suggest a reduced overspray of large droplets little affected by air movement. Although some high pressure techniques such as airless spraying can achieve a relatively high transfer efficiency (and less overspray), the effect of potential back-bouncing from surfaces could also be a contributing factor for increased direct emissions onto the hands.
Thermal fogging techniques has shown to result in lower potential dermal (body) exposures compared to other techniques (Koch et al., 2012), which suggests that the deposition route dominates (with a very high respirable fraction) and with little or no contribution of the direct emission & contact route (AC1.2).
For surface shape, an existing spray model (Brouwer et al., 2001) takes account of small, absorbent or open-structured objects which may increase deposition of the paint spray onto the object and surrounding surfaces and therefore decrease overspray compared to standard, flat objects. Van Drooge et al (2001) also distinguish between large enclosed, reflective objects (3), multiple, dense or small structured objects (1) and open-structured objects (0.3) and found that object shape, besides spraying rate and ventilation, had a significant effect on dermal exposure for a range of spraying techniques using linear regression models. To some extent, the surface size and shape will be related to the spraying technique being used. Other field studies, however, are inconclusive on the effect of surface shape, with comparability of studies hindered by the broad scope of spraying techniques and products used.

An increased effect value is assigned for high speed or rotational spreading tools suggesting that spattering and dripping of product will increase, compared with non-rotational or low-speed tools. Considering rolling and brushing activities, the available data do often indicate an elevated hand exposure for rolling activities, though not always convincingly (Garrod et al., 2000; Gijsbers et al., 2004; Eriksson et al., 2004). Activities with relatively undisturbed surfaces, e.g. dipping (AC2.1) and activities with agitated surfaces, e.g. mixing (AC2.2) may result in substantial differences in surface agitation level. Due to the overall lack of data and poor study comparability, the data does not provide insight into the effect sizes of this determinant. Based on expert opinion, it is assumed reasonable that a greater agitation corresponds with a greater frequency of splashing and spatter and potential hand exposure. Only moderate and high agitation levels are considered for AC2.2.

Surface contamination level and frequency of contacts
For the assessment of hand exposure through the transfer route, two key factors are addressed: (i) surface contamination level and (ii) frequency of contacts. Various determinants are applied to underpin these factors, such as experimental studies that indicate that an increasing surface loading is associated with an increased dermal exposure level (Brouwer et al., 1999; Cohen Hubal et al., 2005; Christopher, 2008), and experimental studies that indicate that an increasing contact frequency is associated with a near-linear increase in dermal exposure level – assuming an effective equilibrium (or saturation) on the hand after multiple contacts (Ivancic et al., 2004; Brouwer et al., 1999; Cohen Hubal et al., 2005). More detailed information can be found in sections 2.3.1 and 2.3.2 (Appendix).

The determinants 'restricted work spaces' and 'product type' are included in the model to consider the frequency of hand-to-surface contacts with surfaces. Spraying performed in cramped spaces such as mushroom scaffolds and greenhouses with narrow row spacing have shown higher exposure rates than more spacious work environments (Schipper et al., 1996; Machera et al, 2003). However, other field studies are less convincing. For example, hand-held lance spraying in cramped, middle-sized, and spacious rooms showed no convincing effect on exposure rates (de Cock et al., 2002), where the tool length may be a contributing factor.
The type of product used may determine the probability of contact between a worker and treated or coated surfaces. For example, when using a cleaning product, a worker may be less wary of hand-to-surface contacts compared to surfaces that are not supposed to be disturbed after application, such as paint. A reduced contact frequency is expected when working with coating products. When handling contaminated objects, workers may also be inclined to exclusively handle the clean surface area of objects - that are for the rest highly contaminated with coatings. Applications that spread paint, lacquer or ink show far lower exposure rates (~50 µg/min/cm²) (e.g. KRIOH, 2002) than cleaning workers (2000 µg/min/cm²) (e.g. Hughson et al., 2004), although data from cleaning workers are probably affected by hand immersions. Both restricted workspaces and product type are acknowledged as determinant – with only weak evidence of an effect on the frequency of contacts and hand exposure.
Surface texture refers to the type of surface from which a surface contaminant is transferred through hand-surface contacts. For example, smooth surfaces are associated with an increased surface-to-hand transfer efficiency compared with rough surfaces (Gorman Ng et al., 2013; Cohen Hubal 2004). This determinant is considered of particular importance for handling of contaminated objects (AC3).

Exposed surface area
The actual proportion of the skin surface area of specific body parts receiving exposure is relatively small and highly variable (Fenske et al., 1990), which can best be demonstrated with visualization data. It has been postulated that dermal exposure that originates from immersion or deposition will represent a more uniform exposure distribution on a body part than exposure originating from splashes and surface contact (Vermeulen et al., 2002).
In the dART model, the exposed surface area (ESA) describes the proportion of a specific body part (e.g. hands) that potentially receives exposure (whether protected or unprotected), typically demonstrated with visualization data (Cherrie et al., 2000; Brouwer et al., 1999). With visualization data often indicating highly variable exposures on skin surface areas of specific body parts for different workplace activities, it was decided to apply a crude and indicative categorization to assess the (potentially) exposed surface area for each exposure route (ESA_{dp}, ESA_e, ESA_t), i.e. where both hands are assigned with a factor 1 (fraction of 100%), both hand palms or fingers of both hands with a fraction of 50% (factor 0.5), and one hand palm or fingers of one hand (25%; factor 0.25). These generic categories were applied based on descriptive information of the type of equipment used or work performed to assess the exposed surface area of each AC (Table 5).

4 Discussion & conclusion

The dART model presents a higher tier mechanistic dermal model (dART) and an extension of the existing ART inhalation model that could (in the future) be integrated into the existing ART software platform. The model and approach described in this report focuses on low-volatile liquid (mist) exposure to the hands. The dART model is based on (i) a source-receptor dermal model, (ii) a structured taxonomy of workplace activities (activity classes) adopted from ART, and (iii) principal modifying factors (MFs) underpinned by empirical evidence and expert judgement. The mechanistic model calculates a relative score for the dermal exposure of a scenario, which is fitted to dermal exposure measurements to translate scores to quantitative exposure estimates (McNally et al.2018).

Development of a (potential) dermal exposure model is a challenge because of the complexity of dermal exposure processes and the lack of standardized methods to measure dermal exposure (Schneider et al, 2000). Contrary to inhalation models and similar to other dermal models (e.g. DREAM), the dART model is a relatively complex model when considering the separate assessment of three transport processes and considering six different activity classes. However, this complexity is partially resolved by the effective use of existing inhalation exposure determinants in ART (those that are relevant for dermal exposure) that are integrated in the dermal model. From a tool user perspective, the ART user inputs are merely extended with a limited number of additional dermal-specific determinants per AC.
Nevertheless, the translation of the dART model into everyday workplace scenarios under REACH could still remain a challenge since the model is prescriptive in character and it will require the implementation of dermal-specific model determinants. Although the implementation of the dART model in software will merely involve an extension of the ART model that is already used for risk assessment purposes, a detailed workflow with examples, like that developed for the ART mechanistic model prior to software development, will be required.

Statistical analysis of dermal data shows that potential dermal exposure has a large temporal component, with a day-to-day variance that suggests that dermal exposure is event-based in most occupational settings (Kromhout & Vermeulen, 2001; Schneider et al., 2000) - though it is not more pronounced than for inhalation exposure. Nevertheless, dermal exposure is assumed to be highly influenced by event-based occurrences such as the probability of touching contaminated surfaces or spatter that is projected onto the skin. Such events often happen by chance and may be dependent on worker behaviour, which can only be assessed using observational methods like DREAM. These event-based exposures are to some degree addressed in the dART model by considering the level of automation (e.g. type of tools/equipment) used for a group of activities, without observation being required from a model user (like in DREAM).

Similar to ART, the effect of worker behaviour on personal exposure is not specifically accounted for. Worker behaviour is assumed to be part of the variability within and between workers in a company (Tielemans et al., 2008). However, variability in dermal exposure is, to some extent, accounted for in the calibration through statistical parameters in the calibration model (specifically log-normal variability is assumed) and by using a variance components analysis as input for exposure estimates (McNally et al., 20187). However, a common issue when using dermal exposure data, in this case for calibration purposes, is the limitations of the data itself in terms of the number of high quality studies available and the contextual information reported. Similar issues were encountered during the characterization of modifying factors of exposure as was the case for ART, and these should be addressed in future research. For example, the majority of field studies concern manual activities such as spraying and spreading, with much less data on (semi-) automated processes for low volatile liquid applications. In that respect, little has changed since the early 2000s with regard to evidence on the independent effects of potentially important dermal determinants (Marquart et al., 2003). An exception of note is experimental studies - for example recent studies on transfer efficiencies (Gorman NG, et al., 2012a).

A specific limitation of assigning multipliers for dermal determinants is the multiple routes of exposure. This was found to be particularly challenging in the case of activities where no specific route of dermal exposure is evident, making it difficult to assign an effect value based on evidence from 'total' dermal exposure data from field studies. In the RISKOFDERM project, occupational activities were clustered in Dermal Exposure Operation units (DEO units), which also involved the identification of the relative contribution of each exposure pathway to total dermal exposure (Marquart et al., 2006; Warren et al., 2003, Kromhout et al., 2004). The direct emission & contact route was observed to contribute to more than 40% of the total dermal exposure during manual dispersion of products and during hand immersions. The deposition route dominated the dermal exposure during spray dispersion activities and the transfer route was the major contributor during handling of contaminated surfaces and dispersion of products with hand-held tools. However, evidence suggests a higher weighting for the direct emission & contact (hand immersion) pathways (Gorman Ng et al, 2013), while the weighting of surface contacts should not be underestimated in relation to deposition (Pronk et al, 2006; Links et al, 2007).
In the dART model, the latter findings were considered during the mechanistic model development taking into account the minimum and maximum factor obtained for each exposure route and for each AC. Instead of using a weighting factor to address the relevance of the three routes of exposure in the mechanistic model, the statistical calibration model was applied to scale and weight the three routes of exposure (per scenario) of corresponding dermal exposure measurements (McNally et al., 2018). This approach ensures that the relevance of exposure routes are dependent on specific exposure scenarios (and their corresponding data) as illustrated in the worked example.

As the removal from the hands or gloves is closely related with dermal sampling techniques, this variable was not included in the mechanistic model but evaluated in the calibration with measurement data. It is well known that factors such as viscosity and stickiness may affect retention and removal from the skin, with an increasing viscosity associated with a significantly higher dermal exposure (Gorman NG et al., 2012; Cinalli et al., 1992). In addition, a pronounced increase in retention during hand immersion was found with increased viscosity levels when both wipe samples and cotton glove samplers were used to sample glycerol solution, with much higher mass retention for cotton gloves (Gorman et al., 2014; Gorman et al, 2013). The dART model is calibrated with dermal exposure data using different sampling techniques, hence the effect of factors such as viscosity on these sampling techniques should also be considered. However, a correction to this effect proved to be problematic because almost all scenarios of the data used for calibration applied high absorbency cotton sampling gloves (McNally et al., 2018). Overall, evidence is still inconclusive on the relationship between viscosity, the activity or way it is brought onto the skin (apart from hand immersions) and considering different sampling methods.

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6 Signature

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7 Figures / tables

Figure 1 Simplified diagram of dermal exposure with key components of the dART model

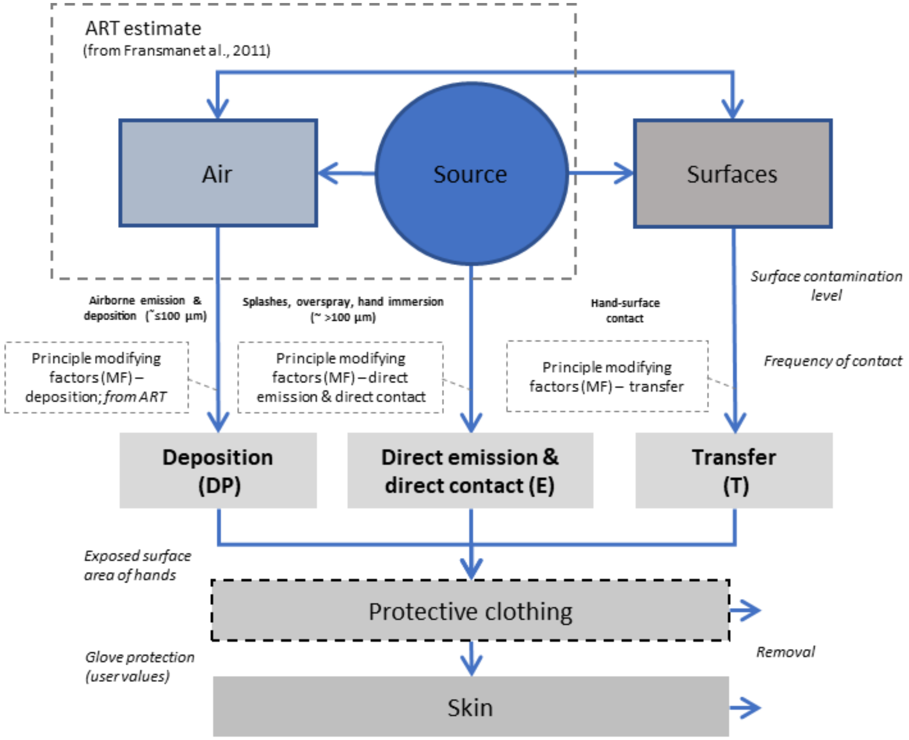

Table 1 Description of modifying factors (MF) proposed for the dART model

Mass transport processes	**Modifying Factor (MF)**	**Description**	**Parameterization**
Deposition (DP_{hands})	All MFs from ART	The estimated air concentration (from ART) of the product is assumed to be correlated with dermal exposure via deposition	Fransman et al (2011)
	Exposed surface area of body part during deposition (ESA_{dp})	The potential fraction of surface area of a specified body part (hands in this model) that is affected by deposition	dART assumes both hands (ESA_{dp}=1)
Direct emission & contact (E_{hands})	Substance direct emission & contact potential (E_e)	Considers product properties that affect the direct emission potential of a product, e.g. viscosity or hardening properties	Table 4
	Localised controls (LC_e)	Control measures in close proximity of the source intended to prevent direct emission (e.g. splashes) to reach the worker	Table 4
	Activity direct emission & contact potential (H_e)	Describes the potential of the activity to result in (i) direct contact with the source (e.g. immersion of hands in product), or (ii) to generate direct emission like splashes or large droplets onto the skin	Table 5
	Exposed surface area of body part during direct emission & contact (ESA_{de})	Indicates the potential fraction of surface area of a specified body part that is affected by direct emission & contact, e.g. back of hands	Table 5
Transfer (T_{hands})	Substance transfer potential (E_t)	Describes the product properties that affect transfer of product from surfaces	Table 4
	Activity transfer potential (H_t)	Activity-related factors that determine the potential transfer of a product from surfaces to the hands. Surface contamination levels (Su) and frequency of surface contacts (F) are considered	Table 5
	Exposed surface area of body part during transfer (ESA_t)	Indicates the potential surface area of a specified body part that is affected by transfer, e.g. both hand palms	Table 5

Table 2 Description of surfaces and related surface contamination levels and frequency of contact

Activity class	**Surface**	**Surface examples**	**Surface contamination (Su)**	**Frequency of contact (F) (Table 5)**
Surface / space spraying (AC1.1 / AC1.2) Spreading of liquid products (AC4) High speed processes (AC5) Transfer, falling liquids (AC6.2)	Hand-held tools, hand-held equipment	Spray gun, lance, spray lines Brush, roller, cloth, sponge, tray Hand-held machinery, tools Container/s, hose, dispenser	Table 3a	• Tools & equipment categories
All ACs with (semi-) automated processes	Remote control panels & devices or control panels at source	Control panels, levers, buttons, control devices	Table 3a	• Adapted DREAM categories
Activities with relatively undisturbed surface (e.g. dipping) (AC2.1) Activities with agitated surfaces (AC2.2)	Immersed objects, tools & equipment	Mixing or dipping equipment, container/vessels	Table 3b	• Tools & equipment categories • Product type (coating vs treatment)
Handling contaminated objects (AC3)	Contaminated objects, incl. treated, coated, contaminated objects *(post application)*	Laminated surfaces, printed objects, painted objects (e.g. in drying room)	Table 3b	• Adapted DREAM categories • Product type (coating vs treatment)
Hand-held surface spraying (AC1.1) Hand-held spreading (AC4)	Treated / coated objects or surfaces *(during application)*	Painted objects, treated crop, disinfected surfaces	Table 3b	• Restricted workspace categories • Product type (coating vs treatment)
All ACs with (semi-) automated processes (except AC6.1)	Surfaces at source when using automated / robotized equipment *(e.g. contact during trouble-shooting)*	Spraying equipment & nozzles, mixing/dipping/filling/spreading equipment at automated processes	Table 3b	• Adapted DREAM categories
High speed processes (AC5)	Machined work pieces	Machined objects contaminated with e.g. metal working fluids	Table 3b	• Adapted DREAM categories
Transfer, falling liquids (AC6.2)	Receiving containers/vessels or accessories	Decanting containers or jugs, snouts, funnels	Table 3b	• Adapted DREAM categories

Table 3a Matrix to derive surface contamination levels (Su) by combining the deposition score (C_{ART}) with direct emission & contact score (E_{hands}*)

Deposition (C_{ART})→ **Direct emission & contact (E_{hands}*)↓**	**High** (>10^{-3})	**Moderate** (<10^{-3} - >10^{-6})	**Low** (<10^{-6})
High (>30)	1	0.3	0.1
Moderate (1 - 30)	0.1	0.01	0.003
Low (<1)	0.03	0.001	0.0001

* excluding ESA_e

Table 3b Matrix to derive surface contamination levels (Su) by combining the intensity of contamination and the proportional contamination

Intensity of contamination → **Proportional contamination ↓**	**High** (thick layer of product, e.g. coated surfaces, immersed objects)	**Moderate** (thin layer of product, e.g. considerable [visible] mist deposit)	**Low** (invisible layer of product, e.g. from limited mist deposit)
High Complete object or entire contacted surface is contaminated; >90% of surface area	1	0.1	0.01
Moderate Partially contaminated object or surface, or one side of object; 10-90 % of surface area	0.1	0.01	0.001
Low Small fraction of object or contacted surface is contaminated; <10% of surface area	0.01	0.001	0.0001

Table 4 Substance- and control-related determinants, categories and multipliers for the direct emission & contact and transfer routes*

Modifying Factor (MF) (from Table 1)	Determinant	Categories	Direct emission & contact		Transfer
Generic MF (equation 1)	Weight fraction (w_f)+		Exact weight fraction, or:		
	(from ART, Fransman et al., 2011)	Pure liquid (100%)	1		
		Main component (50 – 90 %)	0.7		
		Substantial (10 – 50 %)	0.3		
		Minor (5 – 10 %)	0.075		
		Small (1 – 5 %)	0.03		
		Very small (0.5 – 1 %)	0.0075		
		Extremely small (0.1 – 0.5 %)	0.003		
		Minute (0.01 – 0.1 %)	0.0006		
Substance direct emission potential (E_e) & Substance transfer potential (E_t)	Viscosity+ Ж	Low (like water)	1^		0.7
		Moderate (like oil)	0.3^		1
		High (like honey)∩ (ART=0.3)	0.3^		1
	Availabilityˡ (only AC3, coated objects)	The coating product is completely cured, dried or hardened	0.001		0.001
		The coating product is partially cured, dried or hardened	0.1		0.1
		The coating product is not cured, dried or hardened	1		1
	Dilution (only AC3, cleaning)	No dilution | not applicable	1		1
		Diluent used (water/solvent)	0.3		0.3
Localised control (LC_e)	Local exhaust ventilation, screens, glove boxes+		**AC1**	**AC2-AC6**	
		No localised control	1	1	-
		Screens or protective guard (without glove ports) ∩	0.1	0.1	-
		(ART=1)	0	0	-
		Low level containment	0	0	-
		Medium level containment	0	0	-
		High level containment	1	1	-
		LEV - receiving hoods: canopy hoods	0.3	1	-
		LEV - receiving hoods: other	0.3	1	-
		LEV - capturing hoods: fixed hoods	0.7	1	-
		LEV - capturing hoods: movable hoods	0.3	1	-
		LEV - capturing hoods: on tools	1	1	-
		LEV - enclosing hoods: fume cupboard (without	1	1	-
		glove box)	1	1	-
		LEV - enclosing hoods: laminar flow booth	0.7	1	-

Modifying Factor (MF) (from Table 1)	**Determinant**	**Categories**	**Direct emission & contact**		**Transfer**
		LEV - enclosing hoods: other hoods LEV – others Glove bags and glove boxes: glove bag (non-ventilated) Glove bags and glove boxes: glove bag (ventilated) Glove bags and glove boxes: low spec glove bag Glove bags and glove boxes: medium spec glove bag Glove bags and glove boxes: high spec glove bag	0 0 0 0 0	0 0 0 0 0	- - - - -

\- Not applicable
* ART inhalation exposure determinants applied for the deposition route not shown (see Fransman et al., 2011)
\+ This determinant is also an ART determinant
∩ This is an additional category and not included in the ART determinant *(see proposed ART factor in italics)*
Ж Viscosity is expressed here in terms of (i) its effect on the formation and transfer of large droplets from an emission source (e.g. from paint roller) to the worker (E_e), and (ii) potential transfer from surfaces due to retention on surfaces (E_t)
^ Excluding hand immersions (default E_e=1). Effect of viscosity on skin removal is considered in the calibration (see text)
ı Only relevant for handling of contaminated objects (AC3) and exclusively relevant for coating products

Table 5 Activity-related and Exposed Surface Area determinants, categories and multipliers for the direct emission & contact and transfer routes*

Modifying Factor (MF)	Determinant	Categories	Direct emission & contact[^]	Transfer
Spray application of liquids (AC1) - *Surface spraying (AC1.1)*				
Activity direct emission & contact potential (H_e)	Level of automation »hand-held tools/equipment	Short hand tool (<0.5m) Long hand tool or extended tools (≥ 0.5m)	1 0.1	- -
	Level of automation »control panels/devices at source	Repeated or almost constant use Infrequent or occasional use	0.1 0.01	- -
	Use rate[+]	High application rate (> 3 l/minute) Moderate application rate (0.3 - 3 l/minute) Low application rate (0.03 – 0.3 l/minute) Very low application rate (0.03 – 0.3 l/minute)	3 1 1 1	- - - -
	Spray pressure[+]	Spraying with high compressed air use Spraying with no or low compressed air use	3 1	- -
	Direction of application[+]	Exclusively overhead[∩] *(ART=3)* All directions incl. upward Horizontal and downwards Downward only	10 3 1 1	- - - -
	Surface shape	Large, reflective objects Multiple, dense or small structured surfaces Open-structured objects	3 1 0.3	- - -
Activity transfer potential (H_t)	Surface contamination level (Su)	Derive from Table 2 and Tables 3a/b	-	-
	Contact frequency (F) »hand-held tools/equipment	Short hand tool (<0.5m) excl. accessories Short hand tool (<0.5m) incl. accessories Long hand tool or extended tools (≥ 0.5m)	- - -	1 3 3
	Contact frequency (F) »(remote) control panels/devices	Repeated | almost constant use Infrequent | occasional use	- -	3 |10 0.1| 1
	Contact frequency (F) »product type	Spraying for treatment or other purposes Spraying for coating, e.g. paints	- -	3 1
	Contact frequency (F) »restricted workspaces	Restricted workspaces (contact coated/treated surfaces) Unrestricted workspaces	- -	3 0
	Contact frequency (F) »surfaces at source when using automated equipment *(during trouble-shooting)*	No contact Infrequent contact Occasional | repeated contact	- - -	0 0.1 1 | 3
Exposed surface area of body part (ESA_e | ESA_t)	Exposed surface area of hands[∂]	Short hand tool (<0.5m), excl. accessories Other hand-held tools or control panels at the source Remote control panels and devices	0.25 0.5 -	0.25 0.5 0.5

Modifying Factor (MF)	Determinant	Categories	Direct emission & contact[^]	Transfer
Spray application of liquids (AC1) - *Space spraying (AC1.2)*				
Activity direct emission & contact potential (H_e)	Level of automation »hand-held tools/equipment	Short hand tool (<0.5m) Long hand tool or extended tools (≥ 0.5m)	0.1 0.01	- -
	Level of automation »control panels/devices <u>at source</u>	Repeated or almost constant use Infrequent or occasional use	0.1 0.01	- -
	Scale[+]	High scale space spraying, e.g. fogging Low scale space spraying, e.g. fly spray	1 1	- -
	Direction of application	All directions incl. upward Horizontal and downwards Downward only	3 1 1	- - -
Activity transfer potential (H_t)	Surface contamination level (Su)	See Table 2 and Tables 3a/b	-	-
	Contact frequency (F) »hand-held tools/equipment	Short hand tool (<0.5m) excl. accessories Short hand tool (<0.5m) incl. accessories Long hand tool or extended tools (≥ 0.5m)	- - -	1 3 3
	Contact frequency (F) »(remote) control panels/devices	Repeated | almost constant use Infrequent | occasional use	- -	3 |10 0.1| 1
	Contact frequency (F) »surfaces <u>at source</u> when using automated equipment *(e.g. during trouble-shooting)*	No contact Infrequent contact Occasional | repeated contact	- - -	0 0.1 1 | 3
Exposed surface area of body part (ESA_e | ESA_t)	Exposed surface area of hands[∂]	Short hand tool (<0.5m) Other hand-held tools or control panels at the source Remote control panels and devices	0.25 0.5 -	0.25 0.5 0.5
Activities with open liquid surfaces and open reservoirs (AC2) - *Activities with relatively undisturbed surface (e.g. dipping) (AC2.1)*				
Activity direct emission & contact potential (H_e)	Level of automation »hand-held tools/equipment	Direct handling of immersed objects incl. hand immersion Direct handling of immersed objects excl. hand immersion Short hand tool (<0.5m) Long hand tool or extended tools (≥ 0.5m)	500[~] 1 0.3 0.1	- - - -
	Level of automation »control panels/devices <u>at source</u>	Repeated or almost constant use Infrequent or occasional use	0.1 0.01	- -
	Open surface areas[+ Ψ]	Open surface > 3 m^2 Open surface 1 - 3 m^2 Open surface 0.3 - 1 m^2 Open surface 0.1 – 0.3 m^2 Open surface < 0.1 m^2	10 10 3 1 1	- - - - -
	Agitation level [Ψ]	Low agitation – careful dipping, manual mixing Moderate agitation – rapid dipping	1 3	- -
	Orientation of work [Ψ]	All directions incl. upward (overhead lifting device)	3	-

