INTEGRA

Integrated External and Internal Exposure Modelling Platform

(INTEGRA)

B11 - Realistic estimation of exposure to substances from multiple sources
(CEFIC Long-range Research Initiative funded project)

A METHODOLOGICAL FRAMEWORK FOR EXTERNAL EXPOSURE ASSESSMENT IN OCCUPATIONAL SETTINGS

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A. Introduction

A.1 The INTEGRA project

The Integrated External and Internal Exposure Modelling Platform (INTEGRA) project aims to develop a coherent methodological framework to assess the source-to-dose continuum for the entire life cycle of chemicals. The major component of INTEGRA will be a unified computational platform that integrates environmental fate, exposure and internal dose dynamically in time. The computational platform will be based on the existing platform developed in the CEFIC-LRI INTERA[1] and TAGS[2] projects, extended to incorporate several advances, including occupational exposure assessment.

The project is structured into seven work packages that cover stakeholder engagement to define the functional specifications and the applicability domain of the INTEGRA platform, the definition of exposure assessment and physiologically-based pharmacokinetic (PBPK) modelling approaches to be implemented, the validation of the platform outcomes, dissemination activities and project management.

In terms of occupational exposure, the current state of the art is represented by the ECETOC TRA (Targeted Risk Assessment) and the ART (Advanced Reach Tool): TRA as a Tier 1 screening tool for both inhalation and dermal exposure and ART as a higher tier inhalation exposure assessment tool. Further developments of ART are in progress, in particular the development of an occupational dermal exposure tool (DART).

This report discusses the available exposure models for occupational settings and sets out proposals for implementing the framework for inhalation and dermal exposure assessment, and considers whether it is practicable to include exposure by inadvertent ingestion, e.g. from hand-to-mouth contact.

A.2 Occupational exposure, exposure pathways and routes

A.2.1 Inhalation exposure

External exposure for occupational inhalation exposure is usually expressed as the concentration of the contaminant in the worker's breathing zone, i.e. close to their nose and mouth, usually averaged over an 8-hour working day. Task-based measurements may also be provided in some circumstances. It is likely that exposure is reported for groups of workers who were judged to be part of a similarly exposed group, for example a job classification or work area. The data may be summarised as some measure of the group average exposure and the variability, such as geometric mean (GM) and geometric standard deviation (GSD). Inhalation exposures can often be approximately described by a log-normal distribution.

A.2.2 Dermal exposure

For occupational dermal exposure the situation is more complex because the methodologies for measurement are not standardised and the level that is reported depends on the media used to collect the sample. There are three types of sampling system used:

[1] http://www.intera-home.eu/TheProject.aspx
[2] http://www.tags.cperi.certh.gr/index.php?option=com_content&view=frontpage&Itemid=1

- interception methods that use a small pad of collection media placed at the skin surface or use absorbent work clothing to collect the contaminant;
- removal of contaminant from the skin surface (also known as the skin contaminant layer (SCL)) by washing or wiping the skin at a specified time, tape stripping, or the end of the sampling period;
- direct assessment using in-situ detection of the agent or a tracer compound (often a fluorescent material) at the skin surface, e.g. by image acquisition and processing systems, at a specific time.

Occupational dermal exposure data may refer to either a full working shift or may be for a specific work task. Data are often summarised by similarly exposed group as is done for inhalation exposure.

All of the above dermal sampling methods provide measures that are expressed in terms of mass of the contaminant, but they do not provide comparable measures. For example, measurements made using an interception sampler will generally be higher than corresponding measures with removal or direct assessment methodologies. Gorman-Ng *et al* (in preparation) carried out a small laboratory pilot study using simple model compounds to compare different dermal sampling methods. They found that wipe and rinse methods generally gave comparable results for Epsom salts and zinc oxide, but wiping recovered four of five times more calcium acetate contaminant than washing. For glycerol solutions, measurements using interception samplers (gloves) were consistently higher than wipe samples, and at lower levels of exposure the relative difference between the two methods was greater than at higher levels. They concluded that further research is necessary to enable conversion of exposure measurements from one metric to another, so as to facilitate more reliable dermal risk assessment.

Other measures relevant to dermal exposure are only infrequently reported, e.g. the area of skin exposed, the duration of exposure and the concentration of the contaminant in the skin contamination layer. However, these measures are important in assessing the amount of contaminant that may be taken up through the skin.