Modifying Factor (MF)	Determinant	Categories	Direct emission & contact^	Transfer
		Horizontal and downwards Downward only	1 1	- -
Activity transfer potential (H_t)	Surface contamination level (Su)	Derive from Table 2 and Tables 3b	-	-
	Contact frequency (F) »hand-held tools/equipment	Direct handling of immersed objects Short hand tool (<0.5m) Long hand tool or extended tools (≥ 0.5m)	- - -	10 3 1
	Contact frequency (F) »(remote) control panels/devices	Repeated | almost constant use Infrequent | occasional use	- -	3 |10 0.1| 1
	Contact frequency (F) »product type	Dipping or mixing/agitation for treatment applications Dipping or mixing/agitation for coating purposes	- -	3 1
	Contact frequency (F) »surfaces <u>at source</u> when using automated equipment *(e.g. during trouble-shooting)*	No contact Infrequent contact Occasional | repeated contact	- - -	0 0.1 1 | 3
Exposed surface area of body part (ESA_e | ESA_t)	Exposed surface area of hands^∂	Immersion of both full hands Immersion of one full hand or fingers of both hands Immersion of fingers of one hand, or less Handling of small objects with fingers or one hand palm or less Handling larger objects OR control panels/devices <u>at source</u> Remote control panels and devices	1 0.5 0.25 0.25 0.5 -	0.5 0.5 0.25 0.25 0.5 0.5
Activities with open liquid surfaces and open reservoirs (AC2) - *Activities with agitated surfaces (AC2.2)*				
Activity direct emission & contact potential (H_e)	Level of automation »hand-held tools/equipment	Direct handling of immersed objects incl. hand immersion Direct handling of immersed objects excl. hand immersion Short hand tool (<0.5m) Long hand tool or extended tools (≥ 0.5m)	500˜ 1 0.3 0.1	- - - -
	Level of automation »control panels/devices <u>at source</u>	Repeated or almost constant use Infrequent or occasional use	0.1 0.01	- -
	Open surface areas^+ Ψ	Open surface > 3 m^2 Open surface 1 - 3 m^2 Open surface 0.3 - 1 m^2 Open surface 0.1 – 0.3 m^2 Open surface < 0.1 m^2	10 10 3 1 1	- - - - -
	Agitation level ^Ψ	Moderate agitation, e.g. rapid dipping, electroplating High agitation, e.g. high speed mixing	3 10	- -
	Orientation of work ^Ψ	All directions incl. upward (open surfaces above working level) Horizontal and downwards Downward only	3 1 1	- - -
Activity transfer potential (H_t)	Surface contamination level (Su)	Derive from Table 2 and Tables 3b	-	-

Modifying Factor (MF)	Determinant	Categories	Direct emission & contact^	Transfer
	Contact frequency (F) »hand-held tools/equipment	Direct handling of immersed objects Short hand tool (<0.5m) Long hand tool or extended tools (≥ 0.5m)	- - -	10 3 1
	Contact frequency (F) »(remote) control panels/devices	Repeated | almost constant use Infrequent | occasional use	- -	3 |10 0.1| 1
	Contact frequency (F) »product type	Dipping or mixing/agitation for treatment applications Dipping or mixing/agitation for coating purposes	- -	3 1
	Contact frequency (F) »surfaces <u>at source</u> when using automated equipment *(e.g. during trouble-shooting)*	No contact Infrequent contact Occasional | repeated contact	- - -	0 0.1 1 | 3
Exposed surface area of body part (ESA_e | ESA_t)	Exposed surface area of hands[∂]	Immersion of both full hands Immersion of one full hand or fingers of both hands Immersion of fingers of one hand, or less Handling of small objects with fingers or one hand palm or less Handling larger objects OR control panels/devices <u>at source</u> Remote control panels and devices	1 0.5 0.25 0.25 0.5 -	0.5 0.5 0.25 0.25 0.5 0.5
Handling of contaminated objects (AC3)				
Activity direct emission & contact potential (H_e)	Level of automation »hand-held tools/equipment	Direct manual handling of objects Short hand tool (<0.5m), incl. use of cleaning materials (e.g. cloth) Long hand tool or extended tools (≥ 0.5m)	1 0.3 0.1	- - -
	Level of automation »control panels/devices <u>at source</u>	Repeated or almost constant use Infrequent or occasional use	0.1 0.01	- -
	Contaminated surface area[+]	Object surface > 3 m^2 Object surface 1-3 m^2 Object surface 0.3-1 m^2 Object surface 0.1-0.3 m^2 Object surface <0.1 m^2	3 3 1 1 1	- - - - -
	Handling orientation	All directions incl. upward (incl. overhead lifting device) Horizontal and downwards OR downward only	3 1	- -
	Intensity of contamination	High - thick layer of product, e.g. coated surfaces Moderate - thin layer of product, e.g. (visible) mist deposit Low - very thin layer of product, e.g. (invisible) mist deposit	3 1 1	- - -
	Proportional contamination[+]	High – completely contaminated; >90% of surface area Moderate – partially contaminated; 10-90 % of surface area Low – small fraction contaminated; <10% of surface area	3 1 1	- - -
Activity transfer potential (H_t)	Surface contamination level (Su)	Derive from Table 2 and Table 3b	-	-
	Contact frequency (F) »hand-held tools/equipment	Direct manual handling of objects Short hand tool (<0.5m), incl. use of cleaning materials (e.g. cloth)	- -	10 3

Modifying Factor (MF)	Determinant	Categories	Direct emission & contact^	Transfer
		Long hand tool or extended tools (≥ 0.5m)	-	1
	Contact frequency (F) »(remote) control panels/devices	Repeated | almost constant use Infrequent | occasional use	- -	3 |10 0.1| 1
	Contact frequency (F) »product type	Objects contaminated with treatment products or general deposits Objects contaminated with coating products, e.g. paints	- -	3 1
	Contact frequency (F) »surfaces <u>at source</u> when using automated equipment *(e.g. during trouble-shooting)*	No contact Infrequent contact Occasional | repeated contact	- - -	0 0.1 1 | 3
	Surface texture (S_t)	Objects are smooth surfaces, e.g. like glass Objects are rough surfaces, e.g. like sand paper	- -	1 0.3
Exposed surface area of body part (ESA_e | ESA_t)	Exposed surface area of hands∂	Handling small objects with fingers or one hand palm or less Handling larger objects OR remote control panels/devices <u>at source</u> Remote control panels and devices	0.25 0.5 -	0.25 0.5 0.5
Spreading of liquid products (AC4)				
Activity direct emission & contact potential (H_e)	Level of automation »hand-held tools/equipment	Using hand or cloth/sponge immersed in liquid, *incl. hand immersion* Using cloth/sponge, *excl. hand immersion* Short hand tool (<0.5m) Long hand tool or extended tools (≥ 0.5m)	500˜ 1 0.3 0.1	- - - -
	Level of automation »control panels/devices <u>at source</u>	Repeated or almost constant use Infrequent or occasional use	0.1 0.01	- -
	Scale of application+ ψ	Treated area > 10 m²/h∩ *(ART=0.1)* Treated area 3-10 m²/h Treated area 1-3 m²/h Treated area 0.3-1 m²/h Treated area 0.1-0.3 m²/h Treated area < 0.1 m²/h	30 10 10 3 1 1	- - - - - -
	Direction of application ψ	Exclusively overhead All directions incl. upward Horizontal and downwards OR Downward only	10 3 1	- - -
	Tool speed and rotation ψ	Low speed, e.g. wiping High speed rotational tools, e.g. rolling	1 3	- -
Activity transfer potential (H_t)	Surface contamination level (Su)	Derive from Table 2 and Tables 3a/b	-	-
	Contact frequency (F) »hand-held tools/equipment	Using hand or cloth/sponge immersed in liquid Short hand tool (<0.5m), incl. accessories Short hand tool (<0.5m), excl. accessories Long hand tool or extended tools (≥ 0.5m)	- - - -	10 3 1 3
	Contact frequency (F) »(remote) control panels/devices	Repeated | almost constant use Infrequent | occasional use	- -	3 |10 0.1| 1

Modifying Factor (MF)	Determinant	Categories	Direct emission & contact^	Transfer
	Contact frequency (F) »product type	Spreading for treatment or other purposes Spreading for coating, e.g. ink	- -	3 1
	Contact frequency (F) »restricted workspaces	Restricted workspaces (contact coated/treated surfaces) Unrestricted workspaces	- -	3 0
	Contact frequency (F) »surfaces <u>at source</u> when using automated equipment *(e.g. during trouble-shooting)*	No contact Infrequent contact Occasional | repeated contact	- - -	0 0.1 1 | 3
Exposed surface area of body part (ESA_e | ESA_t)	Exposed surface area of hands[∂]	Immersion of both full hands Immersion of one full hand or fingers of both hands Immersion of fingers of one hand, or less Using cloth/sponge, excl. hand immersion Short hand tool (<0.5m) Other hand-held tools OR control panels/devices <u>at source</u> Remote control panels and devices	1 0.5 0.25 0.5 0.25 0.5 -	0.5 0.5 0.25 0.5 0.25 0.5 0.5
Application of liquids in high speed processes (AC5)				
Activity direct emission & contact potential (H_e)	Level of automation »hand-held tools/equipment	Manually operated machinery & tools	1	-
	Level of automation »control panels/devices <u>at source</u>	Repeated or almost constant use Infrequent or occasional use	0.1 0.01	- -
	Scale of application[+]	Large-scale activities, e.g. large scale work pieces Small-scale activities, e.g. small work pieces (e.g. < 10 kg)	3 1	- -
	Level of containment[+]	Open process, excl. protective screens Handling that reduces contact between product and adjacent air	1 0.1	- -
	Tool speed and rotation	Moderate speed machinery or processing High or very high speed machinery or processing	- 3	- -
Activity transfer potential (H_t)	Surface contamination level (Su)	Derive from Table 2 and Tables 3a/b	-	-
	Contact frequency (F) »hand-held tools/equipment	Manually operated machinery & tools	-	10
	Contact frequency (F) »(remote) control panels/devices (e.g. CNC machinery)	Repeated | almost constant use Infrequent | occasional use	- -	3 |10 0.1| 1
	Contact frequency (F) »machined work pieces	Repeated | almost constant use Infrequent | occasional use	- -	3 |10 0.1| 1
	Contact frequency (F) »surfaces <u>at source</u> when using automated equipment *(e.g. during trouble-shooting)*	No contact Infrequent contact Occasional | repeated contact	- - -	0 0.1 1 | 3
Exposed surface area of body part (ESA_e | ESA_t)	Exposed surface area of hands[∂]	Manually operated machinery & tools; handling of machined objects Control panels/devices <u>at source</u> Remote control panels and devices	0.5 0.5 -	0.5 0.5 0.5

Modifying Factor (MF)	Determinant	Categories	Direct emission & contact^	Transfer
Transfer of liquid products (AC6) - Bottom loading (AC6.1)				
Activity direct emission & contact potential (H_e)	Level of automation »control panels/devices at source	Repeated or almost constant use Infrequent or occasional use	0 0	- -
	Use rate+	Transfer of liquid product with flow of > 1000 l/minute Transfer of liquid product with flow of 100 - 1000 l/minute Transfer of liquid product with flow of 10 - 100 l/minute Transfer of liquid product with flow of 1 - 10 l/minute Transfer of liquid product with flow of 0.1 - 1 l/minute Transfer of liquid product with flow of < 0.1 l/minute	0 0 0 0 0 0	- - - - - -
Activity transfer potential (H_t)	Surface contamination level (Su)	Derive from Table 2 and Table 3a	-	-
	Contact frequency (F) »(remote) control panels/devices	Repeated | almost constant use Infrequent | occasional use	- -	3 |10 0.1| 1
Exposed surface area of body part (ESA_e | ESA_t)	Exposed surface area of hands∂	Control panels/devices at source Remote control panels and devices	0.5 -	0.5 0.5
Transfer of liquid products (AC6) - Falling liquids, top loading (AC6.2)				
Activity direct emission & contact potential (H_e)	Level of automation »hand-held tools/equipment	Manual transfer using large (>10L) containers Manual transfer using multiple small/medium containers (≤10L) Manual transfer using a single small/medium container/equipment	3 3 1	-
	Level of automation »control panels/devices at source (e.g. filling machines)	Repeated or almost constant use Infrequent or occasional use	0.1 0.01	- -
	Use rate+	Transfer of liquid product with flow of > 1000 l/minute Transfer of liquid product with flow of 100 - 1000 l/minute Transfer of liquid product with flow of 10 - 100 l/minute Transfer of liquid product with flow of 1 - 10 l/minute Transfer of liquid product with flow of 0.1 - 1 l/minute Transfer of liquid product with flow of < 0.1 l/minute	30 30 10 3 1 0.3	- - - - - -
	Type of application+	Splash loading Submerged loading	10 1	- -
	Level of containment+	Open process, e.g. transfer of liquid into open container Handling that reduces contact between product and adjacent air	1 0.1	- -
Activity transfer potential (H_t)	Surface contamination level (Su)	Derive from Table 2 and Tables 3a/b	-	-
	Contact frequency (F) »hand-held tools/equipment	Manual transfer using large (>10L) containers Manual transfer using multiple small/medium containers (≤10L) Manual transfer using a single small/medium container/equipment	- - -	10 10 3
	Contact frequency (F) »(remote) control panels/devices	Repeated | almost constant use Infrequent | occasional use	- -	3 |10 0.1| 1
	Contact frequency (F)	Repeated | almost constant use	-	3 |10

Modifying Factor (MF)	Determinant	Categories	Direct emission & contact^	Transfer
	»receiving containers/vessels or accessories	Infrequent | occasional use	-	0.1| 1
	Contact frequency (F) »surfaces <u>at source</u> when using automated equipment *(e.g. during trouble-shooting)*	No contact Infrequent contact Occasional | repeated contact	- - -	0 0.1 1 | 3
Exposed surface area of body part (ESA_e | ESA_t)	Exposed surface area of hands∂	Handling of small equipment (<0.1 l/min) Other transfer equipment (>0.1 l/min) OR control panels <u>at source</u> Remote control panels and devices	0.25 0.5 -	0.25 0.5 0.5

\- Not applicable
* ART inhalation exposure determinants applied for the deposition route not shown (see Fransman et al., 2011)
+ This determinant is also an ART determinant
∩ This is an additional category and not included in the ART determinant *(see proposed ART factor in italics)*
^ Only relevant for NF
~ See section 2.2.1 (Appendix)
Ψ Not relevant for hand immersions
∂ Relative multipliers for 100% of the hands (1), 50% of hands (0.5) and 25% of hands (0.25)

Table 6 Summary of the determinant review

Nr	Determinant	Description of evidence and selected model determinants	Selected references
1	Weight fraction	Dermal exposure is generally assumed to correlate linearly with the weight fraction or percentage of a substance (or active ingredient) in a product.	CEB (2000); Mulhausen & Damiano (1998)
2	Viscosity	*General effect:* It is generally found (in field studies) that more viscous products (like oil) cause a lower dermal exposure rate on the hands compared with low viscous liquids (like water). Experimental studies associate higher liquid viscosity with higher dermal exposure during hand immersions. Higher viscosity is associated with lower dermal exposure via deposition in experimental studies. *See hand immersions (item 13)* *Emission of product:* Viscosity of a product can affect the release of different forms of direct emission (e.g. splashes, spatter). Spirit-based liquids (mostly with a similar or lower viscosity than water) spatter and travel further through the air during spreading activities than water-based liquids, probably because they tend to be flicked away more easily as a spray/spatter than water-like products. A similar but opposite effect is expected for low volatile products, where oil-like or more viscous products will tend to adhere to bulk liquids or moving equipment more readily than water-based products (with less direct emissions). *Transfer from surfaces*: Experimental studies did not find any effects of viscosity on exposure by the transfer route (transfer efficiency), while increasing viscosity leads to lower exposures through the deposition pathway. Increased viscosity is associated with a higher retention on surfaces (and film thickness) that can increase transfer via surfaces. *Removal from skin (see item 14)*	Hughson et al (2004); Gijsbers et al (2004), Roff et al (1997) Roff et al (1997), EPA (2011); Cinalli et al (1992) Gorman Ng et al (2013), EPA (2011)
3	Availability; *only AC3, coating products*	Increased drying, curing or hardening properties of a product can result in reduced dermal exposure via hand-surface contact. Limited evidence is available to quantify its effect on surface-to-hand transfer. Studies in auto body repair shops have indicated that skin exposure to isocyanates is common during tasks involving recently applied dried paints (due to slow drying or limited drying time before handling), such as during wet sanding or compounding. A similar effect is expected for low volatile liquids.	Bello et al (2007); de Vries et al (2012)
4	Dilution; *only AC3, cleaning*	The dilution effect resulting from the use of water or solvent to remove a product from surfaces (e.g. during cleaning of equipment with running water), assuming that running water or solvent will result in partial removal of the product from the surface, or product in a diluted form.	No evidence available. See example of cleaning tools in Delgado et al (2004)
5	Control measures » containment » local exhaust ventilation (LEV) » glove bags/boxes	All ART determinants related to the control of air emission (localized controls) and dispersion (e.g. downflow systems, worker enclosures) are adopted from ART for the deposition route (see Fransman et al., 2011). Very little data is available on the effect of LEV on hand exposure during the application of low volatile liquids. Local exhaust ventilations (LEV) systems are generally not designed to capture direct emissions. An exception is spraying activities (AC1) associated with larger droplets from overspray, which is addressed separately. Special attention is given to mobile screens or protective (hand) guards on hand tools (not applied in ART), and the effect of glove bags or glove ports.	Fransman et al (2008); Fransman et al (2011); Flynn et al, 1999
6	Level of automation »hand-held tools/equipment »control panels/devices <u>at source</u>	The level of automation refers to the degree of manual or automated work – which may determine the resulting approximate distance between the worker and the emission source. A description of the tools & equipment used provides an indication of the relevance of direct emission & contact, e.g. direct handling of objects, short or long hand tools, use of control panels. For example, generally a 2 to 3 fold lower hand exposure is found when using long handled tools compared with short handled tools. Dipping activities indicated a gradual decrease in hand exposure when data is grouped in far (0.19 µg/min/cm²), medium (1.29 µg/min/cm²), and close distances (2.61 µg/min/cm²). In terms of transfer activities (AC6.2), laboratory studies with automated and manual handling - the use of different container sizes have shown a relationship between the container size and the amount of hand contamination and spillage.	Machado Neto et al (1997); Nuyttens et al (2009); KRIOH (2002); Gijsbers et al (2004); Erikksson et al (2004); Gilbert et al (1999); Glass et al. (2009); Wassenius et al (1998); Wendel de Joode et al (2005); Hughson et al (2004); Glass et al (2009)

Nr	Determinant	Description of evidence and selected model determinants	Selected references
7	Contact frequency »hand-held tools/equipment »(remote) control panels/devices	Multiple linear regression analysis in various experimental studies revealed that skin loading was largely determined by the contact frequency (1st six contacts). It is important to note that these experiments apply a predetermined surface contamination level and indicated that an effective equilibrium (or saturation) on the hand contact surface is assumed after about six contacts. Of note is that the amount of material that transferred to the skin became smaller after a greater number of contacts.	Ivancic et al., 2004; Brouwer et al., 1999; Cohen Hubal et al., 2005
8	Surface contamination level	Experimental studies indicate that an increasing surface loading is associated with an increased dermal exposure level. In the workplace, surface contamination levels will vary considerably, and this broad range of contamination levels are also applied in experimental settings, e.g. for liquids ranging between <0.0002 mg/cm^2 to ≥1 mg/cm^2.	Brouwer et al., 1999; Cohen Hubal et al., 2005; Christopher, 2008; Gorman NG et al., (2012)
9	Scale of activity »use rate »open surface area »contaminated surface area »scale of application	An increase or decrease in scale of an activity is often correlated with hand exposure, however this is highly dependent on the type of activity or process. For example, 'use rate' is the most appropriate for surface spraying (AC1.1) and 'contaminated surface area' for handling of contaminated objects (AC3).	Llewellyn et al (1996); de Cock et al (2002); Bjugstad et al (1996); Wicke et al (1999); Garrod et al (2000); Gijsbers et al (2004);
10	Direction of application	Direction of application refers to the direction or orientation in which a product is applied (in relation to worker), generally resulting in increased dermal exposure with upward orientated applications. For example, data indicates a twofold increase in dermal exposure for wall spraying versus floor spraying of biocides and substantially increased dermal exposure during overhead airless spraying of antifouling products.	Llewellyn et al (1996); Berger-Preiß et al (2005); Koch et al (2012); Hughes et al (2008); Vercruysse (2000); Garrod et al (2000); Gijsbers et al (2004); Roff et al (1997); Mäkinen et al (2004); Roff et al (2004)
11	Other activity-specific determinants	Spray pressure is associated with different formations of aerosol and overspray. Indicative of direct emission, the overspray concentration per unit of film thickness on surfaces were found to be a factor 2 significantly higher for gravity-feed conventional (pneumatic) spray guns compared to HVLP spraying operations.	Heitbrink et al (1994); Koch et al (2012)
		Surface shape pertains to the shape of objects and surfaces being sprayed, associated with different levels of aerosol formation and overspray. Data analysis suggests that absorbent or open-structured objects may increase deposition of paint spray onto objects and surrounding surfaces and decrease overspray compared to large flat surfaces.	Van Drooge et al (1999); Brouwer et al (2001)
		Tool speed and rotation describes the velocity and type of application method (e.g. rotational) which may result in increased release from a tool (such as spattering from rollers).	Garrod et al (2000); Gijsbers et al (2004); Eriksson et al (2004)
		Restricted workspaces refer to confined spaces or restricted movement and mobility during work, resulting in increased hand-surface contacts. This parameter provides an indication of the contact frequency with surfaces (e.g. treated surfaces) during work in restricted workspaces.	Schipper et al (1996); Machera et al (2003)
		Agitation level is the level of agitation of a liquid during an activity (e.g. mixing), potentially resulting in deposition, splashes and spatter.	No available evidence. ART determinants applied for deposition route.
		Product type distinguishes between products for treatment (or other purposes) and for coating. Applications that spread paint, lacquer or ink show far lower exposure rates (~50 µg/min/cm²) than cleaning workers (2000 µg/min/cm²), though hand immersions may be a contributing factor. A reduced contact frequency is expected when working with coating products.	No specific evidence available. Indicative studies include KRIOH (2002) and Hughson et al (2004)
		Donor surface type or surface texture *(only AC3, manual handling of objects)* refers to the surface texture (smooth, rough) which may alter surface-to-hand transfer efficiency. Smooth surfaces are associated with an increased surface-to-hand transfer efficiency compared with rough surfaces.	Gorman NG et al (2013); Cohen Hubal (2004)

Nr	Determinant	Description of evidence and selected model determinants	Selected references
12	Exposed surface area	Exposed surface area is the proportion of the skin surface area of a specific body part that potentially receives exposure (e.g. fraction of hands affected), typically demonstrated with visualization data in field studies. Descriptive information of the type of equipment used or work performed are applied to assess the exposed surface are for each AC.	Cherrie et al (2000); Brouwer et al (1999), EPA (2011)
13	Hand immersions and maximum retention capacity	With full hand immersions, it is assumed that the maximum retention capacity of the product on the hands has been reached. Studies indicate a retention of ˜5 mg/cm^2 for water, ˜6 mg/cm^2 for light oils and ˜10 mg/cm^2 for mineral oil, considering the estimated film thickness and density of the product. Unpublished data from HSL indicate a retention of approximately 4 ml of water-like substances on both hands, and this value will be applied for low volatile liquids until more evidence becomes available.	Gorman NG et al (2012a); Gorman NG et al (2012b); Gorman NG et al, 2013 ; Cinalli et al (1992) ; EPA (2011) ; HSL (unpublished)
14	Removal from skin & effect of sampling techniques; *not included in mechanistic model (considered in calibration)*	Experimental studies indicate that product on the skin can be removed through contact with surfaces. It is well known that factors such as viscosity and stickiness may affect removal from the skin, with an increasing viscosity associated with a significantly higher dermal exposure. The composition and physicochemical properties (incl. non-polarity) can affect stickiness and removal of the product from the skin irrespective of the viscosity of the product. Experimental studies indicated a pronounced increase in retention during hand immersion with increased viscosity levels when both wipe samples and cotton glove samplers were used to sample glycerol solution, with much higher mass retention for cotton gloves. Overall, evidence is still inconclusive on the relationship between viscosity, the activity or way it is brought onto the skin (apart from hand immersions) and considering different sampling methods.	Gorman NG et al (2014); Gorman NG et al (2013); Gorman NG et al (2012a); Cinalli et al (1992)
15	Glove protection; *not included in mechanistic model*	dART does not provide a protection factor for glove use, however, a model user has the option to adopt their own protection value for gloves for a given workplace scenario. Tests on protective gloves in control conditions only provide a theoretical optimum protection level that is unlikely to be offered to the wearer of such gloves. An analysis of glove protection for five groups of gloves (i.e. butyl/neoprene, latex/PE/vinyl/PVC, nitrile, plastic/rubber and unspecified) (n=508), the geometric mean migration of pesticide through gloves was found to be 0.82% (99.2% protection), with a P75 of 3.95% (96.1% protection) and a P90 of 14.48% (85.5% protection) (Spaan et al., 2013). Creely & Cherrie (2001) found protection factors to range from 96 to 470 (98.96 – 99.79% effective) for two nitrile and PVC gloves, while an average reduction was found between 80.5 and 99.99% by Marquart et al (2016), of which six sets with an average reduction of >95%. A 10^{th} percentile of protection factors for thin 'splash-resistant single-use' (SRSU) gloves against liquids are proposed by Roff (2015), i.e. 7–10, or ˜86% - 90%. Overall, the effect of gloves should be interpreted with caution and on a case-by-case basis.	Creely & Cherrie, 2001; Tsakirakis et al., 2010; Fent *et al.*, 2009; Spaan et al., 2013; Roff, 2015; Marquart et al., 2017

Appendices

In this Appendix, each principle modifying factor (MF) and their underlying determinants are described in more detail for each activity (sub) class. The process of assigning multipliers are described in Chapter 3.

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1. Substance emission potential

Substance emission potential related determinants, categories and multipliers for the direct emission & contact and transfer routes are summarized in Table 4.

1.1 Weight fraction

The weight fraction is the fraction of substance of interest in the product used. The model estimates exposure to the product (not corrected for weight fraction) for each route of exposure, i.e. deposition, direct emission & contact and transfer. The final algorithm includes the weight fraction of all the routes combined.

An evaluation of dermal exposure data of the different activity classes revealed that liquids with a high weight fraction consistently show higher absolute exposures than more diluted solutions. The fraction of a substance in a product is assumed to be linearly related to the concentration of the substance present in the liquid product during use or application. Weight fraction of the substance in the product is corrected accordingly in the model by either using the exact weight fraction or using categories (see Table below). These categories are adopted from ART and relevant for all routes. For transfer activities (AC6), the weight fraction of the product being transferred or poured (with the substance of interest) is considered and not the in-use concentration of the product being mixed. In the case of activities with open liquid surfaces and open reservoirs (AC2), the weight fraction of the product being agitated or mixed is of concern. The latter two activities may occur simultaneously but are assessed separately in the model.

General considerations
Volatility of the product could influence the weight fraction of the substance in the product over extended time periods (due to evaporation), however, it is assumed that the mass of substance remains available for dermal exposure. In cases where the matrix will be fully evaporated (e.g. pesticides in water), the residual can be seen as a powder. The dART model does not take account of these scenarios, e.g. re-entry work. These scenarios will be assessed with a (future) dART model for dermal exposure associated with powders.

Determinant	Categories	All routes
Weight fraction (w_f) (from ART, Fransman et al., 2011)		Exact weight fraction, or:
	Pure liquid (100%)	1
	Main component (50 – 90 %)	0.7
	Substantial (10 – 50 %)	0.3
	Minor (5 – 10 %)	0.075
	Small (1 – 5 %)	0.03
	Very small (0.5 – 1 %)	0.0075
	Extremely small (0.1 – 0.5 %)	0.003
	Minute (0.01 – 0.1 %)	0.0006

1.2 Viscosity

Viscosity refers to a liquid's resistance to flow in a fluid or semi-fluid. It may affect various mass transport processes related to dermal exposure and it is assumed relevant for all the activity classes. For low volatile liquids, viscosity affects various dermal exposure processes along different routes of exposure.

Data

Data suggests that high viscosity (spraying) applications show an average-to-low exposure rate. Hughson et al (2004) and Garrod et al (2000) measured the spraying of anti-fouling paint on ship hulls, and reported exposure rates of 24 and 38 µg/min/cm² respectively. In comparison, a rough estimate of the average exposure rate during other hand-held spraying with low viscous products was found to be approximately 80-90 µg/min/cm². A study by HSL (74/3) observed the dipping of fishing nets into liquids of low and medium viscosity. The low viscosity liquid showed an exposure rate of 3.22 µg/min/cm², in comparison, the medium viscosity liquid product showed an exposure rate of 0.74 µg/min/cm². Three studies have measured the exposure during the handling of a spraying hose or fishing lines (Hughson et al., 2004, HSL, 74/3, Castro Cano et al. 2000). The exposure levels found in these three studies were 20.39, 0.11, and 44.50 µg/min/cm² respectively; the high viscosity paints showed lower exposure than the low viscosity pesticides. In an experiment where wood preservative fluids were brushed on a wooden fence (Roff 1997), it was found that the low viscous spirit-based fluid resulted in an almost four-fold higher dermal exposure compared with more viscous water-based fluids. Spirit-based fluids apparently flicked more easily from brushes and further away than the viscous water-based liquids. This phenomenon may be extrapolated for low volatile products to consider water-like versus oil-like products.
Gijsbers et al (2004) found that hand exposures during pouring activities differed when pouring products of different viscosities, e.g. for water 39.6, oil 1.0, honey 5.8, and grease 6.0 µg/min/cm². However, the use rate determinant may contribute to this difference, though the water- and honey-like products are comparable at use rates of approx. 140 L/min.

An evaluation of viscosity for different activity classes therefore provides very limited insight into the effect of viscosity on dermal exposure. Although not all the data provide a conclusive and consistent outcome, it is generally found that a highly viscous product will result in a lower dermal exposure rate on the hands, and vice versa. An exception is that viscous products tend to result in increased dermal exposures during hand immersion activities.

1.2.1 Deposition

For deposition, the effect of viscosity is adopted from the ART model. The ART model proposed two categories of viscosity, i.e. low (like water) and moderate (like oil). A high viscosity category was excluded because only the low and moderate categories are expected to affect inhalation exposure as described by van Tongeren et. al. (2011) and Cherrie et. al. (2011). However, for dermal exposure, a high viscosity category is relevant via other processes such as removal from surfaces and skin, hence the proposal to also include highly viscous products (e.g. like honey, heavy oil, or ˜>1000 centipoise (cP)). In order to align the dART model with ART, and in the absence of evidence, we assume a typical situation where deposition, transfer and direct emission & contact from high viscosity products are set as equal to moderate viscosity products (Table 4).

Experimental studies provide some insight into the effect of viscosity for the different dermal routes. For the deposition route, Gorman Ng et al. (2013) found that increasing viscosity lowers exposure through the deposition pathway, although not statistically significant. In the dART model, the inhalation estimate from ART (Fransman et al. 2011) is applied to represent the deposition route. The reduced effect of viscous substances on inhalation exposure is therefore in line with findings in experimental studies.

1.2.2 Direct emission & contact

In conclusion, little conclusive evidence is available to substantiate the effect of viscosity on different forms of direct emission (e.g. splashes, spatter). Considering pathways such as splashes, dripping and spattering from emission sources, it is assumed that the effect of viscosity on dermal exposure is comparable with the (earlier described) data review of different activity classes, i.e. a low viscous liquid will result in an increased (potential) dermal exposure. The effect of viscosity on hand immersions has been investigated, but these experimental results essentially represent the retention of liquids on the skin. Due to very different dermal loading processes, the dART model therefore separates the assessment of hand immersions from non-hand immersion activities.

1.2.3 Transfer

An experimental study by Gorman Ng et al. (2013) did not find any effects of viscosity on exposure by the transfer route, while increasing viscosity lead to lower exposures through the deposition pathway. Other experimental studies showed that water-like products had a higher film thickness after the initial contact (2.34^{-3} cm) compared to more oil-like products like mineral oil (1.56^{-3} cm) (EPA, 2011). However, the contacts described in the latter experiments involved the rubbing of the substance on the hands with a saturated cloth – and it is therefore not entirely representative of typical hand-to-surface contacts. Overall, the dART model assumes that viscosity has no significant effect on the transfer efficiency from surfaces to the hands. However, considering the effect of viscosity on the surface retention over time, it is assumed that an increased viscosity will have a slight overall increase in surface retention and subsequent hand exposure through the transfer route (factor 0.7).

The study by Gorman Ng et al. (2013) did not find any effects of viscosity on exposure by the transfer route (surface contact). Based on this evidence, the dART model assumes that viscosity does not affect transfer efficiency from surfaces to the hands. However, for the transfer route, the dART model also considers the effect of viscosity on the retention of products on surfaces during an activity. In the absence of conclusive data, a reasonable assumption would be that an increased viscosity will have a slight overall increase in surface retention, which would signify a higher potential exposure via hand contact.
As the removal from the hands or gloves is closely related with dermal sampling techniques, this variable was not included in the mechanistic model but evaluated in the calibration with measurement data.

Determinant	Categories	Deposition	Direct emission & contact	Transfer
Viscosity[+ Ж]	Low (like water) Moderate (like oil) High (like honey)	1 0.3 0.3[∩]	1[^] 0.3[^] 0.3[^]	0.7 1 1

Determinant	Categories	Deposition	Direct emission & contact	Transfer
Availability[I] (only AC3, coated objects)	The coating product is completely cured, dried or hardened	-	0.001	0.001
	The coating product is partially cured, dried or hardened	-	0.1	0.1
	The coating product is not cured, dried or hardened	-	1	1
Dilution (only AC3, cleaning)	No dilution | not applicable	-	1	1
	Diluent used (water/solvent)	-	0.3	0.3

∩ This is an additional category and not included in the ART determinant

\+ This determinant is also an ART determinant

Ж Viscosity is expressed here in terms of (i) its effect on the formation and transfer of large droplets from an emission source e.g. from paint roller) to the worker (E_e), and (ii) potential transfer from surfaces due to retention on surfaces (E_t)

^ Excluding hand immersions (default E_e=1). Effect of viscosity on skin removal is considered in the calibration (see text)

I Only relevant for handling of contaminated objects (AC3) and exclusively relevant for coating products

1.3 Availability

Availability refers to product properties that affect the rate of hardening, fixating, polymerisation, curing or drying of a product. For most activities, it is assumed that – regardless of these properties – a low volatile product will always be available due to an almost continuous renewed availability, e.g. continuous or repeated application of a product during a specific activity such as spraying, spreading, etc. However, for the activity class *Handling of contaminated objects (AC3)*, contaminated objects may be left in a drying room etc. – which will significantly affect the availability of the product due to drying etc. For this activity class, availability is evaluated by assessing the drying or fixating properties of the product, in combination with the time required for a product to completely harden, fixate, cure or dry on a surface and to become unavailable for surface-to-hand transfer.

Although evidence is limited, studies in auto body repair shops has indicated that skin exposure to isocyanates is common during tasks involving recently applied dried paints, such as wet sanding or compounding (Bello et al., 2007; de Vries et al., 2012). These results suggest that substances in a product (such as free isocyanate species) can be present on dried but not fully cured surfaces.

Three categories are proposed that considers the physicochemical properties related to curing, drying and hardening of a product, in conjunction with the possible effect of the time after the surface contamination occurred. The effect values allocated to these categories reflect a significant reduction in hand exposure if the product is partially or completely hardened by the time a worker is handling the object.

1.4 Dilution

The handling of contaminated objects (AC3) often includes the (partial) removal of product using diluent (e.g. water, solvent) to clean contaminated equipment. In the absence of data, dilution is introduced as a determinant to account for a reduced hand exposure, assuming that for example running water or solvent will result in product in a diluted form. Although no specific evidence is available for the dilution effect, its relevance is evident in practice (e.g. cleaning of tools, Delgado et al., 2004). Only two categories are proposed with a modest reduced effect (0.3) for direct emissions and transfer during these scenarios.

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2. Activity emission potential

The activity emission potential is addressed by looking at each dermal exposure route separately. It is divided in two sections:
- Background *(section 2)*: an overview of the activity profiling, followed by a description of important model determinants relevant for:
  - direct emission & contact (hand immersions & maximum retention capacity);
  - transfer (surface contamination levels, frequency of contacts and surface texture)
- Per Activity Class (AC) *(sections 3 - 14)*: describing the characterization of each AC (AC1-AC6)

2.1 Activity profiling

Each activity (sub) class was profiled to indicate the most important pathways of dermal exposure (Table A). To consider each route of exposure, a more detailed description of each is presented below.

2.1.1 Deposition

Deposition refers to the transport of liquid in the form of mist or spray aerosol from the air to a worker's hands or gloves. Aerosol physics explain numerous mechanisms of deposition and droplet motion in the air, amongst others the settling velocity (Stoke's friction law) and turbulent diffusion (Fick's law) (Hinds, 1999). Aerosol dispersion is incorporated in ART and considers indoor and outdoor locations, various room sizes, air exchange rates and different monodisperse aerosols (ranging from 0.3 to ˜100 µm) (Cherrie et al., 2011). The effect of settling velocities on different aerosol sizes are therefore considered in the ART dispersion component, although it is limited to a droplet size-integrated estimate. The dART model being a generic model, it assumes that ART gives an acceptable estimate of concentration of the product in the air around the worker and that the fraction of product (˜≤100 µm aerodynamic diameter) deposited on the worker's hands or gloves is related to this concentration (as a linear function of time) and that determinants that affect deposition are only addressed insofar as they affect inhalation exposure as described by van Tongeren et. al. (2011) and Cherrie et. al. (2011). As such, *all principle modifier factors (MF) and underlying determinants as proposed in the ART model (Fransman et al., 2011) are adopted for the dART model to predict dermal exposure through the deposition pathway*.

2.1.2 Direct emission & contact

Direct emission & contact concerns the transport of (bulk) product onto a worker from sources in the NF of the worker. For hand exposure, the model distinguishes between two basic forms: (1) bulk product such as splashes and spilling, and large droplets (>100 µm) from overspray, reflected spray / backbouncing (not to confuse with smaller aerosols of ˜≤100 µm as described in the Deposition section), and (2) hand immersion. For this purpose, the direct emission includes the non-inhalable fraction of aerosols with high aerodynamic diameters (cut-off value approximately 100 µm) where sedimentation is rapid and the trajectory of large droplets are mostly unaffected by general air movement. Because direct contact (hand immersion) is an event-based occurrence with different mechanisms of exposure compared to direct emission, *the model explicitly distinguishes between hand immersion activities (during open surface (AC2) and spreading (AC4) activities) and activities without hand-immersion (remainder of ACs).*

2.1.3 Transfer

Transfer describes the transport of a substance through direct contact between a contaminated surface and the skin (Schneider et al., 1999). Two key activity-related determinants of the transfer pathway are included: *surface contamination and contact frequency.*

Table A Profiling of activity classes (ACs)

	dART activity classes	**Relevant routes**	**Type of direct emission & contact possible**	**Surfaces**	**Distinctive characteristics**
AC1	Spray application of liquids 1.1 Surface spraying	**DP, E, T**	- Overspray (e.g. back-bouncing) - Dripping from tools & equipment - Run-off of liquid directly onto hands (spray cans)	• Equipment / tools, e.g. spray gun, hose, canister, backpack • (Remote) control devices & panels • Treated or coated objects / surfaces • Spraying equipment (e.g. nozzles), vehicle exterior, robotized spraying room interior	- Restricted workspaces and product type may determine frequency of contact with coated / treated objects - Possible contact with surfaces close to the source during trouble-shooting (e.g. boom spraying, robotised spraying)
	Spray application of liquids 1.2 Space spraying	**DP**, E, T	- Limited dripping from tools / equipment - Limited run-off of liquids directly onto hands	• Equipment / tools, e.g. lance, hose • (Remote) control devices & panels	- Fine aerosol and limited direct emission
AC2	Activities with open liquid surfaces and open reservoirs 2.1 Activities with relatively undisturbed surfaces	DP, **E, T**	- Immersion of hands - Splashes from open surfaces - Dripping from immersed objects / tools	• (Immersed) objects, tools & equipment • (Remote) control devices & panels • (Immersed) objects during trouble shooting	- Hand immersion possible - Low/moderate agitation relevant - Product type (coating vs treatment) can affect frequency of hand contacts - Possible contact with surfaces close to the source during trouble-shooting (e.g. immersed objects)
	Activities with open liquid surfaces and open reservoirs 2.2 Agitation of liquids	DP, **E, T**	- Immersion of hands possible - Splashes from open surfaces - Dripping from immersed objects / tools	• (Immersed) objects, tools & equipment • (Remote) control devices & panels • (Immersed) objects during trouble shooting	- Hand immersion possible - Moderate/high agitation relevant - Product type (coating vs treatment) can affect frequency of hand contacts - Possible contact with surfaces close to the source during trouble-shooting (e.g. immersed objects)
AC3	Handling of contaminated objects	E, **T**	- Dripping from objects - Run-off of liquid directly onto hands	• Contaminated objects, incl. treated or coated objects; tools / equipment cleaned • (Remote) control devices & panels	- Product type (coating vs treatment) can affect frequency of hand contacts - Availability of product (due to drying, hardening) should be considered - Surface texture highly relevant
AC4	Spreading of liquid products	DP, **E, T**	- Potential hand immersion *(using sponge, kitting with finger)* - Spattering from tools / equipment - Dripping from tools / equipment - Run-off of liquids directly onto the hands	• Equipment / tools, e.g. brush or roller and other accessories • (Remote) control devices & panels • Treated or coated objects / surfaces	- Hand immersion possible - Rotational tools may cause increased direct emissions - Restricted workspaces and product type may determine frequency of contact with coated / treated objects - Possible contact with surfaces close to the source during trouble-shooting
AC5	Application of liquids in high speed processes (e.g. rotating tools)	**DP, E, T**	- Spattering from tools / equipment	• Manually operated tools, equipment • (Remote) control panels incl. CNC machines • Machined work pieces or objects	- Aerosol formation & deposition from machines - Spattering from machines possible - Extensive manual handling of machined objects possible
AC6	Transfer of liquid products 6.1 Bottom loading	DP, **T**	NA	• (Remote) control devices & panels	- Closed systems ((de-)coupling assessed in AC3) - No direct emission & contacts
	Transfer of liquid products 6.2 Top loading (falling liquids, pouring)	DP, **E, T**	- Splashes from containers and open surfaces - Dripping from tools / equipment	• Manual transfer from (source) vessel, containers or equipment (e.g. container, dispenser, pipe, hose)	- Open pour or contained transfer; broad spectrum of level of automation - Semi-automated transfer possible - Splashes possible

	dART activity classes	Relevant routes	Type of direct emission & contact possible	Surfaces	Distinctive characteristics
				• (Remote) control panels of (semi-) automated transfer equipment • Receiving containers and other transfer accessories (e.g. decanting containers or jugs, bottling lines, nozzles, extensions, trunks/snouts, funnels)	- Possible contact with surfaces close to the source during trouble-shooting

DP=deposition; E=direct emission & contact; T=transfer **(in bold the expected dominant route/s)**

2.2 Direct emission & contact potential

2.2.1 *Hand immersions and maximum retention capacity*

In order to estimate dermal exposure during the immersion of hands in a product, the dART model assumes that the maximum loading of the product on the hands is instantly reached. For this purpose, the mechanistic model applies a hand immersion factor that provides an indicative / relative multiplier for instant maximum loading on the hands. While the factor proposed for hand immersion is an indicative (relative) multiplier for instant maximum loading on the hands in the mechanistic model, the effect of hand immersion during an activity (as a function of time) was further evaluated considering hand immersion activities during the model calibration (McNally et al., 2018). For example, for the scenario 'car washing', complete saturation of the hands (hand immersion) was assumed, with measurements treated as right censored in the calibration. Therefore the calibration provides an exposure model resulting in a linear relation between relative scores and dermal loading on the hands.

In order to derive this factor, the maximum (combined) dART score applied for different ACs that excludes hand immersions were derived from the model – which was ˜50. In order to assign a factor for hand immersion activities, a factor of 10 over and above the latter score (of 50) is applied (i.e. 500). The factor of 10 was derived from experimental studies that indicate that during non-hand immersion activities (performed by rubbing of cloth saturated with liquid over the front and back of hands), hand exposure was roughly a factor of 0.5, 0.1 and 0.3 less compared to hand immersions in respectively water, mineral oil and a combination of water and oily products (EPA, 2011). Note that the hand immersion factor is a single all-inclusive value and that any other additional determinants are not considered (except for the exposed surface area of the hands).

A maximum retention capacity is proposed that takes account of the maximum amount (cut-off value) of product mass loading on the hands. Studies indicate a retention of ˜5 mg/cm^2 for water, ˜6 mg/cm^2 for light oils and ˜10 mg/cm^2 for mineral oil, considering the estimated film thickness and density of the product. To our knowledge, no maximum retention capacity values are available from experimental studies for more viscous products. Unpublished data from HSL indicate a retention of approximately 4 ml of water-like substances on both hands, and this value will be applied for low volatile liquids (irrespective of viscosity & density) until more evidence becomes available.

2.2 Transfer potential

2.3.1 *Surface contamination level*

Experimental studies indicate that an increasing surface loading is associated with an increased dermal exposure level (Brouwer et al., 1999; Cohen Hubal et al., 2005; Christopher, 2008). In the workplace, surface contamination levels will vary considerably, and this broad range of contamination levels are also applied in experimental settings, e.g. for liquids ranging between <0.0002 mg/cm^2 to ≥1 mg/cm^2. In order to parameterize surface contamination levels, a description of three qualitative main categories is proposed with their relative (dimensionless) multipliers:

- (very) low multiplier (0.0001), [very low and often non-detectable surface contaminants]
- moderate (0.01), and [thin visible layer]
- (very) high (1), [thick, saturated layer]

The rationale behind the multipliers assigned for the two matrixes are discussed below. Future research initiatives should provide further additional supporting evidence for the testing and refinement of the surface contamination level matrixes by using field measurement data (surface contamination levels) and exposure route-specific experimental studies.

Matrix: deposition vs direct emission & contact (Table 3a)

This matrix is applied for surfaces related to manual tools & equipment in AC1, AC4, AC5, AC6, as well as all (remote) control panels/devices (Table 2). The derived value from the matrix is automatically estimated in the background of the model and does not require additional user input. The matrix provides a relative multiplier for surface contamination levels (in the background of the model) based on:

- the ART model outputs (C_{ART}) using the minimum and maximum scores obtained assuming pure liquids (<10^{-6} to 0.1), and
- the direct emission & contact output of dART (E_{hands}, excl. ESA_e) using the minimum and maximum scores excluding full containment (0->30)

Both ranges from the above mentioned deposition and direct emission & contact routes were subdivided into three categories of low, moderate and high, considering the relevant data associated with these categories. For example, the high deposition category obtained from C_{ART} (score of >10^{-6}) was found to be related to surface spraying activities associated with 'high' airborne concentrations of ≤ 100 μm aerosols. The high direct emission category (>30) is associated with excessive direct emissions associated with for example splashes. These two categorical outputs for deposition and direct emission were combined in a matrix to assign relative multipliers for surface contamination levels (Su), considering the expected contribution by each route. Ideally, such a matrix should also consider the 'proportional' contamination as addressed in Table 3b. However, to simplify Table 3a it was decided to assume that surface loading of tools, equipment and control panels will be distributed 'uniformly' on the surfaces.

A combination of each of the three categories resulted in a qualitative description and multiplier for surface contamination levels (Table below).

Table Description of multipliers assigned for the Table 3a matrix (deposition vs direct emission)

Combination	Multiplier	Description
High DE x High D	1	Thick layer
High DE x Moderate D	0.3	Thin to thick layer
High DE x Low D	0.1	Thin to thick layer
High D x Moderate DE	0.1	Thin to thick layer
High D x Low DE	0.03	Thin layer
Moderate D x Moderate DE	0.01	Thin layer
Moderate DE x Low D	0.003	Thin to invisible layer
Moderate D x low DE	0.001	Thin to invisible layer
Moderate D x low DE	0.0001	Invisible layer

It is expected that the direct emission route (E) will outweigh the deposition route (DP), in particular when considering the proportionally high loading rate in mass of product (mg.min^{-1}) per surface area associated with often event-based direct emissions (splashes, etc). As a result, the assigned multipliers represent the highest values (1 to 0.1) for the high direct emission scores in combination with (high to low) deposition scores.
It is important to note that the low category for direct emission (<1) represents scenarios where direct emissions are unlikely. As a result, for high levels of deposition, a similar effect is found in combination with direct emission (high to low) with the assignment of multipliers 1 to 0.03, and therefore with a slightly lower effect for deposition compared with direct emission. This dominating effect of direct emissions then rapidly tapers off when approaching low direct emission scores (and low/moderate deposition scores).

Matrix: intensity vs proportional (Table 3b)
An alternative matrix is available to assess surface contamination levels in a qualitative or observational manner. The matrix is typically applied to assess contamination levels of surfaces related to processes where a product is intentionally brought onto a surface, e.g. immersed objects (AC2), treated or coated objects (AC1, AC3, AC4), or through contamination related to (or not related to) a specific source.
For this purpose, a surface contamination level is based on user input on the expected (1) intensity of contamination – thus the thickness of the surface layer, and (2) the proportional contamination of the surface or object. This interpretation of object or surface contamination takes account of the potential distribution of the product on the (object) surface. The matrix is used in cases where surface contamination levels originate from processes where a product is intentionally brought onto a surface (e.g. treated or coated objects) or through general contamination not related to a specific source.
Considering the categories used for proportional contamination (high=>90%, mod=10-90% and low=<10%) and intensity (low=invisible, mod=thin layer, high=thick layer), the combination between moderate and high categories are considered to outweigh the other combinations. Surfaces that are contaminated <10% of the surface area (even at high intensity levels of small surface areas) are expected to markedly reduce surface contamination levels relevant for actual hand-to-surface contact. As a result, multipliers assigned to other category combinations (e.g. low*high, mod*mod) suggest a gradually reduced contamination levels, with very low multipliers assigned to low*mod and low*low combinations.