A.2.3 Ingestion exposure

Occupational inadvertent ingestion exposure is defined as ingestion exposure due to contact between the mouth and contaminated hands or objects. Typically, it has received little attention but it has been estimated that about 15% of the UK working population may be at risk of exposure to hazardous substances by inadvertent ingestion (Cherrie *et al,* 2006).

A.2.4 Exposure pathways

Source-receptor mass-balance models are often used in analysing occupational exposure processes. In these systems the source is the processes where the contaminant materials is used or generated, for example a bag filling machine or the electrical discharge point in a welding process. The receptor is the portal of entry into the body of the worker, i.e. inhalation into the nose or mouth, ingestion into the mouth, contact with the skin or injection through the skin. The sources, receptors and intermediate environmental reservoirs may be conceptualised as ‘compartments’ and the pathways as connecting ‘channels’ along which contaminant mass may flow.

A simple conceptualisation of inhalation exposure is shown in Figure 1.1.

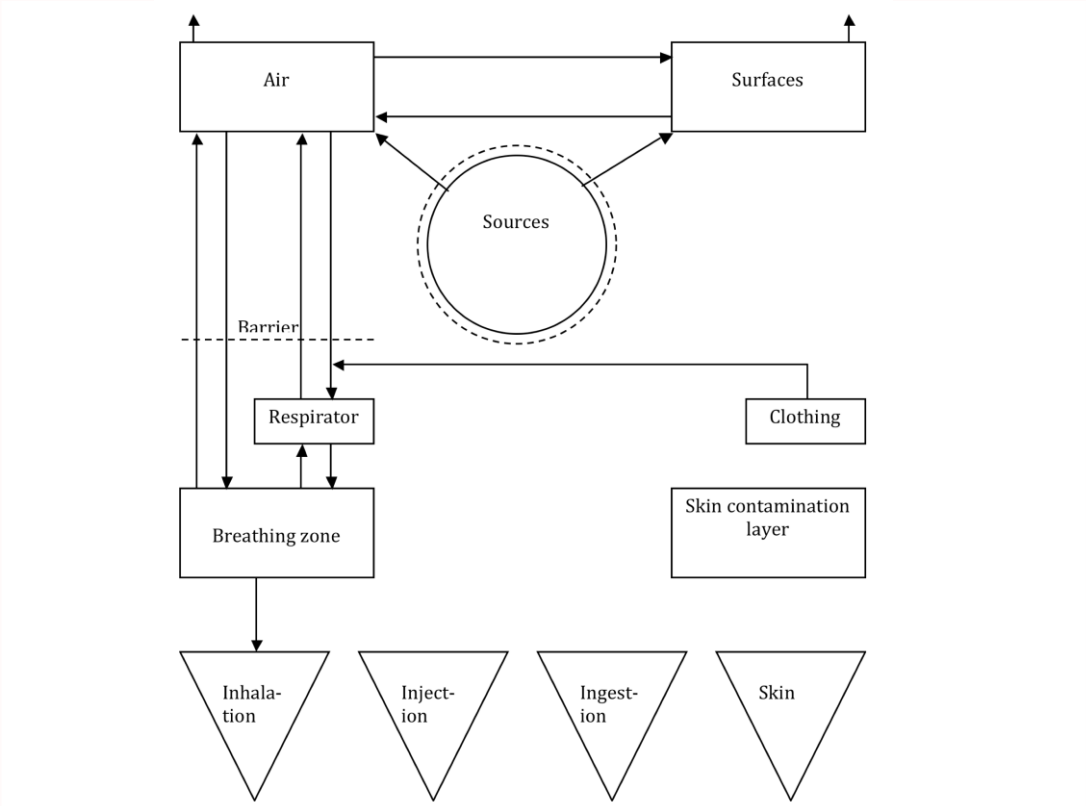

Figure 1.1 A conceptual model of inhalation exposure

In this model there are six environmental compartments: workroom air, surfaces, respirators, clothing, breathing zone and the skin contamination layer (although this is not directly involved in the pathways for inhalation exposure). Each compartment may contain some contaminant mass, and may have other descriptive characteristics, e.g. volume for the air compartment and area contaminated for the surfaces. The lines with arrows show the possible direction of flow of mass contamination. The four portals of entry into the body (routes) and shown as triangles at the bottom of the diagram.

Similar conceptual models for dermal and ingestion exposure are shown in Figures 1.2 and 1.3, respectively.