2.3.2 *Frequency of contacts*

Experimental studies indicate that an increasing contact frequency is associated with a near-linear increase in dermal exposure level – assuming an effective equilibrium (or saturation) on the hand after multiple contacts (Ivancic et al., 2004; Brouwer et al., 1999; Cohen Hubal et al., 2005). It is important to note that these experiments apply a predetermined surface contamination level and indicated that an effective equilibrium (or saturation) on the hand contact surface is assumed after about six contacts. Of note is that the amount of material that transferred to the skin became smaller after a greater number of contacts. It is expected that the type of tools & equipment used during a workplace activity provides a relative indication of the contact frequency with workplace surfaces. The method applied in the dART model to parametrize the frequency of contact and assign a relevant multiplier, is shown in Table 2 (per type of surface). Two possibilities are available for the dART model:

(1) Assuming that a model user will not always be able to assess the contact frequency for some surfaces, determinants such as the (i) type of hand-held tools & equipment used, (ii) the product type (treated vs coated surfaces) and (iii) restricted workspaces are categorised and pre-assigned with multipliers that reflect the potential for hand-to-surface contacts. These determinants are addressed in more detail for each AC in the following sections.

(2) Qualitative categories are directly applied in the case of surfaces such as (i) (remote) control panels / devices, (ii) treated or immersed objects and (iii) contact with surfaces at the source when (for example) using automated / robotized equipment (e.g. contact during trouble-shooting). The importance of including 'trouble-shooting' surfaces are evident in field studies, such as vehicle-mounted boom spraying - where operators are occasionally in contact with highly contaminated spraying equipment during nozzle de-blocking activities and other trouble-shooting activities (Ramwell et al., 2004; LeBailly et al., 2009).
To assess these surfaces, the dART model applies qualitative categories (adapted from the DREAM model) based on an ordinal scoring to estimate the contact frequency (F) with surfaces. Four categories are proposed: unlikely, or <1% of activity (0.1); occasionally, or 1-10% of activity (1); repeatedly, or 10-50% of activity (3); and almost constantly, or ≥50% of activity (10).
If a surface (Table 2) is indicated by the model user as 'not relevant', the model assigns a factor 0 and thereby excludes the surface.

2.3.3 *Surface texture*

The surface texture (or surface donor type) refers to the type of surface from which a surface contaminant will be transferred to the hands. The surface texture is known to affect the transfer efficiency to the skin (e.g. hands) or clothing (e.g. gloves) (Gorman Ng et al. 2013; Hubal 2004). Smooth surfaces are associated with an increased surface-to-hand transfer efficiency compared with rough surfaces.
Due to the complex mix of possible surface textures found in everyday workplace scenarios, the dART model only applies the 'surface texture' parameter for AC3 (handling of contaminated objects) where the same objects with specific surface properties is of concern. For the remaining ACs, a default situation of smooth surfaces is assumed (factor 1).

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3. AC1 Spray application of liquids

A clear distinction between aerosols associated with the deposition route (˜≤100 µm aerodynamic diameter) and direct emission route (>˜100 µm) as defined in the dART model, is not easily defined. Breathing zone samples in experimental settings have shown a mass median diameter (MMD) of paint droplets to vary between 5.9 µm (–1.6 µm) (Flynn et al., 1999; Sabty-Daily et al., 2005) and 7.5 µm (Sabty-Daily, et al, 2005b). Sabty-Daily et al (2005; 2005b) and examined the differences in droplet size distributions of paint droplets that are part of the direct trajectory (and deposited) versus overspray droplets, and found that the overspray (lognormal) droplet size distributions are distributed over 60% of the paint aerosol mass between 2 and 10 µm. In practice, a smaller but significant fraction of 'overspray' can be considered as 'direct emission' (backbouncing, reflected spray) if defined as a non-inhalable fraction of aerosols with aerodynamic diameters of ˜>100 µm. While this distinction is important, we will evaluate overspray (relevant for direct emission) in more general terms as large droplets mostly unaffected by general air movement. Considering the mentioned droplet size distributions, the overspray of concern for direct emissions will relate to reflected spray and back-bouncing of larger droplets not suspended in the air for long, where sedimentation is rapid and the trajectory of large droplets are mostly unaffected by general air movement.

Surfaces identified for surface- and space spraying include (i) hand-held tools and equipment, (ii) the use of remote control panels and (iii) contact with treated or coated surfaces and (iv) surfaces (at source) when using automated / robotized equipment (e.g. contact during trouble-shooting) (see Table 2).

As a general note, all field study data reviewed here excludes mixing and loading activities. Also, any dedicated activities related to the exclusive maintenance or trouble-shooting of equipment (e.g. nozzle unblocking) and cleaning should be addressed in AC3. However, the dART model allows for potential contact with surfaces that are (or were) located at the source (e.g. during a tractor exterior, boom & spraying equipment, interior of a robotized spraying room).

For space spraying, all fogging devices operated 'at a distance', that is, left in a room with a time-triggered mechanism, is also addressed in AC3. The rationale for these exclusions is that spraying/fogging does not occur during these activities, and only relates to the handling of the (inactive) fogging equipment.

Table B1 gives an overview of field studies included for the AC1 review.

4. AC1.1 Surface spraying

4.1 Activity (direct) emission potential

	Determinant	Categories	Deposition	Direct emission & contact^	Transfer
1.1	Level of automation »hand-held tools/equipment	Short hand tool (<0.5m) Long hand tool or extended tools (≥ 0.5m)	- -	1 0.1	- -
	Level of automation »control panels/devices at source	Repeated or almost constant use Infrequent or occasional use	- -	0.1 0.01	- -
1.2	Use rate+	High application rate (> 3 l/minute) Moderate application rate (0.3 - 3 l/minute) Low application rate (0.03 – 0.3 l/minute) Very low application rate (0.03 – 0.3 l/minute)	3 1 0.3 0.1	3 1 1 1	- - - -
1.3	Spray pressure+	Spraying with high compressed air use Spraying with no or low compressed air use	3 1	3 1	- -
1.4	Direction of application+	Exclusively overhead∩ *(ART=3)* All directions incl. upward Horizontal and downwards Downward only	3 3 1 0.3	10 3 1 1	- - - -
1.5	Surface shape	Large, reflective objects Multiple, dense or small structured surfaces Open-structured objects	- - -	3 1 0.3	- - -

∩ This is an additional category and not included in ART
+ This determinant is also an ART determinant
^ Only relevant for NF

4.1.1 Level of automation

Level of automation provides an indication of the degree of manual or automated work and the approximate distance between the worker and the emission source. For hand-held applications, the length and size of spraying equipment can range considerably – depending on the type of application, e.g. spray pistols, lances, extended handles, spraying cans, etc.

Machado Neto et al (1997) evaluated the difference in dermal exposure resulting from a 0.5m and a 1m spray lance. For the body, this resulted in an exposure difference of roughly a factor 1.5. For the hands specifically, however, this factor was closer to 3: which is logical considering the proximity of the hands to the spraying equipment. In the same article, Machado refers to an earlier experiment in which the spraying tool was changed from a 0.5m lance to an alternative 2.2m lance system, which, for the whole body, resulted in an overall 91% dermal exposure reduction.
Nuyttens et al. compared a number of lance spraying methods with spray pistol spraying (Nuyttens et al. 2009). Compared to the spray pistol, one of the lance spray methods (spraying while walking backwards) showed a total body exposure of a factor 3 less. Hand data is available

for this study, but the authors noted the formation of a spray cloud near the hands, presumably due to faulty equipment. For the upper and lower arms, however, the decrease of the aforementioned lance spraying method was a reasonably consistent factor of 2 to 3.
It seems that proximate working tools such as spraying pistols consistently result in a much higher hand exposure than spraying lances. However, the available data do not demonstrate this: some spray pistols gave higher exposure rates than spraying lances, but the opposite is also true. When the overall data concerning spray pistols and spray lances (grouped with knapsack spraying) is compared, similar exposure rates are found, approximately 95 µg/min/cm². With outliers included, the lances actually show a 4-fold higher exposure than spray pistols. It is possible that each study has additional conditions or determinants that obfuscate the true relationship between tool length and exposure.
In terms of the transfer route and the effect of tool length and accessories on the frequency of contacts, very little information is available. At a glance, knapsack sprayers have comparable exposures to lance and pistol spraying equipment using pressurised hoses, suggesting their backpack handling is comparable to the handling of pressured hoses. However, some studies are available in which the handling of the equipment and the handling of the supportive equipment are done by different operators, and measured separately. An anti-fouling study by HSE (HSL report EH74/3 - antifouling) finds a negligible exposure of the line handler compared to the spraying operator (0.1 vs. 38 µg/min/cm² respectively), but this is most likely due to the distance the line handler is removed from the source of exposure; a similar antifouling paint study (Hughson et al. 2004) finds a much higher exposure for the line handler (20.4 vs. the sprayer's 24.0 µg/min/cm²).

Proposed categories
Considering the (limited) evidence, two categories of tool length of spraying equipment is included in the model to account for the distance between the hands of the spraying operator and the actual point of emission. In addition, considering different levels of automation, the frequency of using control panels located at the source is considered.

Relative effect size
Although the data are inconclusive concerning the effects of tool length on hand exposure, a modest effect of tool length on dermal exposure was found. The effect of handling of ancillary accessories (such as backpack tanks, spray canisters, lines, hoses) during spraying activities was also evaluated, although no conclusions can be drawn on its effect on hand exposures.
Data suggest that there's a tendency for reduced hand exposures when spraying with long tool handles. However, no evidence is available to substantiate this effect specifically for large droplets and reflected spray, dripping and run-off onto the hands. Yet, it is reasonable to assume that direct emissions will be reduced when using long or extended tool handles (in particular in combination with upward spraying).
It is assumed that no direct emission & contact will occur during automated spraying systems. However, the model includes the possibility that control panels are located at the source and in close proximity of spraying operations. In the event that this would occur, it is assumed that direct emissions will be dependent on the frequency that an operator use these control panels. Overall, the potential relevance of direct emission is assumed to gradually decrease with increased distance from the source.

4.1.2 Use rate
Use rate refers to the volume of product used per time unit. The use rate is difficult to assess because it is so closely related to the spraying equipment used, which is in turn related to other determinants. Llewellyn et al (1996) failed to find a relationship between use rate and hand exposure during hand-held insecticide spraying. In a lance spraying experiment, Wicke et al (1999) found that when using air injector nozzles,

a doubled use rate corresponded with a 1.5 times increase in exposure, but when they tested hydraulic nozzles, a doubled use rate did not cause any observable difference in exposure. Hines et al (2011) found a statistically significant correlation between hand exposure and amount of used pesticide, as well as between hand exposure and application time, but they did not provide specific exposure values. A foaming study by TNO shows that during clean foam spraying, a use rate of 5.5 L/min corresponded to an exposure rate of 79 µg/min/cm², while a use rate of 1.5 L/min corresponded to an exposure rate of 29 µg/min/cm² (TNO 2003). Although the heightened nozzle pressure of the lower use rate operation (4.5 to 60 bar) suggests a change of equipment, the exposure rate decreased by a factor 2.7.
Aside from these field studies, limited data could be found. Variations in use rate do not appear to affect the exposure rate significantly. Additionally, low use rates do not show exposure rates that are particularly low (e.g. hand-held spraying with 0.08 L/min yielded 136 µg/min/cm² (de Cock et al. 2002)), while high use rates do not show exposure rates that are particularly high (e.g. hand-held spraying with 13 L/min resulted in a hand exposure of 0.9 µg/min/cm² (Bjugstad et al. 1996).
It is possible that a correlation between use rate and exposure is obfuscated by other variables, such as the aforementioned spraying equipment.

Categories
The ART model currently applies the following multipliers for use rate: more than 3 L/min: (‘high’, factor 3), 0.3–3 L/min (‘moderate’, factor 1), 0.03–0.3 L/min (‘low’, factor 0.3) and <0.03 L/min (‘very low’, factor 0.1). These ART categories allow for a difference of factor 30 for air emission and deposition. However, the reviewed dermal studies indicate that use rate has a less distinctive effect on hand exposure.

Relative effect size
Based on the evidence available for use rate and hand exposure, a two-class distinction is defined with a cut-off point of 3 L/min. This value seems suitable, as it includes most knapsack sprayers, which are a significant group in spraying applications. The data shows an average of 61 µg/min/cm² for any application under 3 L/min, and an average of 139 µg/min/cm² for any application above 3 L/min, a factor 2.3. This value represents the effect of use rate over all routes of exposure. In the absence of more specific evidence, a factor 3 is assigned to the direct emission & contact route, in addition to ART multipliers for the deposition route.
It should be noted that the dataset for hand exposure does not include, for example, aerosol spray cans, which may be a spraying technique that changes exposure rate characterisation at low use rates.

4.1.3 Spray technique
Spraying technique refers to the method of spraying – which is determined by amongst others the purpose of the application (e.g. coating, treatment, etc.) and the type of formulation used. The spraying technique involves many interlinked variables such as type of spray nozzles, spray pressure, spray distance, etc.

High-volume low pressure (HVLP) spraying techniques are associated with a high transfer efficiency onto surfaces of about 65%, whereas conventional air atomized spray painting guns are far less efficient (25-35%). The overspray concentration per unit of film thickness on the surface was found to be a factor 2 significantly higher for gravity-feed conventional (pneumatic) spray guns compared to HVLP spraying operations (Heitbrink et al., 1994; Lansink et al., 1997). These studies do not only indicate reduced aerosol concentrations during use of low pressure spray techniques such as HVLP guns, but they also suggest a reduced overspray of large droplets little affected by air movement. However, various high pressure techniques such as airless spraying can achieve a similar transfer efficiency compared with HVLP. That said, direct emissions onto the hands will also be affected by the back-bouncing or reflection from surfaces, which could also be related to the spray pressure (and surface shape) rather than the technique itself.

Categories
Due to the variety of spraying techniques and complexity of factors affecting aerosol formation, overspray and back-bouncing, the two categories proposed by ART are adopted.

Relative effect size
In general, spraying techniques are expected to affect the direct emissions associated with overspray in varying degrees, with high pressure techniques on the higher end, low pressure techniques in a mid-range level and other specialized techniques (e.g. electrostatic techniques) on the lower end. The latter techniques are considered not or less relevant for low volatile products. By using the two categories proposed by ART, an increased direct emission is assumed with high pressure techniques.

4.1.4. Direction of application
Direction of application refers to the direction or orientation in which a worker applies a product. Specific literature concerning the direction of spray application on surfaces is scarce. Concerning whole body exposure, studies seem to unanimously agree that spraying downwards decreases exposure, while an upward spraying orientation increases it. Though not entirely representative of the hands, Llewellyn et al. found a higher dermal exposure during activities involving overhead spraying (Llewellyn et al. 1996). This is confirmed by Berger-Preiß et al (2005) who observed a marked increase in dermal exposure for upwards sprayers (Berger-Preiß et al. 2005). A study by de Vreede et al (1997) also suggests that a low spraying orientation causes a higher exposure to the legs. Another study by Choi et al. considers gender-based height difference a major factor in the increased exposure of females (Choi et al. 2006), meaning females have to angle their spraying equipment further upward. Specifically for the hands, two datasets are available to illustrate the effect of direction of application on deposition of aerosols in the far-field. Vercruysse et al. observed two tractor-mounted boom spraying operations: one on (high) fruit-bearing trees, the other on (low) potato plants (Vercruysse 2000). The respective exposure rates for closed cabin operations were 12.4 and 1.7 µg/min/cm², roughly a factor 7 difference. The exposure rates for open cabin operations were 5.3 and 1.7 µg/min/cm², a factor 3.1. Another study is by Hughes et al (2008) who compared hand-held spraying operations on (low) broccoli and (high) maize, showing exposure rates of 86 and 319 µg/min/cm², a factor of 3.7 difference.
For tractor-mounted boom spraying, data aggregation demonstrated 27.4 µg/min/cm² for 'any' direction, and 2.6 µg/min/cm² for 'down', a factor 10.5, which is in accordance with the ART multiplier of a ten-fold factor between high and low.

Categories
Three categories as proposed by ART (for the deposition route) are adopted and extended for the direct emission & contact route. An additional 4th category is proposed that reflects 'exclusively overhead work'.

Relative effect size

Spraying downward may result in exposure of the legs or feet, but is not expected to significantly affect hand exposure (considering gravity and operator orientation). Conversely, dripping from a lance pointed upwards is associated with increased exposure to the hands by both the deposition and direct emission & contact routes.

Based on the data review, the aggregated data for hand-held spraying pistols, lances, and knapsack sprayers into the three categories 'downward', 'level', and 'all directions incl. upward' showed hand exposures of 28.3, 36.9 and 573 µg/min/cm² respectively – indicate relative factors of 1:1.3:20 respectively.

These factors suggest that 'level' and 'downward' show similar exposure rates, and they are assigned the same exposure weight. For the 'all directions incl. upward' category, after omitting extreme outliers from the dataset and taking into consideration existing ART multipliers, a factor 3 is set for the direct emission & contact route.

A new category is proposed named 'exclusively overhead work' (not in ART) that is assigned with a factor of 10 in direct emission & contacts, based on evidence that overhead airless spraying of antifouling products can result in an increase of body exposures of up to 125 times (Koch et al., 2012).

4.1.5 Surface shape

The surface shape determinant pertains to the shape of objects and surfaces being sprayed. The surface shape is expected to determine the degree of reflected spray or back-bouncing from surfaces. Also, when spraying overhead surfaces, the shape of these surfaces can affect dripping from equipment and surfaces. An existing spray model (Brouwer et al., 2001) takes account of small, absorbent or open-structured objects which may increase deposition of the paint spray onto the object and surrounding surfaces and therefore result in a decrease of overspray compared to standard, flat objects. Van Drooge et al (2001) also distinguish between large enclosed, reflective objects (3), multiple, dense or small structured objects (1) and open-structured objects (0.3) and found that object shape, besides spraying rate and ventilation, had a significant effect on dermal exposure for a range of spraying techniques using linear regression models. Other field studies, however, are inconclusive on the effect of surface shape, with comparability of studies hindered by the broad scope of spraying techniques and products used. Also, to some extent, the surface size and shape will be related to the spraying technique being used. With the current evidence available, it is proposed to adopt the categories and multipliers from Van Drooge et al (2001).

4.2 Activity transfer potential

	Determinant	Categories	Deposition	Direct emission /contact^	Transfer
See 2.3.1	Surface contamination level (Su)	Derive from Table 2 and Tables 3a/b	-	-	-
See 2.3.2	Contact frequency (F) »hand-held tools/equipment	Short hand tool (<0.5m) excl. accessories Short hand tool (<0.5m) incl. accessories Long hand tool or extended tools (≥ 0.5m)	- - -	- - -	1 3 3
	Contact frequency (F) »(remote) control panels/devices	Repeated | almost constant use Infrequent | occasional use	- -	- -	3 |10 0.1| 1
	Contact frequency (F)	Spraying for treatment or other purposes	-	-	3

	Determinant	Categories	Deposition	Direct emission /contact^	Transfer
	»product type	Spraying for coating, e.g. paints	-	-	1
	Contact frequency (F) »restricted workspaces	Restricted workspaces (contact coated / treated surfaces)	-	-	3
		Unrestricted workspaces	-	-	0
	Contact frequency (F) »surfaces at source when using automated equipment *(during trouble-shooting)*	No contact	-	-	0
		Infrequent contact	-	-	0.1
		Occasional | repeated contact	-	-	1 | 3

^ Only relevant for sources in NF

4.2.1 Contact frequency

4.2.1.1 Hand-held tools/equipment

The level of automation as described in the previous section not only provide an indication of the approximate distance between a worker and contaminated tools and equipment, but also the potential frequency of hand contact. A summary of findings from available field studies is presented in section 4.1 and Table B1. Although the data are inconclusive concerning the effects of tool length on hand exposure, a modest effect of tool length on dermal exposure was found. The effect of handling of ancillary accessories (such as backpack tanks, spray canisters, lines, hoses) during spraying activities was also evaluated, although no specific conclusions can be drawn on the frequency of hand contacts and resulting hand exposures.

Proposed categories
The model applies three tool/equipment configurations for hand-held applications and two categories for the use of (remote) control panels and devices – including the interior of a vehicle such as steering wheels and controls relevant for tractor-mounted spraying systems.

Relative effect size
Data suggest that there's a tendency for reduced hand exposures when spraying with long tool handles. The frequency of hand contacts with a spraying device will be determined by the number of times the device is picked up and put down, and the number of times the device is switched between hands. Field studies also indicate that transfer appear to be an important pathway during spraying applications compared with deposition (Pronk et al, 2006; Links et al, 2007). A reasonable assumption would be that short hand tools (e.g. <0.5m) where no additional accessories are used (e.g. lines, hose), less hand contacts with equipment can be expected compared to the use of other hand-held configurations. Short hand tools are typically held in a single grip for extended periods, with occasional releases and grasping of the tool. In terms of longer / extended tools or tools where the use of additional accessories (backpack tanks, paint containers, spray canisters, lines or hoses) are required, an increase in hand contact seems plausible.

4.2.1.2 Product type

The product type relates to the purpose of the liquid used - whether it is applied on a surface for treatment or as a coating. Although the field study data used in this report is skewed towards agricultural treatment applications (Table B1), the few available coating applications like painting were found to have below average exposure rates. An explanation for this finding is that the product type affects the frequency of contacts with either tools & equipment or treated or coated objects. The type of product sprayed and type of application may determine the probability of contact between a worker and tools & equipment and treated or coated surfaces. For example, when an operator is spraying a cleaning product, they may be less wary of accidental exposure compared to when they spray liquids that should not be disturbed after application, such as paint. For this purpose, two categories are proposed that assigns an increased contact frequency for spraying for treatment activities as opposed to coating applications.

4.2.1.3 Restricted workspace

Restricted workspaces refer to confined workspaces that are entered during work, or treated/coated objects that restrict movement and mobility during work. Restricted workspaces are expected to affect the frequency of contact with treated or coated surfaces.

Specific field studies that deals with the effect of restricted workspaces are scarce (Table B1). De Cock *et al.* tested hand-held lance spraying in rooms of different sizes, the results of which show no convincing effect of restricted workspaces: a cramped, middle-sized, and spacious room gave exposure rates of 22, 136, and 31µg/min/cm² respectively (de Cock et al. 2002). Schipper (1996) however found that cramped situations appear conducive to higher exposure rates and contamination when they tested the spraying of mushroom scaffolds and observed high exposure rates – the single highest outlier in the available data (14795 µg/min/cm²) was observed here. Crops in greenhouses also showed above average exposure rates, and cramped greenhouses even more so: the data shows high exposure rates in greenhouses with cramped (<1m) row spacing (215 µg/min/cm²) compared to greenhouses with wider row spacing (113 µg/min/cm²). The available data is not convincing when considering the current data. The reason why a weak or no effect was found for restricted workspace could be the lack of contextual information regarding cramped workspaces.

Categories

Restricted workspaces may require an awkward working posture. Restricted workspaces may include the spraying of surfaces inside objects (e.g. inside of cylinders), difficult to access spaces (e.g. crawl spaces) or walking through treated objects (e.g. dense restricting objects or crop). Two categories are proposed for this purpose: restricted and unrestricted

Relative effect size

In the absence of conclusive evidence, the assumption is made that an increased hand exposure is associated with surface spraying activities in restricted workspaces. Although restricted workspaces may also (indirectly) affect the direct emission & contact route, it is excluded as it is addressed in the ‘direction of application’ and ‘tool length’.

4.3 Exposed surface area of the hands

	Determinant	Categories	Deposition	Direct emission & contact ^	Transfer
See section 16	Exposed surface area of hands	Short hand tool (<0.5m), excl. accessories	1	0.25	0.25
		Other hand-held tools or control panels at the source	1	0.5	0.5
		Remote control panels and devices	1	-	0.5

^ Only relevant for sources in NF

The categories applied to describe the tools & equipment used, and the use of control panels are applied to determine the exposed surface area (section 16).

For the *deposition route* – it is assumed that both hand surface areas are fully exposed (factor 1), regardless of the orientation of the hands and whether the hands are grasping surfaces.

For the *direct emission & contact and transfer,* it is assumed that during the use of short hand tools excluding accessories (e.g. spray can) – the exposed surface area of the hands are mostly limited to one hand palm or back of one hand. When using control panels & devices, it is assumed to involve both hand palms.

5. AC1.2 Space spraying

5.1 Activity (direct) emission potential

	Determinant	Categories	Deposition	Direct emission & contact ^	Transfer
1.1	Level of automation »hand-held tools/equipment	Short hand tool (<0.5m) Long hand tool or extended tools (≥ 0.5m)	- -	0.1 0.01	- -
	Level of automation »control panels/devices at source	Repeated or almost constant use Infrequent or occasional use	- -	0.1 0.01	- -
1.2	Scale+	High scale space spraying, e.g. fogging Low scale space spraying, e.g. fly spray	10 1	1 1	- -
1.3	Direction of application	All directions incl. upward Horizontal and downwards Downward only	- - -	3 1 1	- - -

+ This determinant is also an ART determinant
^ Only relevant for sources in NF

5.1.1 Level of automation

Level of automation provides an indication of the degree of manual or automated work and the approximate distance between the worker and the emission source. For hand-held applications, the length and size of spraying equipment can range considerably – depending on the type of application. No data is available to rigorously underpin the effect of direct emission on hand exposure for space spraying operations. Evidence from surface spraying operations is considered to assist in the evaluation of this determinant.