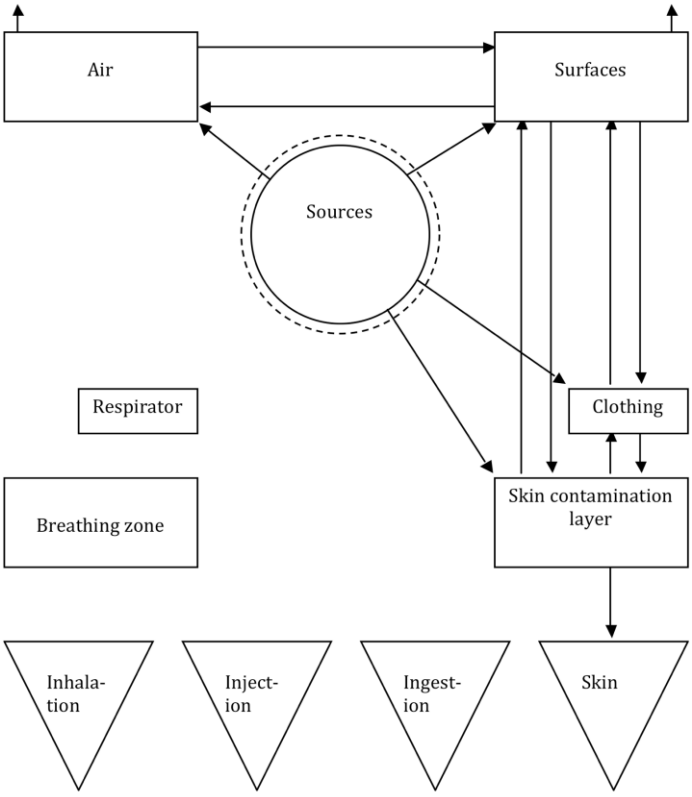

Figure 1.2 A conceptual model of dermal exposure

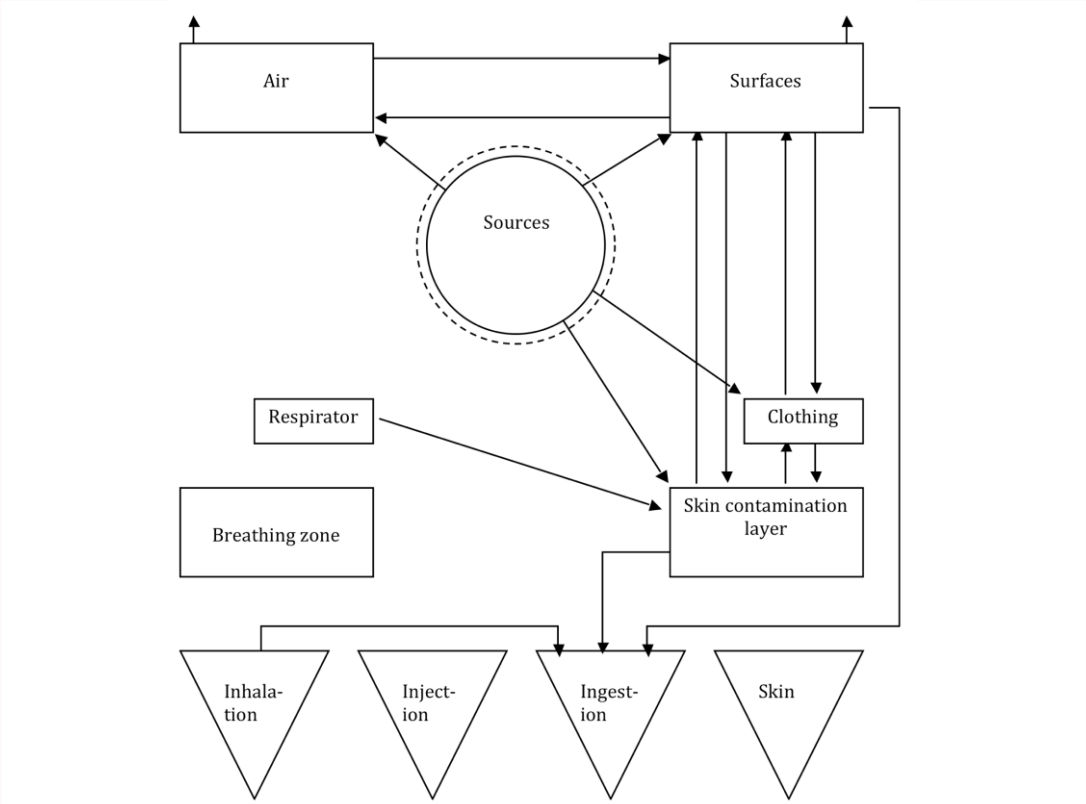

Figure 1.3 A conceptual model of inadvertent ingestion exposure

All three models illustrate the potential interconnections between exposures by different routes and, for example, the air and surface compartments may influence exposure by inhalation, ingestion and skin contact. In particular there is a close association between inadvertent ingestion and hand skin exposure because of the key role of hand-to-mouth transfer for inadvertent ingestion.