Proposed categories

It is assumed that similar tool & equipment configurations are applied compared with surface spraying applications, e.g. spray cans, short and long lances, etc. It should be noted that all fogging devices operated ‘at a distance’ (left in a room with a time-triggered mechanism) are excluded and assessed in AC3, because fogging does not occur during these activities.
Two categories of tool length of hand-held spraying equipment is included in the model to account for the distance between the hands of the spraying operator and the actual point of emission. In addition, considering different levels of automation, the frequency of using control panels located at the source is considered.

Relative effect size

A specific difference in space spraying compared with surface spraying is the release mechanism (nozzle, etc) and therefore the absence or limited release of large droplets. Also, it does not include spraying of surfaces, thus reflected / overspray spray is not considered for space spraying. Therefore, compared with space spraying, a reduced effect on hand exposure is proposed for hand-held spraying equipment (see surface spraying).

It is assumed that no direct emission will occur during automated space spraying or fogging systems. However, the model includes the possibility that control panels are located at the source and in close proximity of space spraying operations. In the event that this would occur, the same multipliers are applied for control panels at the source (see surface spraying). Overall, the potential relevance of direct emission is assumed to gradually decrease with increased distance from the source.

5.1.2 Scale

Space spraying can range from small scale applications (fly spraying) to large scale applications (fogging). De Cock *et al.* found an exposure rate of 1040 µg/min/cm² during a use rate of 0.7 L/min, while (HSE, 1999c) measured a hand exposure rate of 0.03 µg/min/cm² during a use rate of 0.12 L/min. However, the latter is a measurement under protective gloves, but nonetheless a relatively low exposure and allowing for a high protection factor (de Cock et al., 2002; HSE, 1999c). Bjugstad et al. found an exposure of 1.8 µg/min/cm² during a use rate of 0.2 L/min (Bjugstad et al. 1996). With only three studies, insufficient data is available to justify the effect of scale and its effect on increased hand exposure associated with direct emissions.
The categories from ART are adopted to categorise the scale of space spraying. In the absence of conclusive data at present, the effect of scale during space spraying is assumed to have no effect on hand exposure.

5.1.3 Direction of application

Specific literature concerning the direction of space spray applications and its effect on hand exposure is not available. As reflected spray does not occur during space spraying, dermal exposure through direct emission & contact is limited. Both small and large scale space spraying operations are generally performed in any direction, and dripping and run-off onto the hands on the hands during upward orientations cannot be excluded.
Three categories for the direction of application (as applied in ART for surface spraying) is adopted to signify the potential for increased direct emissions for 'all directions incl. upward'.

5.2 Activity transfer potential

	Determinant	Categories	Deposition	Direct emission & contact^	Transfer
See 2.3.1	Surface contamination level (Su)	See Table 2 and Tables 3a/b	-	-	-
See 2.3.2	Contact frequency (F) »hand-held tools/equipment	Short hand tool (<0.5m) excl. accessories Short hand tool (<0.5m) incl. accessories Long hand tool or extended tools (≥ 0.5m)	- - -	- - -	1 3 3
	Contact frequency (F) »(remote) control panels/devices	Repeated | almost constant use Infrequent | occasional use	- -	- -	3 |10 0.1| 1
	Contact frequency (F) »surfaces <u>at source</u> when using automated equipment *(e.g. during trouble-shooting)*	No contact Infrequent contact Occasional | repeated contact	- - -	- - -	0 0.1 1 | 3

^ Only relevant for sources in NF

5.2.1 Contact frequency

5.2.1.1 Hand-held tools/equipment

Surface spraying data suggest that there's a tendency for reduced hand exposures when spraying with long tool handles. In the absence of data, it is assumed that this evidence can also be applied for space spraying activities. Field studies also indicate that transfer appear to be an important pathway during spraying applications compared with deposition (Pronk et al, 2006; Links et al, 2007). The same categories and multipliers are proposed as for surface spraying.

5.3 Exposed surface area of the hands

	Determinant	Categories	Deposition	Direct emission & contact ^	Transfer
See section 16	Exposed surface area of hands	Short hand tool (<0.5m), excl. accessories	1	0.25	0.25
		Other hand-held tools or control panels at the source	1	0.5	0.5
		Remote control panels and devices	1	-	0.5

^ Only relevant for sources in NF

The categories applied to describe the tools & equipment used, and the use of control panels are applied to determine the exposed surface area (section 16). The same categories and multipliers are proposed as for surface spraying.

Table B1 Hand exposure data for spraying activities (AC1)

Reference	Scenario	Additional scenario information	Direction of application	Use rate (L/min)	Sample time (min)	n (#)	GM (µg/min/cm²)	Sampling method	Measurement
Baldi 2005	Tractor-mounted boomspraying	Open field, mostly closed cabins	Down	6.8	116	71	3.2	Handwashing	Unprotected
	Knapsack spraying (lance)	Open field	Down	N/A	32.0	2	2.1	Handwashing	Unprotected
	Knapsack spraying (lance)	Open field	Down	N/A	32.0	1	1.0	Handwashing	Protected
Bjugstad 1996	Knapsack mist blower	Greenhouse (narrow)	Any	2.0	480.0	3~6	8.2	Pads	Unprotected
	Knapsack spraying (lance)	Greenhouse (narrow)	Any	2.1	480.0	3~6	18.0	Pads	Unprotected
	Hand-held pistol spraying	Greenhouse (narrow)	Any	13	480.0	3~6	0.9	Pads	Unprotected
	Fogging	Greenhouse (narrow)	Any	0.193	480.0	3~6	1.8	Pads	Unprotected
Choi 2006	Hand-held lance spraying	Orchard (mandarin)	Any	7.1	45.0	4	2524.6	Cotton gloves	Unprotected
De Cock 2002	Hand-held lance spraying	Cramped room	Any	0.2	56.3	6	21.7	Cotton gloves	Unprotected
	Hand-held lance spraying	Middle-sized room	Any	0.1	81.5	4	135.7	Cotton gloves	Unprotected
	Hand-held lance spraying	Spacious room	Any	0.4	68.2	5	30.9	Cotton gloves	Unprotected
	Fogging	Middle-sized room	Any	0.7	70	1	1040.0	Cotton gloves	Unprotected
Cruz Márquez 2004	Pulled lorry spraying	Greenhouse (cramped)	Any	4.2	90.0	2	124.4	Cotton gloves	Unprotected
Delgado 2004	Hand-held pistol spraying	Painting a car, top-to-down ventilation	Level (27 level, 2 down)	0.1	15.9	29	2.6	Cotton gloves	Unprotected
Vreede 1994	Hand-held pistol spraying		Level	8.4	81.1	20	88.6	Cotton gloves	Unprotected
Vreede 1997	Hand-held lance spraying	Orchard-like (tree nursery)	Level	N/A	28.3	6	5.4	Cotton gloves	Unprotected
	Hand-held boom lance spraying	Orchard-like (tree nursery)	Level	N/A	29.2	6	13.9	Cotton gloves	Unprotected
Vreede 1997	Tractor-mounted boomspraying	Cabin, orchard-like (tree nursery)	Any	10.5	49.3	6	9.7	Cotton gloves	Unprotected
	Tractor-mounted boomspraying	No cabin, orchard-like (tree nursery)	Any	7.7	29.3	3	143.2	Cotton gloves	Unprotected
EUROPOEM-11	Knapsack spraying (lance)	Orchard	Any	0.9	35.6	15	34.4	Vinyl gloves	Unprotected
	Knapsack spraying (lance)	Orchard	Any	0.9	35.6	15	0.2	Hand washing	Protected
EUROPOEM-25	Knapsack spraying (lance)	Grass	Down	1.3	107.0	9	10.9	Cotton gloves	Unprotected
EUROPOEM-45	Tractor-mounted boomspraying	Closed cabin, open field	Down	15.9	66.3	4	1.3	Cotton gloves	Unprotected

Reference	Scenario	Additional scenario information	Direction of application	Use rate (L/min)	Sample time (min)	n (#)	GM (µg/min/cm²)	Sampling method	Measurement
	Tractor-mounted boomspraying	Open cabin, open field	Down	13.2	72.4	6	6.2	Cotton gloves	Unprotected
EUROPOEM-72	Hand-held lance spraying	Greenhouse (narrow)	Level / any	2.8	25.1	6	1.6	Cotton gloves under neoprene gloves	Protected
EUROPOEM-73	Hand-held lance spraying	Greenhouse (narrow)	Any	4.0	33.7	26	40.8	Cotton gloves	Unprotected
Gerritsen-Ebben 2009	Tractor-mounted boomspraying	Cabin, open field	Any	51.1	84.5	12	8.8	Cotton gloves	Unprotected
	Tractor-mounted boomspraying	Cabin, open field	Any	51.1	84.5	12	0.0	Cotton gloves under protective gloves	Protected
Hughes 2008	Hand-held lance spraying	Greenhouse (narrow)	Low / Level	1.0	19.3	4	85.9	Cotton gloves	Unprotected
	Hand-held lance spraying	Greenhouse (narrow)	Any	0.9	20.7	3	318.6	Cotton gloves	Unprotected
Machado Neto	Knapsack spraying (lance)	Knapsack, weeds	Down	N/A	240.0	N/A	20.6	Cotton gloves	Unprotected
Machera 2001	Knapsack spraying (lance)	Contaminated	Any	0.8	17.0	2	4596.8	Cotton gloves	Unprotected
	Knapsack spraying (lance)		Any	0.8	17.0	2	88.2	Cotton gloves under nitrile gloves	Protected
Machera 2002	Hand-held lance spraying	Greenhouse (cramped)	Any	4.5	16.6	10	440.0	Cotton gloves	Unprotected
Machera 2003	Knapsack spraying (lance)	Greenhouse (narrow), contamination in half of the samples	Any	0.8	15.0	2	1878.6	Cotton gloves	Unprotected
	Hand-held lance spraying	Greenhouse (cramped)	Any	2.4	35.0	3	81.9	Nitrile gloves	Unprotected
Nuyttens 2009	Hand-held pistol spraying	Greenhouse (narrow)	Any	3.6	N/A	8	52.5	Cotton gloves	Unprotected
	Hand-held lance spraying	Greenhouse (narrow), possible equipment defect hand exposure	Any	3.6	N/A	8	241.9	Cotton gloves	Unprotected
	Pulled lorry spraying	Greenhouse (narrow)	Any	9.1	N/A	8	152.8	Cotton gloves	Unprotected
Preller 1999	Hand-held pistol spraying	-	Any	N/A	36.8	9	308.5	Handwashig	Unprotected
	Hand-held pistol spraying	-	Any	N/A	39.4	6	23.2	Handwashig	Protected
Schipper 1996	Tractor-mounted boomspraying	Cabin, open field	Any	6.8	266	11	1.6	Cotton gloves	Unprotected
	Tractor-mounted boomspraying	No cabin, open field	Any	6.8	242	4	10.8	Cotton gloves	Unprotected
Spaan 2008	Pulled lorry spraying	Mushroom scaffolds	Any	30.9	8	2	97.8	Cotton gloves	Unprotected
	Scaffold drencher spraying	Mushroom scaffolds	Any	18.8	13	1	14796.6	Cotton gloves	Unprotected
Tsakirakis 2010	Hand-held boom lance spraying	Greenhouse (narrow)	Any	5.5	57.2	10	71.7	Nitrile gloves	Unprotected

Reference	**Scenario**	**Additional scenario information**	**Direction of application**	**Use rate (L/min)**	**Sample time (min)**	**n (#)**	**GM (µg/min/cm²)**	**Sampling method**	**Measurement**
	Hand-held boom lance spraying	Greenhouse (narrow)	Any	5.5	57.2	10	4.1	Cotton gloves under nitrile gloves	Protected
Tsakirakis 2011	Knapsack spraying (lance)	Orchard	Any	0.5	119.8	20	1.2	Nitrile gloves	Unprotected
	Knapsack spraying (lance)	Orchard	Any	0.5	119.8	20	0.0	Cotton gloves under nitrile gloves	Protected
HSE, 1999	Hand-held lance spraying	-	Any	30.5	40.4	13	4.6	Protected: under protective gloves	Protected: under protective gloves
	Airless paint lance / pistol spraying	Ship hull, high pressure	Level	0.9	106.7	6	37.8	Surrogate: cotton gloves	Surrogate: cotton gloves
	Airless paint lance / pistol spraying	Ship hull, high pressure	Level	1.9	219.0	19	0.3	-	Protected: cotton gloves
	Fogging	Fogging source at waist level	Any	0.1	60.1	8	0.0	-	Protected
Hughson 2004	Hand-held lance / pistol spraying	Large ship hull, 10% volatile	Level	0.7	101.1	12	24.0	Cotton gloves	Unprotected
Johnson 2005	Hand-held lance spraying	Pavements	Down	0.0	172.2	12	0.0	Cotton gloves under protective gloves	Protected
	ATV-mounted spray bars	Pavements	Down	2.1	33.8	21	1.8	Cotton gloves	Unprotected
TNO 2003	Handheld lance / pistol spraying		Down	5.5	12.4	5	78.6	Protective gloves(used as sampling gloves)	Unprotected
	Handheld lance / pistol spraying		Down	1.5	14.6	7	29.4	Protective gloves(used as sampling gloves)	Unprotected
Vercruysse 2000	Tractor-mounted boomspraying	Closed cabin, orchard	Any	>5	44.3	12	12.4	Cotton gloves	Unprotected
	Tractor-mounted boomspraying	Open cabin, orchard	Any	>5	82.7	7	5.3	Cotton gloves	Unprotected
	Tractor-mounted boomspraying	Closed cabin, open field	Down	32.8	18.6	6	1.7	Cotton gloves	Unprotected
	Tractor-mounted boomspraying	Open cabin, open field	Down	29.8	20.1	7	1.5	Cotton gloves	Unprotected

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6. AC2 Activities with open liquid surfaces and open reservoirs

This AC concerns activities associated with liquid products in a bath or other reservoir. ART defines two subclasses: AC2.1 activities with relatively undisturbed surfaces and AC2.2 activities with agitated surfaces. These subclasses differ mostly with respect to the contribution of the deposition route of exposure. As such, the review of these two subclasses is largely identical (except for 'level of agitation').

Although there is a clear distinction between 'dipping' and 'mixing' activities, categories are defined for determinants that integrate these different types of activities. For example, in AC2, 'manual mixing' is interpreted as the use of a mixing stick or device that is, similar to dipping activities, immersed in the liquid product. Note that immersed objects that are handled after mixing or dipping activities (e.g. in drying rooms) are considered part of AC3 (handling of contaminated objects).

Surfaces identified for AC2 include (i) immersed objects, tools & equipment, (ii) the use of remote control panels and (iii) surfaces (at source) when using automated / robotized equipment (e.g. contact during trouble-shooting) (see Table 2).

A preliminary note on the data availability of this AC: very few studies were found suitable, with often a distinction between data where protective gloves are either worn or not (actual and potential exposure). With so small a number, inter-study comparison has little merit, but intra-study data does offer insight for this review.

Table B2 gives an overview of field studies included for the AC2 review.

7. AC2.1 Activities with relatively undisturbed surfaces

7.1 Activity (direct) emission potential

	Determinant	Categories	Deposition	Direct emission & contact ^	Transfer
1.1	Level of automation »hand-held tools/equipment	Direct handling of immersed objects incl. hand immersion	-	500˜	-
		Direct handling of immersed objects excl. hand immersion	-	1	-
		Short hand tool (<0.5m)		0.3	-
		Long hand tool or extended tools (≥ 0.5m)		0.1	-
	Level of automation »control panels/devices at source	Repeated or almost constant use	-	0.1	-
		Infrequent or occasional use	-	0.01	-
1.2	Open surface areas+ ψ	Open surface > 3 m^2	0.001	10	-
		Open surface 1 - 3 m^2	0.001	10	-
		Open surface 0.3 - 1 m^2	0.001	3	-
		Open surface 0.1 – 0.3 m^2	0.001	1	-
		Open surface < 0.1 m^2	0.001	1	-
1.3	Agitation level ψ	Low agitation – careful dipping, manual mixing	-	1	-
		Moderate agitation – rapid dipping	-	3	-
1.4	Orientation of work ψ	All directions incl. upward (overhead lifting device)	-	3	-
		Horizontal and downwards	-	1	-
		Downward only	-	1	-

\+ This determinant is also an ART determinant
^ Only relevant for NF
ψ Not relevant for hand immersions
˜ See section 2.2.1

7.1.1 Level of automation

Level of automation provides an indication of the degree of manual or automated work and the approximate distance between the worker and the emission source.
While the degree of contact with contaminated or treated objects is not generally documented, some data is available on the distance between worker and exposure source. In an exposure study by HSL (HSL FS/PR/01/98), measurements were taken during dipping of various types of objects. The data was grouped into three categories: ‘far’, ‘medium’ and ‘close’ distances from the source. The ‘far’ group shows an exposure of 0.19 µg/min/cm², the ‘medium’ group an exposure of 1.29 µg/min/cm², and the ‘close’ group an exposure of 2.61 µg/min/cm².

Proposed categories

Manual dipping activities concern the immersion of objects, tools & equipment into a liquid product, whereas all automated activities are related to the use of control panel and devices. The manner in which contact is made with the immersed object is of importance. This may

occur by immersing the hands into the liquid, or using various forms of hand tools or automated systems to manually move or hoist objects. Automated systems such as hoists controlled with panels may be relevant for objects or dipping / mixing baths in the NF.
Six categories are proposed – four categories related to manual activities and two categories representing automated systems using control panels & devices at the source. A crucial differentiation in this determinant is that a separate manual activity is proposed that focuses on hand immersions.

Relative effect size
For non-hand immersion activities, data suggest that there's a tendency for reduced hand exposures when working further away from dipping activities. However, no evidence is available to substantiate this effect specifically for splashes, dripping and run-off onto the hands. Yet, it is reasonable to assume that these forms of direct emissions will be reduced when using long or extended tool handles control panels at the source (as opposed to direct manual handling of objects).
No direct emission & contact is expected to occur during automated spraying systems. An exception will be when control panels are located at the source and in close proximity of dipping operations. If so, the relevance of direct emissions for control panels at the source will be dependent on the frequency of using these controls. Overall, the potential relevance of direct emission is assumed to gradually decrease with increased distance from the source.

The case of hand immersion activities, the model requires user input to determine whether a worker is required to immerse their hands in a liquid product (or not). Direct handling of (immersed) objects (incl. hand immersion) will result in maximum skin loading of the affected surface area of the hands. The method applied to determine the hand immersion factor is described in section 2.2.1. Note that the hand immersion factor is a single all-inclusive value and that any other additional determinants are not considered (except for the exposed surface area of the hands).

7.1.2 Open surface areas
Due to the overall lack of contextual data and poor study comparability (Table B2), the data does not provide much insight into the effect of open surface areas on hand exposure. It is assumed that larger open surfaces are related to larger scale activities and related direct emissions, which will increase the potential of splashing and dripping. The ART categories are adopted to represent both the deposition and direct emission & contact routes. Despite the increased effect sizes proposed for larger surface areas, these effects should be seen in relation to potential localized control measures such as containment and the level of agitation of the process.

7.1.3 Agitation level
No conclusive data is available that report on dipping speed or mixing velocities that might indicate agitation level. Due to the overall lack of contextual data and poor study comparability, the data does not provide insight into the effect of this determinant on potential exposure rates (Table B2).
A reasonable assumption would be that a greater agitation (type of dipping, stirring or blending activity) corresponds to higher potential for splashes and thereby hand exposure. Two categories are proposed that reflect typical level of agitation possible for AC2.1. The agitation level is assumed to be limited compared to more agitated mixing processes as described in AC2.2.

7.1.4 Orientation of work

Although activities in AC2.1 will mostly describe level or downward orientations, it is common during dipping operations that cranes or hoists are used to lift objects overhead, often in close proximity of an operator. Downward and level orientations in a dipping study (HSL FS/PR/01/98) show exposure rates of 0.8 and 2.6 µg/min/cm² respectively. Roff *et al.* (2004) report exposures of 1.97 and 1.62 µg/min/cm² (under gloves) for down and level orientations respectively. Similarly, Mäkinen *et al.* (2004) report exposures of 0.04 and 0.01 µg/min/cm² for down and level orientations respectively. It is unclear if the 'level' work mentioned in field studies refer to objects that are typically below or above the hands.

Three categories are proposed to distinguish between different orientations. A moderate increase in hand exposure is proposed for the potential of dripping and splashes from dipping processes, assuming that hand exposure will increase if immersed objects are orientated above a worker's hands.

7.2 Activity transfer potential

	Determinant	Categories	Deposition	Direct emission & contact^	Transfer
See 2.3.1	Surface contamination level (Su)	Derive from Table 2 and Tables 3b	-	-	-
See 2.3.2	Contact frequency (F) »hand-held tools/equipment	Direct handling of immersed objects Short hand tool (<0.5m) Long hand tool or extended tools (≥ 0.5m)	- - -	- - -	10 3 1
	Contact frequency (F) »(remote) control panels/devices	Repeated | almost constant use Infrequent | occasional use	- -	- -	3 |10 0.1| 1
	Contact frequency (F) »product type	Dipping or mixing/agitation for treatment applications Dipping or mixing/agitation for coating purposes	- -	- -	3 1
	Contact frequency (F) »surfaces <u>at source</u> when using automated equipment *(e.g. during trouble-shooting)*	No contact Infrequent contact Occasional | repeated contact	- -	- - -	0 0.1 1 | 3

^ Only relevant for sources in NF

7.2.1 Contact frequency

7.2.1.1 Hand-held tools/equipment

The level of automation as described in the previous section not only provide an indication of the approximate distance between a worker and contaminated tools and equipment, but also the potential frequency of hand contact. The same six categories are proposed – four categories related to manual activities and two categories representing automated systems using control panels & devices. A reasonable assumption would be that the frequency of contacts with immersed objects would gradually decrease, e.g. from direct manual handling of objects to using short handled tools or equipment, followed by long or extended tool handles.

7.2.1.2 Product type

The product type relates to the purpose of the liquid used - whether it is applied on a surface for treatment or as a coating. The available data do not allow for a meaningful comparison of datasets with coating versus cleaning products (Table B2). The type of product used in immersion or mixing baths is expected to determine the probability of contact between the worker and treated or coated surfaces. It is assumed that contact with coated surfaces is easier and more commonly avoided than treated surfaces, considering the fact that coated surfaces are generally not supposed to be touched after application. In the absence of data, the effect values associated with other activities such as surface spraying operations and spreading are assumed indicative.

7.3 Exposed surface area of the hands

	Determinant	Categories	Deposition	Direct emission & contact ^	Transfer
See section 16	Exposed surface area of hands	Immersion of both full hands	1	1	0.5
		Immersion of one full hand or fingers of both hands	1	0.5	0.5
		Immersion of fingers of one hand, or less	1	0.25	0.25
		Handling of small objects with fingers or one hand palm or less	1	0.25	0.25
		Handling larger objects OR control panels/devices at source	1	0.5	0.5
		Remote control panels and devices	1	-	0.5

^ Only relevant for sources in NF

The categories applied to describe the tools & equipment used, and the use of control panels are applied to determine the exposed surface area (section 16).

For the *deposition route* – it is assumed that both hand surface areas are fully exposed (factor 1), regardless of the orientation of the hands and whether the hands are grasping surfaces.

For *hand immersions*, three categories are distinguished to establish the degree of immersion, ranging from both full hands to the immersion of fingers of one hand.

For *non-immersion* activities, for both direct emission & contact and transfer, the size of the open containers (indicative of the size of objects being handled) is applied to indicate the exposed surface area of the hands involved during dipping and mixing.

The use of control panels are assumed to involve two hand palms relevant for the transfer pathway.

8. AC2.2 Activities with agitated surfaces

8.1 Activity (direct) emission potential

	Determinant	Categories	Deposition	Direct emission & contact ^	Transfer
1.1	Level of automation »hand-held tools/equipment	Direct handling of immersed objects incl. hand immersion Direct handling of immersed objects excl. hand immersion Short hand tool (<0.5m) Long hand tool or extended tools (≥ 0.5m)	- - - -	500˜ 1 0.3 0.1	- - - -
	Level of automation »control panels/devices <u>at source</u>	Repeated or almost constant use Infrequent or occasional use	- -	0.1 0.01	- -
1.2	Open surface areas+ ψ	Open surface > 3 m^2 Open surface 1 - 3 m^2 Open surface 0.3 - 1 m^2 Open surface 0.1 – 0.3 m^2 Open surface < 0.1 m^2	0.3 0.1 0.03 0.01 0.003	10 10 3 1 1	- - - - -
1.3	Agitation level ψ	Moderate agitation, e.g. rapid dipping, electroplating High agitation, e.g. high speed mixing	- -	3 10	- -
1.4	Orientation of work ψ	All directions incl. upward (open surfaces above working level) Horizontal and downwards Downward only	- - -	3 1 1	- - -

\+ This determinant is also an ART determinant
^ Only relevant for sources in NF
ψ Not relevant for hand immersions
˜ See section 2.2.1

8.1.1 Level of automation

Level of automation provides an indication of the degree of manual or automated work and the approximate distance between the worker and the emission source. Similar to AC2.1, the same six categories are proposed – four categories related to manual activities and two categories representing automated systems using control panels & devices at the source. Likewise, the same effect sizes of categories are proposed because no conclusive evidence is available to substantiate differences between these ACs. The only exception is that ART applies different effect values for the estimation of deposition.

8.1.2 Open surface areas

In terms of open surface areas and its effect on direct emission & contact, no substantial differences are proposed compared to AC2.1. The same categories are applied from AC2.1, including the respective effect sizes.

8.1.3 Agitation level

The type of mixing activity may result in substantial differences in surface agitation, corresponding to a greater frequency of splashing and spatter. Due to the overall lack of data and poor study comparability (Table B2), the data does not provide insight into the effect of dipping speed or mixing velocities on hand exposure.

A reasonable assumption would be that a greater agitation corresponds to higher potential for splashes and thereby hand exposure. For AC2.2, the agitation level is expected to be excessive compared to less agitated dipping and mixing processes as described in AC2.1, hence the two categories proposed that reflect higher agitation levels.

8.1.4 Orientation of work

For orientation of work and its effect on direct emission & contact, no substantial differences are proposed compared to AC2.1. The same categories are applied from AC2.1, including the respective effect sizes.

8.2 Activity transfer potential

	Determinant	Categories	Deposition	Direct emission & contact^	Transfer
See 2.3.1	Surface contamination level (Su)	Derive from Table 2 and Tables 3b	-	-	-
See 2.3.2	Contact frequency (F) »hand-held tools/equipment	Direct handling of immersed objects Short hand tool (<0.5m) Long hand tool or extended tools (≥ 0.5m)	- - -	- - -	10 3 1
	Contact frequency (F) »(remote) control panels/devices	Repeated | almost constant use Infrequent | occasional use	- -	- -	3 |10 0.1| 1
	Contact frequency (F) »product type	Dipping or mixing/agitation for treatment applications Dipping or mixing/agitation for coating purposes	- -	- -	3 1
	Contact frequency (F) »surfaces at source when using automated equipment *(e.g. during trouble-shooting)*	No contact Infrequent contact Occasional | repeated contact	- - -	- - -	0 0.1 1 | 3

^ Only relevant for sources in NF

8.2.1 Contact frequency

8.2.1.1 Hand-held tools/equipment

Similar to activities with relatively undisturbed surfaces, AC2.1.

8.2.1.2 Product type
Similar to activities with relatively undisturbed surfaces, AC2.1.

8.3 Exposed surface area of the hands

	Determinant	Categories	Deposition	Direct emission & contact ^	Transfer
See section 16	Exposed surface area of hands	Immersion of both full hands	1	1	0.5
		Immersion of one full hand or fingers of both hands	1	0.5	0.5
		Immersion of fingers of one hand, or less	1	0.25	0.25
		Handling of small objects with fingers or one hand palm or less	1	0.25	0.25
		Handling larger objects OR control panels/devices at source	1	0.5	0.5
		Remote control panels and devices	1	-	0.5

^ Only relevant for sources in NF

The categories applied to describe the tools & equipment used, and the use of control panels are applied to determine the exposed surface area (section 16). The same categories and multipliers are proposed as for AC2.1.

Table B2 Hand exposure data of open liquid surfaces and reservoirs (AC2)

Ref number	Scenario	Additional scenario information	Distance to source	Orientation	Viscosity	n (#)	GM (µg/min/cm²)	Sampling method	Measurement
Roff 2004	Agitated liquid surfaces, incl. dipping	Electroplating	Close	Down / level	Water	8	1.615	Cotton gloves under protective gloves	Protected
	Agitated liquid surfaces, incl. dipping	Electroplating	Medium	Down / level	Water	13	2.187	Cotton gloves under protective gloves	Protected
	Agitated liquid surfaces, incl. dipping	Electroplating	Far	Down / level	Water	1	0.785	Cotton gloves under protective gloves	Protected
	Agitated liquid surfaces, incl. dipping	Electroplating	Close / medium / far	Down	Water	16	1.974	Cotton gloves under protective gloves	Protected
	Agitated liquid surfaces, incl. dipping	Electroplating	Close / medium / far	Level	Water	6	1.617	Cotton gloves under protective gloves	Protected
Mäkinen 2004	Agitated liquid surfaces, incl. dipping	Electroplating, remote controlled crane	Close	Down / level	Water	4	0.019	Handwashing	Unprotected
	Agitated liquid surfaces, incl. dipping	Electroplating, remote controlled crane	Medium	Down / level	Water	10	0.019	Handwashing	Unprotected
	Agitated liquid surfaces, incl. dipping	Electroplating, remote controlled crane	Far	Down / level	Water	10	0.022	Handwashing	Unprotected
	Agitated liquid surfaces, incl. dipping	Electroplating, remote controlled crane	Close / medium / far	Down	Water	12	0.040	Handwashing	Unprotected
	Agitated liquid surfaces, incl. dipping	Electroplating, remote controlled crane	Close / medium / far	Level	Water	17	0.012	Handwashing	Unprotected
HSL FS/PR/01/98	Dipping. relatively undisturbed surfaces	Fishing nets	N/A	N/A	Water	4.0	3.224	-	Protected
	Dipping. relatively undisturbed surfaces	Fishing nets	N/A	N/A	Oil	5	0.740	-	Protected
RISKOFDERM 2003	Dipping. relatively undisturbed surfaces	Degreasing	N/A	N/A	Water	17	2.083	Cotton gloves	Unprotected
HSL FS/PR/01/98	Dipping. relatively undisturbed surfaces	Various objects	Close	Down / level	Water	3	2.605	-	Protected
	Dipping. relatively undisturbed surfaces	Various objects	Medium	Down / level	Water	8	1.29	-	Protected
	Dipping. relatively undisturbed surfaces	Various objects	Far	Down / level	Water	1	0.19	-	Protected
	Dipping. relatively undisturbed surfaces	Various objects	Close / medium / far	Down	Water	7	0.80	-	Protected

Ref number	Scenario	Additional scenario information	Distance to source	Orientation	Viscosity	n (#)	GM (µg/min/cm²)	Sampling method	Measurement
	Dipping. relatively undisturbed surfaces	Various objects	Close / medium / far	Level	Water	5	2.60	-	Protected

References AC2

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EPA (2000). "Options for revising CEB's method for screening-level estimates of dermal exposure."

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Hubal, E. A. C., Suggs, J. C., Nishioka, M. G., & Ivancic, W. A. (2004). Characterizing residue transfer efficiencies using a fluorescent imaging technique. Journal of Exposure Science and Environmental Epidemiology, 15(3), 261-270.

Mäkinen, M. and M. Linnainmaa (2004). "Dermal exposure to chromium in electroplating." Annals of occupational hygiene 48(3): 277-283.

Roff, M., et al. (2004). "Dermal exposure to electroplating fluids and metalworking fluids in the UK." Annals of occupational hygiene 48(3): 209-217.

9. AC3 Handling of contaminated objects

This AC is defined as the handling of solid objects that may be contaminated with (in this case) a liquid of interest, originating from treatment or (general) contamination (Marquart et al. 2011). This may include heat drying tasks, painted surfaces or objects, maintenance of fuel pumps, coupling and decoupling of hoses or other equipment (associated with AC6), handling of contaminated tools, sorting of objects or items, assembly work, placing and collecting of a fogging device, unblocking or replacement of blocked spray nozzles, etc. It is assumed that the objects are handled after they have become contaminated (post application or post contamination). It includes the removal of a substance or product of interest (that is a surface contaminant) from surfaces or equipment being handled, incl. scrubbing, wiping, washing off (e.g. paint from equipment or tools). However it excludes the spreading of (cleaning) products onto or off surfaces.

Surfaces identified for AC3 include (i) contaminated objects, incl. treated, coated, contaminated objects (post application), (ii) the use of remote control panels and (iii) surfaces (at source) when using automated / robotized equipment (e.g. contact during trouble-shooting) (see Table 2). The transfer route (surface to skin) is considered the most important route of exposure during handling of contaminated objects. Although the direct emission & contact route is considered less important than transfer in this activity class, it is assumed possible that dripping and run-off onto the hands may occur in case of highly contaminated objects.

In the data evaluation, the use personal protective equipment is also included in the comparisons. These outcomes should therefore be interpreted with caution.

Table B3 gives an overview of the studies included for the AC3 review.

9.1 Activity (direct) emission potential

	Determinant	Categories	Deposition	Direct emission & contact^	Transfer
1.1	Level of automation »hand-held tools/equipment	Direct manual handling of objects	-	1	-
		Short hand tool (<0.5m), incl. use of cleaning materials (e.g. cloth)	-	0.3	-
		Long hand tool or extended tools (≥ 0.5m)	-	0.1	-
	Level of automation »control panels/devices <u>at source</u>	Repeated or almost constant use	-	0.1	-
		Infrequent or occasional use	-	0.01	-
1.2	Contaminated surface area+	Object surface > 3 m^2	0.001	3	-
		Object surface 1-3 m^2	0.001	3	-
		Object surface 0.3-1 m^2	0.001	1	-
		Object surface 0.1-0.3 m^2	0.001	1	-
		Object surface <0.1 m^2	0.001	1	-
1.3	Handling orientation	All directions incl. upward (incl. overhead lifting device)	-	3	-
		Horizontal and downwards OR downward only	-	1	-

	Determinant	Categories	Deposition	Direct emission & contact^	Transfer
1.4	Intensity of contamination	High - thick layer of product, e.g. coated surfaces	-	3	-
		Moderate - thin layer of product, e.g. (visible) mist deposit	-	1	-
		Low - very thin layer of product, e.g. (invisible) mist deposit	-	1	-
1.5	Proportional contamination+	High – completely contaminated; >90% of surface area	1	3	-
		Moderate – partially contaminated; 10-90 % of surface area	0.3	1	-
		Low – small fraction contaminated; <10% of surface area	0.1	1	-

+ This determinant is also an ART determinant
^ Only relevant for NF exposures

9.1.1 Level of automation

The available data (Table B3) provide little contextual information on the actual tools and equipment used to handle contaminated objects. In general, it is assumed that the work involves direct manual handling of the objects, e.g. nets, spraying hoses, saplings, timber, blocked nozzles. However, no data is available to evaluate different levels of automation such as the use of hand tools, hoists, etc, or these are not reported.

Proposed categories

The manner in which contact is made with the object is of importance. This may occur by handling the contaminated object directly, or using various forms of hand tools or automated systems. Automated systems such as hoists controlled with panels may also be relevant.
Based on this rationale, 5 categories are proposed – 3 categories related to manual activities and 2 categories representing automated systems using control panels & devices at the source.

Relative effect size

No conclusive evidence is available to underpin the effect of manual and automated handling of contaminated objects on hand exposure. A similar effect of reduced exposures with increased automation as was found in the data review of AC2 can be expected. It would be reasonable to assume that dripping and run-off onto the hands will be reduced when using long or extended tool handles or control panels at the source (as opposed to direct manual handling of the object itself). No direct emission & contact will occur during automated handling systems. However, the model includes the possibility that control panels are located at the source and in close proximity of automated handling operations. In the event that this would occur, it is assumed that direct emissions will be dependent on the frequency that an operator use these control panels. Overall, the potential relevance of direct emission is assumed to gradually decrease with increased distance from the contaminated objects handled.

9.1.2 Contaminated surface area

Contaminated surface area describes the size / surface area of objects being handled. Data regarding the contaminated surface area and its effect of hand exposure is limited (Table B3). Field measurements collected during the handling of large-scale objects such as fishing nets (HSL FFSU/03/01) and timber (Garrod *et al.* 1999) do generally show higher exposure than manipulation of small-scale objects such as equipment (HSL EH74/3) or saplings (HSL FFSU/03/01). However, comparisons are hampered by insufficient contextual information in the respective studies.
The ART categories are adopted to evaluate the potential effect of dripping and run-off onto the hands associated with different contaminated surface areas. It is assumed that direct emission & contact and hand exposure increases with larger sized surface areas.

9.1.3 Handling orientation

The handling orientation describes the position of the worker in relation to the object being handled. Limited data is available to evaluate the effect of different handling orientations. The data only concerns downward and level (manual) handling of objects and exclude any overhead work which is often associated with overhead lifting devices (Table B3). In the absence of evidence, the effect of orientation found in other activities such as dipping and mixing (AC2) provide an indicative effect value for dripping and run-off during the upward/overhead handling of contaminated objects. Two broad categories are proposed that differentiate between level/downward and upward/overhead orientations.

9.1.4 Intensity of contamination

Intensity of contamination describes the thickness of the layer of a product on a surface or object. This determinant, in combination with the proportional contamination, reflects the probability that product will drip and run-off from objects being handled. The available data reviewed provide some insight in the effect of surface contamination levels in general (Table B3). For example, saplings (HSL FFSU/03/01) that are considered touch-dry show low exposure rates (0.0001, 0.01 µg/min/cm²) compared to objects reported to be more wet, e.g. spraying equipment (HSL EH74/3) at 0.05 µg/min/cm² and fishing nets (HSL FFSU/03/01) at 0.09 µg/min/cm². A timber handling study by Garrod *et al.* (1999) reports an exposure rate of 0.36 µg/min/cm² for touch-dry timber handling (n=19), and an exposure rate of 4.18 µg/min/cm² for soaked timber handling (n=45). While the data is informative, it only concerns manual handling and it is not possible to draw conclusions regarding the contribution of direct emission to the reported hand exposures. As such, only the category ‘high - thick layer of product’ is assigned with an increased value to represent the reasonable assumption that high surface contamination levels can contribute to increased direct emissions and hand exposures.

9.1.5 Proportional contamination

Proportional contamination refers to the proportion or fraction of the total surface area of an object or surface that is contaminated by a product. This determinant, in combination with the intensity of contamination, reflects the probability that product will drip and run-off from objects being handled. The available data reviewed provide some insight in the effect of surface contamination levels in general. Although informative, it only concerns manual handling and it is not possible to draw conclusions regarding the contribution of direct emission to the reported hand exposures. Therefore, only the category ‘high – completely contaminated; >90% of surface area high - thick layer of product’ is assigned with an increased value to represent the reasonable assumption that high surface contamination levels can contribute to increased direct emissions and hand exposures.

9.2 Activity transfer potential

	Determinant	Categories	Deposition	Direct emission & contact^	Transfer
See 2.3.1	Surface contamination level (Su)	Derive from Table 2 and Table 3b	-	-	-
See 2.3.2	Contact frequency (F) »hand-held tools/equipment	Direct manual handling of objects Short hand tool (<0.5m), incl. use of cleaning materials (e.g. cloth) Long hand tool or extended tools (≥ 0.5m)	- - -	- - -	10 3 1
	Contact frequency (F) »(remote) control panels/devices	Repeated | almost constant use Infrequent | occasional use	- -	- -	3 |10 0.1| 1
	Contact frequency (F) »product type	Objects contaminated with treatment products or general deposits Objects contaminated with coating products, e.g. paints	- -	- -	3 1
	Contact frequency (F) »surfaces <u>at source</u> when using automated equipment *(e.g. during trouble-shooting)*	No contact Infrequent contact Occasional | repeated contact	- - -	- - -	0 0.1 1 | 3
See 2.3.3	Surface texture (S_t)	Objects are smooth surfaces, e.g. like glass Objects are rough surfaces, e.g. like sand paper	- -	- -	1 0.3

∩ This is an additional category and not included in ART
^ Only relevant for sources in NF

9.2.1 Contact frequency

9.2.1.1 Hand-held tools/equipment

The level of automation as described in the previous section not only provide an indication of the approximate distance between a worker and contaminated tools and equipment, but also the potential frequency of hand contact. A summary of findings from available field studies is presented in section 9.1 and Table B3. Since no contextual data is available of the frequency of contacts with objects, no conclusive evidence is available to underpin this determinant. When considering experimental studies (8.3.2.), a gradual increase in hand exposure is proposed with an increase in hand contacts with contaminated objects, varying with different levels of automation (from direct handling to long hand tools).

9.2.1.2 Product type

The available data do not allow for a meaningful comparison of datasets with coating versus cleaning products (Table B3). The type of product with which objects are contaminated is expected to determine the probability of contact with the worker. It is assumed that contact with coated surfaces is easier and more commonly avoided than treated surfaces, considering the fact that coated surfaces are generally not supposed to be touched after application. In the absence of data, the effect values associated with other activities such as surface spraying operations (AC1.1) and spreading (AC4) are assumed indicative.

9.2.2 Surface texture

The surface texture (or surface donor type) refers to the type of surface from which a surface contaminant will be transferred to the hands. The surface texture is known to affect the transfer efficiency to the skin (e.g. hands) or clothing (e.g. gloves) (Gorman Ng et al. 2013; Hubal 2004). Smooth surfaces are associated with an increased surface-to-hand transfer efficiency compared with rough surfaces. It is of particular importance during the handling of contaminated objects when the same objects with specific surface properties is of concern.

9.3 Exposed surface area of the hands

	Determinant	Categories	Deposition	Direct emission & contact ^	Transfer
See section 16	Exposed surface area of hands	Handling small objects with fingers or one hand palm or less	1	0.25	0.25
		Handling larger objects OR remote control panels/devices <u>at source</u>	1	0.5	0.5
		Remote control panels and devices	1	-	0.5

^ Only relevant for sources in NF

The categories applied to describe the tools & equipment used, and the use of control panels are applied to determine the exposed surface area (section 16). For the *deposition route* – it is assumed that both hand surface areas are fully exposed (factor 1), regardless of the orientation of the hands and whether the hands are grasping surfaces.

For the *direct emission & contact and transfer,* very small contaminated surface areas (<0.1 m^2) are assumed to involve smaller exposure surface areas of the hands (e.g. the fingers or one hand palm or less), as opposed to larger contaminated surface areas of objects.

When using control panels & devices, it is assumed to involve both hand palms.

Table B3 Hand exposure data of handling of contaminated objects (AC3)

Ref	**Scenario**	**Additional scenario information**	**Surface area**	**Contamination level**	**Surface texture**	**Orientation**	**Viscosity**	**n (#)**	**GM (µg/min/cm²)**	**Sampling method**	**Measurement**
Hughson 2004	Equipment manipulation during spraying activities	Antifouling lineman	Medium (line)	Wet	Smooth	Down	Oil	12	20.39	Cotton gloves	Unprotected
HSL EH74/3	Equipment manipulation during spraying activities	Antifouling lineman (ancillary tasks)	Medium (line)	Wet	Smooth	Down	Oil	2	0.11	-	Surrogate: cotton gloves
	Equipment manipulation during spraying activities	Antifouling lineman (ancillary tasks)	Medium (line)	Wet	Smooth	Down	Oil	5	0.05	-	Protected
Delgado 2004	Equipment washing	Cleaning with water, then rubbing dirty areas	Small (tool)	Wet	Smooth	Down / level	Water	30	16.53	Cotton gloves	Unprotected
HSL FFSU/03/01	Handling of objects	Pesticide-treated plants are packaged and planted	Medium (sapling)	Touch-dry	Rough	Level	Water	7	0.00	-	Protected
	Handling of objects	Pesticide-treated plants are packaged and planted	Medium (sapling)	Touch-dry	Rough	Level	Oil	4.0	0.01	-	Protected
HSL FFSU/03/01	Handling of objects	Re-deployment fishing nets	Medium (nets)	Touch-dry	Rough	Down / level	Water	3	0.20	-	Protected
	Handling of objects	Re-deployment fishing nets	Medium (nets)	Wet	Rough	Down / level	Oil	5	0.09	-	Protected
Castro Cano 2000	Equipment manipulation during spraying activities	Pesticide lineman	Medium (line)	Wet	Smooth	Down	Water	2	44.50	Cotton gloves	Unprotected
Garrod 1999	Handling of objects	Moving timber	Medium (timber)	Touch-dry	Rough	Down / level	Water	19	0.36	Cotton gloves under protective gloves	Protected
	Handling of objects	Moving timber	Medium (timber)	Soaked	Rough	Down / level	Water	45	4.18	Cotton gloves under protective gloves	Protected

Ref	Scenario	Additional scenario information	Surface area	Contamination level	Surface texture	Orientation	Viscosity	n (#)	GM (µg/min/cm²)	Sampling method	Measurement
EUROPOEM-45	Equipment manipulation during spraying activities	Tractor-mounted boom spraying, handling outside of cabin	Large (tractor)	Wet	Smooth	Down / level	Water	10	96.10	Nitrile gloves	Unprotected

References AC3

Castro Cano, M., et al. (2000). "Gas chromatographic method and whole body dosimetry for assessing dermal exposure of greenhouse applicators to chlorpyrifos-methyl and fenitrothion." Analytica chimica acta 423(1): 127-136.

Delgado, P., et al. (2004). Potential dermal exposure during the painting process in car body repair shops. Annals of occupational hygiene 48(3): 229-236.

EPA (2000). "Options for revising CEB's method for screening-level estimates of dermal exposure."

EUROPOEM 2002: Executive summaries of EUROPOEM studies 1-78. Study 45

Garrod, A., et al. (1999). "Exposure to preservatives used in the industrial pre-treatment of timber." Annals of occupational hygiene 43(8): 543-555.

HSL research report FFSU/03/01

Health & Safety Executive. (1999) Dermal exposure to nonagricultural pesticides (EH74/3). Exposure assessment document. Sudbury: HSE Books, Norwich, UK. ISBN 07176 17181

Hughson, G. and R. Aitken (2004). Determination of dermal exposures during mixing, spraying and wiping activities. Annals of occupational hygiene 48(3): 245-255.

Marquart, H., et al. (2011). "Classification of occupational activities for assessment of inhalation exposure." Annals of occupational hygiene 55(9): 989-1005.

10. AC4 Spreading of liquid products

This activity class includes activities in which a liquid is spread onto surfaces by using a wide range of manual or automated methods (e.g. hands, brush, roller, sponge, cloth, kitting tool, laminating, printing, etc.). It includes cleaning activities where the substance or product of interest is applied to a surface, but excludes removal of a surface contaminant layer from surfaces (e.g. cleaning contaminated spreading tools, see AC3).

The direct emission & contact route is of particular importance in the spreading activity class. For transfer, surfaces identified for spreading activities include (i) hand-held tools and equipment, (ii) the use of remote control panels and (iii) contact with treated or coated surfaces and (iv) surfaces (at source) when using automated / robotized equipment (e.g. contact during trouble-shooting) (see Table 2).

As a general note, all field study data reviewed here excludes mixing and loading activities. Also, any dedicated activities related to the exclusive maintenance or trouble-shooting of equipment or tools should be addressed in AC3. However, the dART model allows for potential contact with surfaces that are (or were) located at the source (e.g. correction of trouble-shooting laminating machine during work).

Table B4 gives an overview of the studies included for the AC4 review. All field study data reviewed here are limited to spreading activities. Mixing, loading, and handling operations are considered different activities that will be modelled separately.

10.1 Activity (direct) emission potential

	Determinant	Categories	Deposition	Direct emission & contact$^{\wedge}$	Transfer
1.1	Level of automation »hand-held tools/equipment	Using hand or cloth/sponge immersed in liquid, *incl. hand immersion*	-	500$^{\sim}$	-
		Using cloth/sponge, *excl. hand immersion*	-	1	-
		Short hand tool (<0.5m)	-	0.3	-
		Long hand tool or extended tools (≥ 0.5m)	-	0.1	-
	Level of automation »control panels/devices <u>at source</u>	Repeated or almost constant use	-	0.1	-
		Infrequent or occasional use	-	0.01	-
1.2	Scale of application$^{+\,\psi}$	Treated area > 10 m²/h$^{\cap}$	0.1	30	-
		Treated area 3-10 m²/h	0.1	10	-
		Treated area 1-3 m²/h	0.1	10	-
		Treated area 0.3-1 m²/h	0.1	3	-
		Treated area 0.1-0.3 m²/h	0.01	1	-
		Treated area < 0.1 m²/h	0.001	1	-
1.3	Direction of application $^{\psi}$	Exclusively overhead	-	10	-
		All directions incl. upward	-	3	-
		Horizontal and downwards OR Downward only	-	1	-
1.4	Tool speed and rotation $^{\psi}$	Low speed, e.g. wiping	-	1	-

	Determinant	Categories	Deposition	Direct emission & contact^	Transfer
		High speed rotational tools, e.g. rolling	-	3	-

∩ This is an additional category and not included in ART
+ This determinant is also an ART determinant
ψ Not relevant for hand immersions
˜ See section 2.2.1
^ Only relevant for NF

10.1.1 Level of automation

Level of automation provides an indication of the degree of manual or automated work and the approximate distance between the worker and the emission source. For hand-held applications, the length and size of spraying equipment can range considerably – depending on the type of application, e.g. short-handled brushes and rollers, long extended tool handles, etc.

In order to review the data, consideration was given to hand immersion activities, 'short' tools (typically brushes) and 'long' tools (typically mopping) (Table B4). The available data indicate that hand immersion is an important factor that significantly increases hand exposure. The highest exposure rates are reported by Hughson *et al.* (2004) and a car washing study (TNO 2003) (487 and 2326 µg/min/cm² respectively), in addition to two sponge cleaning operations that show considerably higher exposure rates than other spreading applications. As for non-hand immersion applications, short tools generally appear to result in higher exposure rates than long tools. Garrod *et al.* (2000) and RISKOFDERM (HSL 2003) are two field studies involving brushing activities that show high exposure rates (60.6 and 173.1 µg/min/cm² respectively). Additionally, in the aforementioned lacquer study (KRIOH 2002), short tools show a markedly higher exposure rate than long tools (3.24 vs. 0.24 µg/min/cm² respectively). On the other hand, Gijsbers *et al.* (2004) and Erikksson *et al.* (2004) fail to find this correlation, but this may be due to the fact that their extended tool is a roller and not a brush (see tool speed and rotation).