A.3 Aims and objectives of this report

This report reviews the available modelling tools to define the INTEGRA methodological framework for external exposure in occupational settings. In particular the report defines the input and output variables from the identified models, the underlying model equations and how the tools could be adapted to provide input to the INTEGRA PBPK model. It also discusses the strengths and weaknesses of combining modelled external exposure data from different routes.

B. Inhalation exposure models

B.1 General review of available models

There is a wide range of model tools available for estimating inhalation exposure, many of which have been developed in support of the REACH Regulations. Tier 1 screening tools include COSHH-Essentials, ECETOC Targeted Risk Assessment (TRA) tools, Exposure Assessment Tool

for Metals and Inorganic Substances (MEASE), Easy-to-use workplace control scheme for hazardous substances (EMKG) and Stoffenmanager. A comprehensive review of these models is currently being carried out as part of the E-TEAM project[3]. Tier 1 tools generally provide conservative estimates of worker exposure and can be used to screen for chemicals and scenarios where risk cannot be ruled out. If a Tier 1 assessment does not demonstrate an adequate level of protection, then a Tier 2 assessment may be required. A Tier 2 modeling tool, the Advanced REACH Tool (ART) has recently been developed for use in REACH (Fransman *et al,* 2011, Tielemans *et al,* 2011, Schinkel *et al,* 2013). The INTEGRA project decided *a priori* to focus on ART as the occupational exposure tool for inhalation.

B.2 The Advanced REACH Tool (ART)

The ART is a web-based software tool that combines a mechanistic model with a Bayesian component that can be used to update exposure estimates with measurement data. The tool is freely available online[4] at The overall design architecture of ART is shown in Figure 2.1. A detailed description of the mechanistic model, underlying assumptions, assignment of model scores and calibrations can be found in the final project report (Fransman *et al,* 2013) and in various papers (Fransman *et al,* 2011, Schinkel *et al,* 2013).

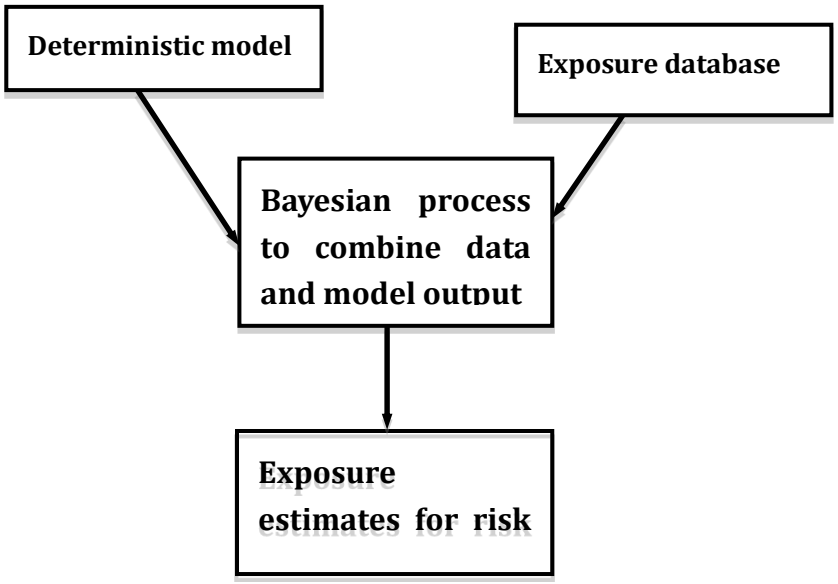

Figure 2.1 Schematic outline of ART

B.2.1 Mechanistic model

The mechanistic model is described in Fransman *et al* (2011). It is based on a conceptual framework that uses a source receptor approach (Cherrie and Schneider (1999), Tielemans *et al,* (2008)). The workspace is divided into two compartments: the near-field centred on the worker

[3] http://www.eteam-project.eu/
[4] https://www.advancedreachtool.com/.