Proposed categories

Manual spreading activities concern the use of tools and equipment, which may include hand immersions in the product. Automated activities are related to the use of control panel and devices. Six categories are proposed – four categories related to manual activities and two categories representing automated systems using control panels & devices at the source.

Relative effect size

Data suggest that there's a tendency for reduced hand exposures when spreading with long tool handles as opposed to short handled tools. However, no evidence is available to substantiate this effect specifically for splashes from containers, spattering from rolling equipment, dripping from brushes and run-off from hand tools onto the hands. Yet, it is reasonable to assume that direct emissions will be reduced when using long or extended tool handles.

It is assumed that no direct emission & contact will occur during automated spreading systems. However, the model includes the possibility that control panels are located at the source and in close proximity of spreading operations. In the event that this would occur, it is assumed that direct emissions will be dependent on the frequency that an operator use these control panels. Overall, the potential relevance of direct emission is assumed to gradually decrease with increased distance from the source.

Hand immersion
The case of hand immersion activities, the model requires user input to determine whether a worker is required to immerse their hands in a liquid product (or not). Direct handling of (immersed) objects (incl. hand immersion) will result in maximum skin loading of the affected surface area of the hands. The method applied to determine the hand immersion factor is described in section 2.2.1. Note that the hand immersion factor is a single all-inclusive value and that any other additional determinants are not considered (except for the exposed surface area of the hands).

10.1.2 Scale of application
The scale of the application for spreading applications refers to the rate of using a product – expressed as the surface area treated or coated per time unit. It is assumed that an increased rate of applying surfaces relates to an increased frequency of spattering or splashing during spreading. The effect of scale of application is reflected in the available data. An antifouling paint application by Garrod et al. (2000) shows an above-average scale (22.6 m^2/h) with an above-average exposure rate (60.6 µg/min/cm^2). In comparison, a lower-scale (7.8 m^2/h) brushing application in the same study found an exposure of only 4.2 µg/min/cm^2, which is similar to a painting study by Gijsbers *et al.* (2004) which matched an average scale of 5.31 m^2/h to an exposure of 2.14 µg/min/cm^2. A floor lacquer study (KRIOH 2002) has the highest scale in the available data (approx. 160 m^2/h), but shows only a marginal exposure rate, with specialised tools and a downward orientation likely contribute to this. Of particular interest is a study by Hughson *et al.* (2004), in which sponges are used in a cleaning operation. When sorted in groups according to tools used and direction of application, two groups of scale of ~12 m^2/h show an exposure rate of ~2000 µg/min/cm^2, while two groups of scale of ~15 m^2/h show exposures of ~2800 µg/min/cm^2. However, it is possible that this difference is caused by a larger number of hand immersions in the latter groups. In general, it is possible that a correlation between scale of application and exposure is obfuscated by other variables, such as the orientation of work and hand immersions.

Categories
Five categories as proposed by ART are proposed. In ART, the highest scale category is set at > 3 m^2/h, which is exceeded by all data used in this review. For this reason, an additional category (>10 m^2/h) was added to accommodate the direct emission & contact route.

Relative effect size
Based on this evidence, the largest application rate category (treated area > 10 m^2/h) is allocated with a high effect value for potential splashes, spattering, dripping and run-off onto the hands. The remaining categories reflect a gradual decrease in direct emissions and hand exposure associated with a reduced scale.

10.1.3 Direction of application
A limited number of field studies are available that describe upward or overhead spreading applications. However, the available data does show exposures considerably higher than comparable studies without overhead/upward applications. Garrod *et al.* (2002) describe an antifouling paint application, in which the worker is positioned beneath a small boat. For a simple brushing and rolling application, it shows an

above average hand exposure rate (60.6 µg/min/cm²) compared to other brushing scenarios, (Gijsbers et al. 2004), (Roff 1997). Hughson *et al.* (2004) reports on exposure from cleaning with a sponge in multiple orientations, with the overhead orientation showing a higher exposure rate than 'level' applications (2790 vs. 2073 µg/min/cm²). Although not all studies show a difference between down and level orientations, the lowest exposure rates in the data are found in downward orientations. An example include an ink spreading study (KRIOH 2003) and a floor lacquer study (KRIOH 2002) with exposures of 0.009 and 0.24 µg/min/cm², respectively. In conclusion, the data indicate a moderate relationship between the direction of application and hand exposure. Overall, caution should be taken when comparing the data as a large number of factors may contribute to the differences in hand exposure rates.

Categories
Three categories as proposed by ART (for the deposition route) are adopted and extended for the direct emission & contact route. An additional 4th category is proposed that reflects 'exclusively overhead work'.

Relative effect size
Based on the data review, in addition to similar evidence found for activities such as surface spraying, the highest effect value is assigned to 'exclusively overhead work'. This effect is followed by the category 'all directions incl. upward' category and therefore suggesting that spattering, dripping and run-off of product will increase with upward or overhead applications, effectively increasing hand exposure.

10.1.4 Tool speed and rotation
Tool speed and rotation describes the velocity and type of application method (e.g. rotational) used. It focuses on the centrifugal forces that may reach levels where a liquid product is separated from the tool as bulk fluid, typically forming spattering. Garrod *et al.* (2002) report an above-average exposure (60.6 µg/min/cm²) for its antifoulant application which used both rollers and brushes. Gijsbers *et al.* (2004) report data for two different tool lengths; the longer tool showed a slightly elevated exposure rate compared with the shorter (2.321 µg/min/cm² vs.1.78 µg/min/cm²). If the longer tool is a paint roller instead of a brush, the rotation factor may account for the increased exposure. Eriksson *et al.* (2004) found an exposure rate of 12.49 µg/min/cm² for a paint rolling application, which is considerably higher than most simple paint brushing activities (e.g. Roff: 1~1.6 µg/min/cm², and Garrod; 4.2 µg/min/cm²).

Categories
Two categories are proposed to distinguish between low and high speed (rotational) tools.

Relative effect size
Based on the data review, an increased effect value is assigned for high speed or rotational tools suggesting that spattering, dripping and run-off of product will increase when using such tools, effectively increasing hand exposure.

10.2 Activity transfer potential

	Determinant	Categories	Deposition	Direct emission & contact^	Transfer
See 2.3.1	Surface contamination level (Su)	Derive from Table 2 and Tables 3a/b	-	-	-
See 2.3.2	Contact frequency (F) »hand-held tools/equipment	Using hand or cloth/sponge immersed in liquid Short hand tool (<0.5m), incl. accessories Short hand tool (<0.5m), excl. accessories Long hand tool or extended tools (≥ 0.5m)	- - -	- - -	10 3 1 3
	Contact frequency (F) »(remote) control panels/devices	Repeated | almost constant use Infrequent | occasional use	- -	- -	3 |10 0.1| 1
	Contact frequency (F) »product type	Spreading for treatment or other purposes Spreading for coating, e.g. ink	- -	- -	3 1
	Contact frequency (F) »restricted workspaces	Restricted workspaces (contact coated/treated surfaces) Unrestricted workspaces	- -	- -	3 0
	Contact frequency (F) »surfaces <u>at source</u> when using automated equipment *(during trouble-shooting)*	No contact Infrequent contact Occasional | repeated contact	- - -	- - -	0 0.1 1 | 3

10.2.1 Contact frequency

10.2.1.1 Hand-held tools/equipment

The level of automation as described in the previous section not only provide an indication of the approximate distance between a worker and contaminated tools and equipment, but also the potential frequency of hand contact. A summary of findings from available field studies is presented in Table B4. Although the data are inconclusive concerning the effects of tool length on hand exposure, a modest effect of tool length on dermal exposure was found. Insufficient contextual data is available to extract conclusive evidence on the effect of handling of ancillary accessories (such as paint trays, buckets, etc) during spreading activities on the frequency of hand contacts and its effect on hand exposures.

Proposed categories

Spreading activities may include the use of equipment that is immersed with the product (e.g. cloths), or using various forms of hand tools or automated systems. The model applies four tool/equipment configurations for hand-held applications and two categories for the use of (remote) control panels and devices.

Relative effect size

Data suggest that there's a tendency for reduced hand exposures when spreading with long tool handles. The frequency of hand contacts with a spreading equipment will be determined by the number of times the equipment is picked up and put down, and the number of times the equipment is switched between hands. A reasonable assumption would be that short hand tools (e.g. <0.5m) where no additional accessories are used (e.g. trays, buckets, etc), less hand contacts with equipment can be expected compared to the use of other hand-held configurations. Short hand tools are typically held in a single grip for extended periods, with occasional releases and grasping of the tool. In terms of longer / extended tools or tools where the use of additional accessories (trays, buckets, etc) are required, an increase in hand contact and hand exposure seems plausible.

10.2.1.2 Product type

The product type relates to the purpose of the liquid used - whether it is applied on a surface for treatment or as a coating. Whereas the field study data for surface spraying (AC1.1) is skewed towards agricultural treatment applications (Table B1), the spreading data (Table B4) mostly concerns coating products, which does not allow for a comprehensive evaluation of different product types (treatment vs coating). However, the available data suggest that lower hand exposure rates are associated with spreading applications of coating products, compared with other applications such as treatment or cleaning. For example, applications that spread paint, lacquer or ink show far lower exposure rates (~50 µg/min/cm²) than cleaning workers (2000 µg/min/cm²). At the same time, various determinants may contribute to this effect. For example, full hand immersion is not uncommon during cleaning operations and resulted in these high exposure levels for treatment/cleaning products. The relevance of the product type for contact frequencies with equipment, tools and surfaces are assumed to be similar for application techniques such as spraying and spreading, and therefore this determinant is also included for spreading activities (as described in AC1.1).

10.2.1.3 Restricted workspace

Restricted workspaces refer to confined workspaces that are entered during work, or treated/coated objects that restrict movement and mobility during work. Restricted workspaces are expected to affect the frequency of contact with treated or coated surfaces.

A floor lacquer study (KRIOH 2002) mentions that its workers assumed a crouched position during work with the hand exposure of 3.24 µg/min/cm², slightly above comparable studies (Roff: 1~1.6 µg/min/cm², Gijsbers; 1.78 µg/min/cm²). In this comparison, the direction of application for the lacquer study is 'down', whereas the other studies reported a level orientation, so the difference may be underestimated. Another study by Garrod *et al.* (2000) in which a boat was treated with antifouling paint reported an above average exposure for paint brushing (60.6 µg/min/cm²). Although the direction of application plays a part in this, having to work beneath a boat may constitute a cramped workspace, contributing to the found exposure. However, the available data is too limited for conclusive evidence, which could be explained by the lack of contextual information available regarding cramped workspaces in the data and other contributing determinants.

Categories

Restricted workspaces may require an awkward working posture. Restricted workspaces may include the spreading of surfaces inside objects (e.g. inside of cylinders), difficult to access spaces (e.g. crawl spaces) or walking through or working (in close proximity) of treated objects or surfaces. Two categories are proposed for this purpose: restricted and unrestricted.

Relative effect size
In the absence of conclusive evidence, the assumption is made that an increased hand exposure is associated with spreading activities in restricted workspaces. Although restricted workspaces may also affect the direct emission & contact route, it is excluded as it is addressed in the 'direction of application' and 'tool length'.

10.3 Exposed surface area of the hands

	Determinant	Categories	Deposition	Direct emission /contact ^	Transfer
See section 16	Exposed surface area of hands	Immersion of both full hands	1	1	0.5
		Immersion of one full hand or fingers of both hands	1	0.5	0.5
		Immersion of fingers of one hand, or less	1	0.25	0.25
		Using cloth/sponge, excl. hand immersion	1	0.5	0.5
		Short hand tool (<0.5m)	1	0.25	0.25
		Other hand-held tools OR control panels/devices at source	1	0.5	0.5
		Remote control panels and devices	1	-	0.5

^ Only relevant for sources in NF

The categories applied to describe the tools & equipment used, and the use of control panels are applied to determine the exposed surface area (section 16).
For the *deposition route* – it is assumed that both hand surface areas are fully exposed (factor 1), regardless of the orientation of the hands and whether the hands are grasping surfaces.
For *hand immersions*, three categories are distinguished to establish the degree of immersion, ranging from both full hands to the immersion of fingers of one hand.
For *non-immersion* activities, in case of both direct emission & contact and transfer, it is assumed that during the use of short hand tools excluding accessories (e.g. ready-to-use kit or glue) – the exposed surface area of the hands are mostly limited to the fingers or one hand palm or less. All other tools and equipment, including control panels, are assumed to involve two hand palms. When using control panels & devices, it is assumed to involve both hand palms.

Table B4 Hand exposure data of spreading activities (AC4)

Ref	Scenario	Additional scenario information	Direction of application	Viscosity		Tool length	Scale (m²/h)	Use rate (L/min)	Sample time (min)	n (#)	GM (µg/min/cm²)	Sampling method	Measurement
Lingk et. al. 2006	Brushing (paint)	-	Level	Water		Short	7.02	0.203	38	80	2.77	Cotton gloves	Unprotected
TNO 2003	Surface wiping	Hand immersion, car body	Level	Water		Sponge	N/A	N/A	8	12	487.05	Handwashing	Unprotected
HSL 2003	Brushing (cleaning)	-	Level	Honey		Short	N/A	N/A	31	5	173.14	Cotton gloves	Unprotected
KRIOH 2003	Spreading (ink)	-	Down	Water		Short	N/A	0.003	406	16	0.01	Handwashing	Protected
KRIOH 2002	Spreading (lacquer)	Uncomfortable crouched position	Down	Oil		Short	203.50	0.052	16	11	3.24	Handwashing	Unprotected
	Spreading (lacquer)	Uncomfortable crouched position	Down	Oil		Long	134.66	0.245	81	19	0.24	Handwashing	Unprotected
Hughson 2004	Surface wiping	Large scale	Down	Water		Long	12.53	0.459	11	8	1913.15	Cotton gloves over protective gloves	Unprotected
	Surface wiping	Hand immersion, large scale	Down	Water		Sponge	15.30	0.425	12	9	2835.52	Cotton gloves over protective gloves	Unprotected
	Surface wiping	Hand immersion, large scale	Level	Water		Sponge	12.11	0.438	12	5	2073.49	Cotton gloves over protective gloves	Unprotected
	Surface wiping	Hand immersion, large scale	Overhead	Water		Sponge	15.00	0.417	13	2	2790.67	Cotton gloves over protective gloves	Unprotected
Eriksson 2004	Rolling (paint)	-	Down	Honey		Long	N/A	0.476	60	30	12.49	Patches	Unprotected
Garrod 2000	Brushing and rolling (paint)	Antifouling (small boats)	Overhead	Oil		Short	22.55	0.039	96	2	60.56	Cotton gloves	Unprotected
	Brushing and rolling (paint)	Antifouling (small boats)	Overhead	Oil		Short	24.29	0.047	78	8	0.78	Cotton gloves	Protected
	Brushing (preservatives)	-	Level	Water		Short	7.80	0.035	146	13	4.22	Cotton gloves	Unprotected
	Brushing (preservatives)	-	Level	Water		Short	9.68	0.023	155	1	0.17	Cotton gloves	Protected
Gijsbers 2004	Brushing and rolling (paint)	-	Level	Water		Short	8.77	0.015	70	11	1.78	Cotton gloves	Unprotected
	Brushing and rolling (paint)	-	Level	Water		Long	3.58	0.017	78	25	2.32	Cotton gloves	Unprotected
Roff 1997	Brushing (paint)	-	Level	Spirit-based		Short	N/A	0.033	46	11	1.65	Handwashing	Unprotected
	Brushing (paint)	-	Level	Water		Short	N/A	0.028	44	13	1.03	Handwashing	Unprotected

References AC4

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11. AC5 Application of liquids in high speed processes

AC5 concerns exposure to liquids in conjunction with high velocity processes, for example metal working fluids used in CNC machining, circular saws and drills, soaked objects being centrifuged, or press printing. Activities in this activity class can vary from rotating pipes in oil drilling to small-scale hobbyist metal working machines.

Concerning the three routes of exposure - deposition will be calculated using ART. For direct emission & contact, spattering from processes and run-off or dripping from machined work pieces is considered. Note that dripping from machinery itself is considered less relevant during the use of machinery or handling of machined objects, as dripping is typically found under machinery (e.g. dripping trays) and objects is assumed to be handled in a level or downward orientation.

Contaminated surfaces for high speed processes were identified as manually operated machinery & tools, CNC machines or (remote) control panels. Other possible surfaces include ‘machined work pieces’ that are generally handled immediately after processing. Note that the exclusive handling of machined objects (when the machining process is inactive, or at other storage/handling locations) should be addressed as handling of contaminated objects (AC3).

Limited data are available to quantitatively evaluate hand exposure during high speed processes. Where possible, the available studies were evaluated and applied to devise appropriate determinants, their categories and weights.

11.1 Activity (direct) emission potential

	Determinant	Categories	Deposition	Direct emission /contact^	Transfer
1.1	Level of automation »hand-held tools/equipment	Manually operated machinery & tools	-	1	-
	Level of automation »control panels/devices at source	Repeated or almost constant use Infrequent or occasional use	- -	0.1 0.01	- -
1.2	Scale of application⁺	Large-scale activities, e.g. large scale work pieces Small-scale activities, e.g. small work pieces (e.g. <10 kg)	3 1	3 1	- -
1.3	Level of containment⁺	Open process, excl. protective screens Handling that reduces contact between product and adjacent air	1 0.3	1 0.1	- -
1.4	Tool speed and rotation	Moderate speed machinery or processing High or very high speed machinery or processing	- -	- 3	- -

⁺ This determinant is also an ART determinant
^ Only relevant for NF

11.1.1 Level of automation

Level of automation provides an indication of the degree of manual or automated work and the approximate distance between the worker and the emission source. No data could be found to evaluate the effect of manual and automated high speed processing on hand exposure. Wassemius et al (1998) found an association between the machining cycle time and relative wet time of the hands, but no association between the type of cutting machine and the predictability of the degree of wetness on the hands of machine operators. Their study did not consider the cumulative dermal loading that is associated with most dermal sampling techniques. The latter authors distinguished between:

- Computer-controlled cutting tools, automatic exchange of tools and products
- Computer-controlled cutting tools, automatic exchange of tools and manual exchange of products
- Computer-controlled cutting tools, manual exchange of tools and products
- Manually controlled cutting tools, manual exchange of tools and products

Considering the variations of manual and automated processes relevant for high speed processes, two categories are proposed to assess direct emissions (i.e. manually operated machinery & tools; control panels/devices at source).

Although no conclusive evidence is available, it would be reasonable to assume that spattering and run-off from surfaces will be reduced during (semi-)automated processes compared to manually operated machinery & tools. It is assumed that direct emission is likely to occur during the use of manually operated machinery & tools, whereas direct emissions are excluded for automated high speed processes. However, the model includes the possibility that control panels are located at the source and in close proximity of automated processes. In the event that this would occur, it is assumed that direct emissions will be dependent on the frequency that an operator use these control panels (repeated or almost constant use, versus infrequent or occasional use). Overall, the relevance of direct emission & contact is assumed to gradually decrease with increased distance from the source and reduced frequency of use.

11.1.2 Scale of application

No data could be found to evaluate the effect of scale of the application during high speed processes on hand exposure. Categories as proposed by ART is applied for the air emission and deposition route, and extended to the direct emission & contact route. In the absence of evidence, the effect value proposed in the ART model (large scale activities) for deposition is assumed representative to reflect increased spattering and hand exposure associated with the scale of application.

11.1.3 Level of containment

Wassemius et al (1998) and Wendel de Joode et al (2005) distinguished between different types of machining processes, ranging from computer-controlled cutting tools and automatic exchange of tools and machined objects, to manually controlled cutting tools and manual exchange of tools and machined objects. The larger computer controlled and automated machinery is often provided with enclosures that ensures some form of containment and potential reduction in spattering from high speed processes. Open processes were the most significant indicator of dermal exposure when sampling with both VITAE and pads. Cranes are commonly used by machine operators to move the products or machined objects (Wassenius et al, 1998; Wendel de Joode et al, 2005), which is also possible with work pieces in close proximity of workers.

Categories as proposed by ART is applied for the air emission route, and to the direct emission & contact route. An effect value is proposed to indicate a substantial reduction in spattering associated with partial enclosure of sources – comparable with the ART score assigned to the same determinant.

11.1.4 Tool speed and rotation

Tool speed and rotation describes the velocity and type of application method (e.g. rotational) used. It focuses on the centrifugal forces that may reach levels where a liquid product is separated from the tool as bulk fluid, typically forming spattering. Two categories are proposed to distinguish between moderate and high (or very high) speed processing. Only the latter category is considered in AC5 (as defined in ART). In the absence of evidence, the effect of tool speed and rotation found in other activities such as spreading (AC4) is applied, and although not directly comparable, available evidence provide some indication of the relationship between tool speed and rotation on the potential for spattering. An increased effect value is assigned for high speed processes suggesting that spattering of product will increase, effectively increasing hand exposure compared with other ACs.

11.2 Activity transfer potential

	Determinant	Categories	Deposition	Direct emission & contact^	Transfer
See 2.3.1	Surface contamination level (Su)	Derive from Table 2 and Tables 3a/b	-	-	-
See 2.3.2	Contact frequency (F) »hand-held tools/equipment	Manually operated machinery & tools	-	-	10
	Contact frequency (F) »(remote) control panels/devices (e.g. CNC machinery)	Repeated | almost constant use Infrequent | occasional use	- -	- -	3 |10 0.1| 1
	Contact frequency (F) »machined work pieces	Repeated | almost constant use Infrequent | occasional use	- -	- -	3 |10 0.1| 1
	Contact frequency (F) »surfaces <u>at source</u> when using automated equipment *(e.g. during trouble-shooting)*	No contact Infrequent contact Occasional | repeated contact	- - -	- - -	0 0.1 1 | 3

11.2.1 Contact frequency

11.2.1.1 Hand-held tools/equipment

Manually controlled cutting tools, machined work pieces or (rotating) equipment or parts typically in contact with cutting fluids are typically identified as potential surfaces exposed to during high speed processes. Hand contacts of machine operators with cutting fluid may occur during the gripping of a wet product or a tool, or the touching of machine parts that are covered with cutting fluid (Wassemius et al., 1998). For hand-held tools and equipment, a single category is proposed that represents manually controlled cutting tools and manual exchange of tools and products. In the absence of conclusive evidence, a high intensity (frequency) of hand contacts with such tools is assumed reasonable and justifiable.

11.2.1.2 Machined work pieces

In some workplaces, workers' major activities during high speed processes may involve putting in work pieces, taking work pieces out, cleaning of work pieces with compressed air and the tuning of machines (Wendel de Joode et al., 2005). The latter authors also distinguished between the number of work pieces used or handled by a worker during high speed processes, i.e. 0–53; >53–200 and >200. Although useful, the models only showed weak significance for the handling rate, which became more prominent when considering >200 and <200 work pieces handled. Cranes are commonly used by machine operators to move the products or machined objects (Wassenius et al, 1998; Wendel de Joode et al, 2005), which will affect the number of hand contacts.
Four categories are proposed (from 'no contact' to 'repeated contact') to signify the frequency of contacts with work pieces and assigned with the adapted DREAM multipliers.

11.3 Exposed surface area of the hands

	Determinant	Categories	Deposition	Direct emission & contact ^	Transfer
See section 16	Exposed surface area of hands	Manually operated machinery & tools; handling of machined objects	1	0.5	0.5
		Control panels/devices <u>at source</u>	1	0.5	0.5
		Remote control panels and devices	1	-	0.5

^ Only relevant for sources in NF

The categories applied to describe the tools & equipment used, and the use of control panels are applied to determine the exposed surface area (section 16.
For the *deposition route* – it is assumed that both hand surface areas are fully exposed (factor 1), regardless of the orientation of the hands and whether the hands are grasping surfaces.
For *direct emission & contact and transfer*, it is assumed that machinery and equipment that are handled during high speed processes will involve both hands, resulting in direct emissions and transfer on one side of both hands respectively. Likewise, when using control panels & devices, it is assumed to involve both hand palms.

References AC5

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12. AC6 Transfer of liquids

Two activity (sub) classes are defined for transfer applications: AC6.1 bottom loading, and AC6.2 falling liquids (top loading) (Marquart et al., 2011). This AC consists of activities in which a stream of liquid product is transferred from one reservoir to the next.

The two subclasses reflect the manner in which this occurs: in bottom loading, the liquid is transferred via the bottom of a container using a pressurised system. Examples include tanker loading at bulk terminals, underwing aircraft refuelling, and transfer of volatiles in bottom load tankers. Bottom loading (AC6.1) is generally used for fuels or volatile substances, and often include vapour recovery systems (thus not relevant for low volatile liquids). The coupling and decoupling of closed transfer lines and hoses, which is performed prior to or after actual transfer of liquids, are excluded in AC6. These activities are assessed in AC3 - handling of contaminated objects. For example, prior to and after transfer using mechanical transfer devices, a comprehensive protocol is followed to connect and disconnect hoses, etc.

For falling liquids (AC6.2), liquid flows from one container into another (often lower) container i.e. top loading. Examples include filling or emptying of drums, filling or emptying equipment, decanting containers, refuelling cars, over-wing aircraft refuelling, and pouring in general. Top loading techniques can be manual or mechanical – manual loading is predominant in the reviewed data, and is often done by emptying containers.

The direct emission & contact route is of particular importance in AC6.2. Direct emissions may include dripping from containers, pipes, hoses, splashes from open reservoirs or receiving vessels or containers and run-off from surfaces onto the hands.

Manual transfer equipment include (source) vessels, containers or equipment (incl. pipes, hoses, taps, dispensers) and (semi-) automated transfer / filling equipment (e.g. filling machines, bottling machines, production facilities) where (remote) control panels and devices are used. Other surfaces may be related to receiving containers and other transfer accessories (e.g. decanting containers or jugs, containers in filling machine, nozzles, extensions, trunks/snouts, funnels) (see Table 2).

Table B5 gives an overview of the studies included for the AC6 review. All field study data reviewed here are limited to transfer activities. Activities that exclusively relates to mixing, loading, and handling operations are considered different activities that will be modelled separately. However, most available data on falling liquids (or top loading activities) not only involve the manual pouring of a liquid into a tank – but may also involve mixing of products.

13. AC6.1 Bottom loading

13.1 Activity (direct) emission potential

	Determinant	Categories	Deposition	Direct emission & contact^	Transfer
1.1	Level of automation »control panels/devices at source	Repeated or almost constant use Infrequent or occasional use	- -	0 0	- -
1.2	Use rate+	Transfer of liquid product with flow of > 1000 l/minute Transfer of liquid product with flow of 100 - 1000 l/minute Transfer of liquid product with flow of 10 - 100 l/minute Transfer of liquid product with flow of 1 - 10 l/minute Transfer of liquid product with flow of 0.1 - 1 l/minute Transfer of liquid product with flow of < 0.1 l/minute	0.001 0.001 0.001 0.001 0.001 0.001	0 0 0 0 0 0	- - - - - -

\+ This determinant is also an ART determinant
^ Only relevant for NF

13.1.1 Level of automation

Level of automation provides an indication of the degree of manual or automated work and the approximate distance between the worker and the emission source. No data is available for evaluation of hand exposure during bottom loading activities (except for coupling & decoupling handling activities after these transfers). For bottom loading activities, contained systems are used and only worker exposure to control panels and devices are considered. Being closed systems, the direct emission & contact from these transfer systems are considered impossible (with the exception of accidents) and assigned with a factor 0, regardless of the frequency of using these control panels.

13.1.2 Use rate

Use rate refers to the volume of product used per time unit. The same rationale apply for this determinant as described in 1.1.

13.2 Activity transfer potential

	Determinant	Categories	Deposition	Direct emission & contact^	Transfer
See 2.3.1	Surface contamination level (Su)	Derive from Table 2 and Table 3a	-	-	-
See 2.3.2	Contact frequency (F) »(remote) control panels/devices	Repeated | almost constant use Infrequent | occasional use	- -	- -	3 | 10 0.1 | 1

^ Only relevant for sources in NF

As indicated in the Table above, the surface contamination levels and frequency of contacts with (remote) control panels & devices are described elsewhere.

13.3 Exposed surface area of the hands

	Determinant	Categories	Deposition	Direct emission & contact ^	Transfer
See section 16	Exposed surface area of hands	Control panels/devices at source	1	0.5	0.5
		Remote control panels and devices	1	-	0.5

^ Only relevant for sources in NF

The categories applied to describe the tools & equipment used, and the use of control panels are applied to determine the exposed surface area (section 16).
For the *deposition route* – it is assumed that both hand surface areas are fully exposed (factor 1), regardless of the orientation of the hands and whether the hands are grasping surfaces.
For the *direct emission & contact and transfer,* it is assumed that during the use of control panels & devices, both hand palms are involved.

14. AC6.2 Falling liquids (top loading)

14.1 Activity (direct) emission potential

	Determinant	Categories	Deposition	Direct emission & contact^	Transfer
1.1	Level of automation »hand-held tools/equipment	Manual transfer using large (>10L) containers Manual transfer using multiple small/medium containers (≤10L) Manual transfer using a single small/medium container/equipment	- - -	3 3 1	- - -
	Level of automation »control panels/devices at source	Repeated or almost constant use Infrequent or occasional use	- -	0.1 0.01	- -
1.2	Use rate+	Transfer of liquid product with flow of > 1000 l/minute Transfer of liquid product with flow of 100 - 1000 l/minute Transfer of liquid product with flow of 10 - 100 l/minute Transfer of liquid product with flow of 1 - 10 l/minute Transfer of liquid product with flow of 0.1 - 1 l/minute Transfer of liquid product with flow of < 0.1 l/minute	0.1 0.03 0.01 0.003 0.001 0.001	30 30 10 3 1 0.3	- - - - - -
1.3	Type of application+	Splash loading Submerged loading	3 1	10 1	- -
1.4	Level of containment+	Open process, e.g. transfer of liquid into open container Handling that reduces contact between product and adjacent air	1 0.3	1 0.1	- -

∩ This is an additional category and not included in ART
\+ This determinant is also an ART determinant
^ Only relevant for NF

14.1.1 Level of automation

Level of automation provides an indication of the degree of manual or automated work and the approximate distance between the worker and the emission source.

Data

Most data involve manual activities where small scale filling of canisters or backpack tanks occur, but also pouring to tank top (sprayers) and induction bowls. Two experimental studies tested the effect of container sizes and the pouring of liquids. Gilbert et al (1999) compared the pouring of 10L and 2L, both from a 10L container, and found that the full container caused the worker much more trouble, reflected in an exposure rate difference of 16.4 vs 0.5 µg/min/cm². A study by Glass et al (2009) tested three different containers: 5L, 10L and 20L. While the former two were comparable (1.4 and 1.8 µg/min/cm²), the 20L container showed an increased exposure rate (7.6 µg/min/cm²). Finally, two mixing-loading operations in the data set both reported their container size: Spaan et al (2008) used a 5L container, while Hughson et al (2004) used a 25L container. The respective exposure rates of these studies are 1.54 and 250.21 µg/min/cm², although different conditions apply.

Laboratory studies with different container sizes have shown a relationship between the container size and the amount of hand contamination and spillage (Glass et al., 2009). For tank top pouring, the smallest containers (1 litre) resulted in hand contamination of <0.01 ml in 100% of the cases, while for the largest container (10 litre), 72% of the hand contaminations were <0.01 ml. The same effect was found when pouring into induction hoppers.

The data suggest a correlation between container size and hand contamination during pouring – with an increased hand contamination when pouring from larger containers. However, container sizes should be evaluated carefully since it could be related with the 'use rate' (section 14.1.2). Also, using many small containers does not per definition mean a reduced hand contamination (due to splashes) compared with using a few large containers, although this may differ for hand exposure through transfer (hand contacts) with contaminated containers (see next section).
It is notable that hand exposures appear to be higher when not only pouring is performed, but also mixing (Table B5). Although increased exposures can be expected due to splashes and dripping associated with pouring activities, it is not addressed in AC6.2 but a separate assessment is required for mixing activities (AC2.2).

Proposed categories
Five categories are proposed to evaluate the level of automation and its effect on direct emissions during falling liquids / top loading (3 manual and 2 (semi-)automated at the source). A crude distinction between the number of events associated with manual handling of transfer equipment is proposed to indicate an increased frequency of direct emissions (e.g. splashes).

Relative effect size
No field study data is available to underpin the effect of splashes, dripping and run-off onto the hands on hand exposure. It is reasonable to assume that direct emission & contact will be reduced with more automated transfer processes, and with increased frequency of transfer events. For this purpose, a distinction is made between single and multiple events.

14.1.2 Use rate
Use rate refers to the volume of product used per time unit. Aggregation of the data into groups of <10 L/min, 10-100 L/min and >100 L/min shows exposure rates of 5.44, 12.12 and 22.70 µg/min/cm² respectively, indicating consistent increases in hand exposure rate. Gijsbers et al (2004) found that transfer of oil-like products shows a considerably lower exposure rate than the more viscous products, which could be explained by the use rate, which is much lower in the oil group (13 vs. 145 and 29 L/min). However, the viscosity itself could be contributing factor here as well. The data provides some evidence to support the assumption that use rate is correlated with hand exposure rate. Although the effect of different container sizes is also considered relevant, the use rate is considered the key exposure determinant.

The ART categories for use rate is applied for the deposition route, and extended for the direct emission & contact route. Based on the available evidence, it is assumed that use rate is related to hand exposure during top loading. In the absence of field data on the direct emission & contact in particular, it is assumed reasonable that a high use rate is associated with increased splashes, dripping and run-off during top loading activities, resulting in increased hand exposure.

14.1.3 Type of application

The type of application refers to a specific application method / technique used during an activity (sub) class. Two main types of application are relevant for falling liquids (top loading) activities. First, splash loading is the pouring of a liquid into an open reservoir from above, which may result in splashes. Second, submerged loading refers to the ‘injection’ of a liquid into a reservoir from above but beneath the surface level (not to be confused with bottom loading techniques). Besides a reduced aerosol formation (see ART) during submerged loading, it is also expected to reduce (if not eliminate) splashing during top loading activities.
The ART categories are adopted to categorise the type of application. In the absence of data, a reasonable assumption is that, similar to the effect values relevant for deposition (from ART), submerged loading will reduce splashes and potential hand exposure.

14.1.4 Level of containment

The level of containment refers to a degree of enclosure, in this case a top loading activity. This determinant is similar to ‘containment, enclosure’ discussed in the section ‘localized controls’, but more specific for this activity class as described in ART.
The size of the reservoir opening can differ considerably between different top loading operations. It may range from the use of funnels that reduces the opening size, to induction bowls and the opening size of vehicle fuel tanks. Apart from a reduced aerosol formation and potential deposition (see ART), the level of containment is assumed to reduce (if not eliminate) splashing during top loading activities.
The ART categories are adopted to categorise the level of containment. In the absence of field data, a reasonable assumption is that effect values relevant for deposition (from ART) are also relevant to indicate the reduced effect of contained top loading operations on splashes and potential hand exposure.

14.2 Activity transfer potential

	Determinant	Categories	Deposition	Direct emission & contact^	Transfer
See 2.3.1	Surface contamination level (Su)	Derive from Table 2 and Tables 3a/b	-	-	-
See 2.3.2	Contact frequency (F) »hand-held tools/equipment	Manual transfer using large (>10L) containers Manual transfer using multiple small/medium containers (≤10L) Manual transfer using a single small/medium container / equipment	- - -	- - -	10 10 3
	Contact frequency (F) »(remote) control panels/devices	Repeated | almost constant use Infrequent | occasional use	- -	- -	3 | 10 0.1 | 1
	Contact frequency (F) » receiving containers/vessels or accessories	Repeated | almost constant use Infrequent | occasional use	- -	- -	3 | 10 0.1 | 1
	Contact frequency (F) »surfaces <u>at source</u> when using automated equipment *(during trouble-shooting)*	No contact Infrequent contact Occasional | repeated contact	- - -	- - -	0 0.1 1 | 3

^ Only relevant for sources in NF

14.2.1 Contact frequency

14.2.1.1 Hand-held tools/equipment

To assess transfer through manually handling of (contaminated) containers & equipment, the frequency of hand contacts is of concern. The data suggest a correlation between container size and hand contamination during pouring – with an increased hand contamination when pouring from larger containers. However, it is not certain if these increased hand contaminations are related to direct emissions (splashes) or transfer (hand contacts), or both. Considering the observational data, the frequency of hand contacts is expected to be prominent during the manual use of containers, which involves the opening and closing of lids and manhandling during top loading. This also applies for handling of multiple pipes, hoses, taps, etc. In cases where a single container, pipe hose, dispenser, etc are used, the frequency of contacts is assumed less. Considering this, the same categories are adopted from the 'level of automation' determinant applied for the assessment of direct emissions. A reduced hand exposure is only expected with the manual transfer using a single small / medium container or equipment.

14.2.1.2 Receiving containers/vessels or accessories

Besides hand-held (source) containers & equipment (incl. pipes, hoses, taps, dispensers) used, a wide range of equipment are typically used on the 'receiving-end' of transfer operations, e.g.
receiving containers such as bottles, vessels, decanting containers or jugs, containers in filling machines, nozzles, extensions, trunks / snouts, funnels. As these accessories are often handled separately from source containers and equipment, they are specifically identified for AC6.2 (Table 2). To assess the frequency of contacts with these surfaces, the adapted DREAM categories are applied (as described in section 2.3.2).

14.3 Exposed surface area of the hands

	Determinant	Categories	Deposition	Direct emission & contact ^	Transfer
See section 16	Exposed surface area of hands	Handling of small equipment (<0.1 l/min)	1	0.25	0.25
		Other transfer equipment (>0.1 l/min) OR control panels <u>at source</u>	1	0.5	0.5
		Remote control panels and devices	1	-	0.5

^ Only relevant for sources in NF

The categories applied to describe the tools & equipment used, and the use of control panels are applied to determine the exposed surface area (section 16). For the *deposition route* – it is assumed that both hand surface areas are fully exposed (factor 1), regardless of the orientation of the hands and whether the hands are grasping surfaces.
For the *direct emission & contact and transfer,* it is assumed that during the handling of small containers, pipettes and other small transfer equipment, the fingers or one hand palm or less is used. Larger equipment are associated with the use of both hands, with potential direct emissions or transfer of either both hand palms or the back of both hands.

Table B5 Hand exposure data of transfer of liquid activities (AC6)

Ref	Scenario	Additional scenario information	Viscosity	Use rate (L/min)	Sample time (min)	n (#)	GM (µg/min/cm²)	Sampling method	Measurement
Delgado 2004	Pouring	Filling spray gun canister	Oil	0.73	2.6	27	26.25	Cotton gloves	Unprotected
Fransman 2004	Mixing & loading	Preparing drugs	Water	0.01	34.9	30	0.00	Gloves and handwashing	Unprotected
	Pouring	Decanting urine	Water	0.05	5.9	29	0.37	Gloves and handwashing	Unprotected
Gerritsen-Ebben 2009	Pouring	Filling tractor spray container	Water	NA	84.6	12	8.26	Cotton gloves over protective gloves	Unprotected
	Pouring	Filling tractor spray container	Water	NA	84.6	12	0.00	Cotton gloves onder protective gloves	Protected
Gijsbers 2004	Pouring	Into misc. container	Water	137.79	72.2	16	39.58	Cotton gloves	Unprotected
	Pouring	Into misc. container	Oil	13.03	60.6	7	1.03	Cotton gloves	Unprotected
	Pouring	Into misc. container	Honey	144.60	41.5	2	5.82	Cotton gloves	Unprotected
	Pouring	Into misc. container	Honey	28.95	55.0	5	5.98	Cotton gloves	Unprotected
	Loading	Into mixers or equipment	Water	13.98	6.2	28	54.94	Cotton gloves	Unprotected
Gilbert 1999	Pouring	10 liter container, pour 10 liter	Water		0.4	5	16.43	Cotton gloves	Unprotected
	Pouring	10 liter container, pour 2 liter	Water		0.3	5	0.50	Cotton gloves	Unprotected
HSL Poultry	Mixing & loading	Loading high pressure spray device	Water	NA	15.0	3	9.32	-	Protected
HSL report EH74/3 1999	Mixing & loading	Loading antifoulant sprayer	Oil	1.29	163.6	8	9.80	-	Surrogate: cotton gloves
	Mixing & loading	Loading antifoulant sprayer	Oil	2.29	209.8	16	0.19	-	Protected
Hughes 2008	Mixing & loading	Backpack sprayer	Water	NA	NA	6	256.83	Cotton gloves	Unprotected
Hughson 2004	Mixing & loading	Antifoulant, 25l container	Oil	1.32	73.1	9	250.21	Cotton gloves over protective gloves	Unprotected
Glass 2009	Pouring	Induction bowl, 5 L poured	Water	26.61	0.2	4	1.38	Cotton gloves	Unprotected
	Pouring	Induction bowl, 10 L poured	Water	35.74	0.3	7	1.81	Cotton gloves	Unprotected
	Pouring	Induction bowl, 20 L poured	Water	30.61	0.9	8	7.56	Cotton gloves	Unprotected
Spaan 2008	Mixing & loading	Filling tractor spray container, (5l container)	Water	NA	21.5	15	1.54	Cotton gloves	Unprotected
Vreede 1994	Mixing & loading	Filling tractor spray container	Water	9.12	15.0	20	0.72	Cotton gloves	Unprotected

Ref	Scenario	Additional scenario information	Viscosity	Use rate (L/min)	Sample time (min)	n (#)	GM (µg/min/cm²)	Sampling method	Measurement
Vreede 1997-1	Mixing & loading	Filling tractor spray container (360 ml formulation on 100l)	Water	0.05	7.6	12	0.72	Cotton gloves	Unprotected
Vreede 1997-2	Mixing & loading	Filling tractor spray container (90 ml on 100l)	Water	NA	12.2	9	1.60	Cotton gloves	Unprotected

References AC6

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15. Control measures

Localized and dispersion controls were evaluated by considering the existing control measures proposed in ART which was derived from an Exposure Control Efficacy Library (ECEL) and an expert elicitation process (Fransman et al., 2008). All ART determinants related to the control of air emission (localized controls) and dispersion (e.g. downflow systems, worker enclosures) are adopted from ART for the deposition route (see Fransman et al., 2011).

15.1 Local exhaust ventilation systems (LEVs)

The effect of LEV on air emission is addressed in ART (Fransman et al., 2011) and adopted for the deposition route (multipliers ranging from 0.5 to 0.01). These multipliers are based on studies focusing on control efficiency of LEV on inhalation exposure (Fransman et al., 2008).
Very little data is available on the effect of LEV on hand exposure (via direct emission & contact and transfer) during the application of low volatile liquids. Local exhaust ventilations (LEV) systems are generally not designed to capture direct emissions (spattering, dripping, splashes). An exception is made for some types of LEV that are used during spraying activities (AC1) where overspray, reflected spray (back-bouncing from surfaces) may occur. For example, capture velocities of LEV can be effective enough to extract (or displace) course droplets, and it is expected that receiving- and fixed LEV systems will extract course droplets away from the hands (0.3) – although less effective than for smaller aerosols (˜≤100 µm aerodynamic diameter). Movable hoods and other LEV systems are expected to reduce direct emissions less effectively (0.7). Canopy hoods, fume cupboards and laminar flow booths may require the worker to use their hands between the source and the extraction hood – and are therefore assumed to be ineffective to mitigate hand exposure (factor 1).

15.2 Containment, enclosures

ART’s containment categories are intended to evaluate air emissions from sources. Enclosures are typically provided in the form of screens, hoods or lids on or around a source, and are particularly important to control skin exposure in general. ARTs containment categories are applied to incorporate the effect of containment on the deposition route, with multipliers between 0.1 and 0.001. However, enclosing hoods are only considered relevant when hands are not used beyond the enclosure or when it is equipped with a glove box or bag.
For the control of dermal exposure, specific definitions concerning the use of ‘screens’ have to be made, as the mere presence of a screen says little about actual protection of the hands. Considering this, an additional localized control is proposed for dART, i.e. screens or protective guards (without glove ports) between the source and hands and can be defined as:
- Any screens that are fixed or mobile that are placed between the emission source and the worker, excl. glove ports
- Protective screens or guards fitted on for example the handles of hand tools, excl. glove ports

This new addition in the list of controls may not reduce air emissions (and were not defined in ART), but are expected to considerably reduce direct emissions (factor 0.1). In contrast, where screens or enclosures are fitted with glove bags or glove ports - it is assumed that exposure from any direct emissions are completely eliminated (factor 0). The effect of containment, screens and glove boxes/bags are assigned with these effect values across all activity classes.

The effect of local exhaust ventilation, screens and glove boxes are presented in the Table* below.

Determinant	Categories	Deposition	Direct emission & contact		Transfer
Local exhaust ventilation, screens, glove boxes+			**AC1**	**AC2-AC6**	
	No localised control	1	1	1	-
	Screens or protective guard (without glove ports)	1∩	0.1	0.1	-
	Low level containment	0.1	0	0	-
	Medium level containment	0.01	0	0	-
	High level containment	0.001	0	0	-
	LEV - receiving hoods: canopy hoods	0.5	1	1	-
	LEV - receiving hoods: other	0.2	0.3	1	-
	LEV - capturing hoods: fixed hoods	0.1	0.3	1	-
	LEV - capturing hoods: movable hoods	0.5	0.7	1	-
	LEV - capturing hoods: on tools	0.1	0.3	1	-
	LEV - enclosing hoods: fume cupboard (without glove box)	0.01	1	1	-
	LEV - enclosing hoods: laminar flow booth	0.1	1	1	-
	LEV - enclosing hoods: other hoods	0.1	1	1	-
	LEV – others	0.5	0.7	1	-
	Glove bags and glove boxes: glove bag (non-ventilated)	0.01	0	0	-
	Glove bags and glove boxes: glove bag (ventilated)	0.001	0	0	-
	Glove bags and glove boxes: low spec glove bag	0.001	0	0	-
	Glove bags and glove boxes: medium spec glove bag	0.0003	0	0	-
	Glove bags and glove boxes: high spec glove bag	0.0001	0	0	-

∩ This is an additional category and not included in ART

+ This determinant is also an ART determinant

**Note: ART's suppression techniques and vapour recovery systems are not relevant for low-volatiles and are excluded. Also, determinants related to control of dispersion (e.g. downflow systems, worker enclosures) are adopted from ART for the deposition route (see Fransman et al., 2011).*

15.3 Other controls

A large number of (administrative) controls can be applied to reduce dermal exposures. Where appropriate, these controls are included as determinants in the model (e.g. 'availability' where the curing/drying time is considered before commencing with work). Other determinants such as specialized surface cleaning methods (such as vacuuming prior to handling) are not specifically addressed and it is advised that the relevant 'surface contamination level' (at the time of handling) is applied in such cases. If automated processes are introduced in the workplace (which will imply a new activity and exposure scenario), the dART model requires the assessment of the new activity.

Hand protection such as gloves is not applied in the mechanistic model, but included in the exposure estimates (using the calibration model) where a model user can apply their own preferred (regulatory) glove protection values. A brief review is provided in the Appendix (section 18).

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16. Exposed surface area of the hands

Exposed surface area is defined as the proportion of the skin surface area of a specific body part, whether protected or unprotected, that potentially receives exposure (fraction of hands affected). It is widely acknowledged as an important factor in dermal exposure models (EPA, 2011) and illustrated in visualization techniques (Cherrie et al, 2000; Brouwer et al, 1999). The actual proportion of the skin surface area of specific body parts receiving exposure is relatively small and highly variable (Fenske et al., 1990), which can best be demonstrated with visualization data. It has been postulated that dermal exposure that originates from immersion or deposition will represent a more uniform exposure distribution on the body (and body parts) than exposure originating from splashes and surface contact (Vermeulen et al., 2002).
It was decided to apply an indicative categorization to assess the (potential) exposed surface area for each exposure route (ESA_{dp}, ESA_e, ESA_t), i.e. where both hands are assigned with a factor 1 (fraction of 100%), both hand palms or fingers of both hands with a fraction of 50% (factor 0.5) and one hand palm or fingers of one hand (25%; factor 0.25).
These generic categories were applied based on descriptive information of the type of equipment used or work performed to assess the exposed surface area of each AC (Table 5).

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17. Removal processes

As the removal from the hands or gloves is closely related with dermal sampling techniques, this variable was not included in the mechanistic model but evaluated in the calibration with measurement data (McNally et al., 2018). A pronounced increase in retention during hand immersion was found with increased viscosity levels when both wipe samples and cotton glove samplers were used to sample glycerol solution, with much higher mass retention for cotton gloves (Gorman et al., 2014; Gorman et al, 2013). The dART model is calibrated with dermal exposure data using different sampling techniques, hence the effect of factors such as viscosity on these sampling techniques should also be considered. Overall, evidence is still inconclusive on the relationship between viscosity, the activity or way it is brought onto the skin (apart from hand immersions) and considering different sampling methods.

Various experimental studies found that increasing viscosity (and stickiness) resulted in significant higher dermal exposure (Gorman NG et al., 2012; Cinalli et al., 1992). Assuming that hand immersion studies are indicative of the retention of substances on the skin (i.e. after skin loading via different routes), water-like substances has shown to result in a reduced film thickness on the hands (4.99^{-3} cm) compared to a range of different viscous oily substances (˜8.7^{-3} cm), suggesting a factor of ˜0.5 difference (EPA, 2011). This effect can be more significant, as indicated by the immersion studies by Gorman Ng et al (2012) where a factor 0.11 difference was found for dermal loading of the index finger when immersed into respectively 20% and 87% glycerol solutions (2730 ug/cm^2 and 23760 µg/cm^2).

Other removal processes, such as handwashing, are not included in the model and will influence the hand exposure over the day. Therefore, a model user wishing to combine estimates from the dART model to a single work shift exposure value, should evaluate the influences of such processes on a case-by-case basis.

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18. Hand protection

The dART model does not provide a protection factor for glove use, however, a model user has the option to adopt their own protection value for gloves for a given workplace scenario. Tests on protective gloves in control conditions only provide a theoretical optimum protection level that is unlikely to be offered to the wearer of such gloves. An analysis of glove protection for five groups of gloves (i.e. butyl/neoprene, latex/PE/vinyl/PVC, nitrile, plastic/rubber and unspecified) (n=508), the geometric mean migration of pesticide through gloves was found to be 0.82% (99.2% protection), with a P75 of 3.95% (96.1% protection) and a P90 of 14.48% (85.5% protection) (Spaan et al., 2013). Creely & Cherrie (2001) found protection factors to range from 96 to 470 (98.96 – 99.79% effective) for two nitrile and PVC gloves, while an average reduction was found between 80.5 and 99.99% by Marquart et al (2016), of which six sets with an average reduction of >95%. A 10^{th} percentile of protection factors for thin 'splash-resistant single-use' (SRSU) gloves against liquids are proposed by Roff (2015), i.e. 7–10, or ˜86% - 90%. Overall, the effect of gloves should be interpreted with caution and on a case-by-case basis.

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