(within 1 m from the worker's head) and the far-field comprised of the rest of the workplace. Total personal exposure is then the sum of contributions from near-field and far-field sources. The equations used in the model are outlined in Appendix 1.

Seven modifying factors (MFs) are incorporated into the model: substance emission potential; activity emission potential; localised control; dilution; segregation; separation and surface contamination/fugitive emissions. These are described briefly in Table 2.1.

Table 2.1 Description of potential modifying factors (MFs) (from Tielemans *et al,* 2008)

Principal MFs	**Description**
Substance emission potential	Determines the intrinsic emission potential of a substance (e.g. dustiness for particulate agents and volatility for liquids).
Activity emission potential	Describes the potential of the activity to generate exposure and is determined by the following characteristics: type and amount of energy transfer (e.g. amount of product used), and product-to-air interface (e.g. level of containment).
Localised controls	Control measures in close proximity of the source intended to remove emissions (e.g. LEV, wet suppression techniques).
Segregation	Isolation of sources from the work environment without containment of the source itself (e.g. separate drying room).
Dispersion (dilution)	Natural and mechanical ventilation characteristics, determining the dilution of air contaminants through the room, i.e. between NF-FF zone and FF outside.
Personal enclosure (separation)	Providing a worker with a personal enclosure within a work environment (e.g. air conditioned cabin).
Surface contamination and fugitive emissions	Emission related to release of deposited contaminants on surrounding surfaces (including worker clothing) due to natural means or general workplace activities (e.g. moving equipment/vehicles) and unintended and unpredictable leaks from process equipment.

The MFs and the development of a classification and relative scoring system for each MF is described in detail in the ART report. The systems were based on reviews of the scientific literature, measured exposure data, and expert judgement. They were then reviewed by one or more independent experts from industry, research institutes, and public authorities.

A list of parameters required to run this model can be found in Appendix 2.

The model produces an exposure score that provides a relative ranking of geometric mean exposure levels for different scenarios. Estimates of between-company, between-worker and within-worker variability, which were derived from the literature (Kromhout *et al,* 1993; Symanski *et al,* 2006), are used to provide initial estimates of the variability of an exposure distribution for a particular scenario. These scores are then calibrated using a comprehensive database containing exposure measurements covering various substances, occupational settings, time periods and countries (Schinkel *et al,* 2011) to provide estimates of exposure (full-shift and long-term average) in mg/m^3.

B.2.2 Bayesian update

A Bayesian approach is used to combine the model estimates with measured exposure levels to provide updated exposure estimates. This is fully described in a paper by McNally *et al* (2013) and presented in Schinkel *et al (*2013).

The estimates can be updated using either the user's own uploaded data or one or more analogous measurement series selected from the ART database (Schinkel *et al,* 2013) or a combination of the two.

If the user's own data is used, it is recommended that only measurements collected from scenarios which are fully analogous be uploaded to that being assessed are used.

If the user chooses to select data from the ART exposure library, based on the input parameters, ART will select any analogous scenarios which can then be browsed to select the appropriate one. Each has a description and summary statistics are presented. It is important that the user ensures that the chosen scenario is analogous to that being assessed, otherwise the estimates may be biased.

Currently, the ART database contains data for 117 different exposure scenarios which comprise 1944 individual measurements (Schinkel *et al,* 2013). These scenarios covering handling solid objects, handling powders, granules or pelletised material, handling low-volatility liquids, handling volatile liquids and handling liquids in which powders are dissolved or dispersed.

Both parts are combined in a Bayesian statistical framework in order to produce more precise estimates for specific exposure scenarios.

Updating the mechanistic model using Bayesian techniques will result in a reduction in uncertainty of the estimate of a particular percentile and hence more precise estimates for specific exposure scenarios. The influence which the data has depends on the number of measurements, variability of the data and number of workers and companies covered and how similar the model scenario is to the measured scenario.

B.2.3 Using the model

Currently the model is web based and the user enters information for each scenario separately. The steps in the ART mechanistic model are shown in Figure 2.2. Information on the scenario and substance used are required first. Next, up to four activities for the scenario can be defined, along with their duration. A non-exposure period can also be used and assigned a duration period. The duration of activities and non-exposure period should be 480 minutes. Although it is still possible to obtain an exposure assessment caution should be exercised in their interpretation since ART variability estimates are based on shift measurements.

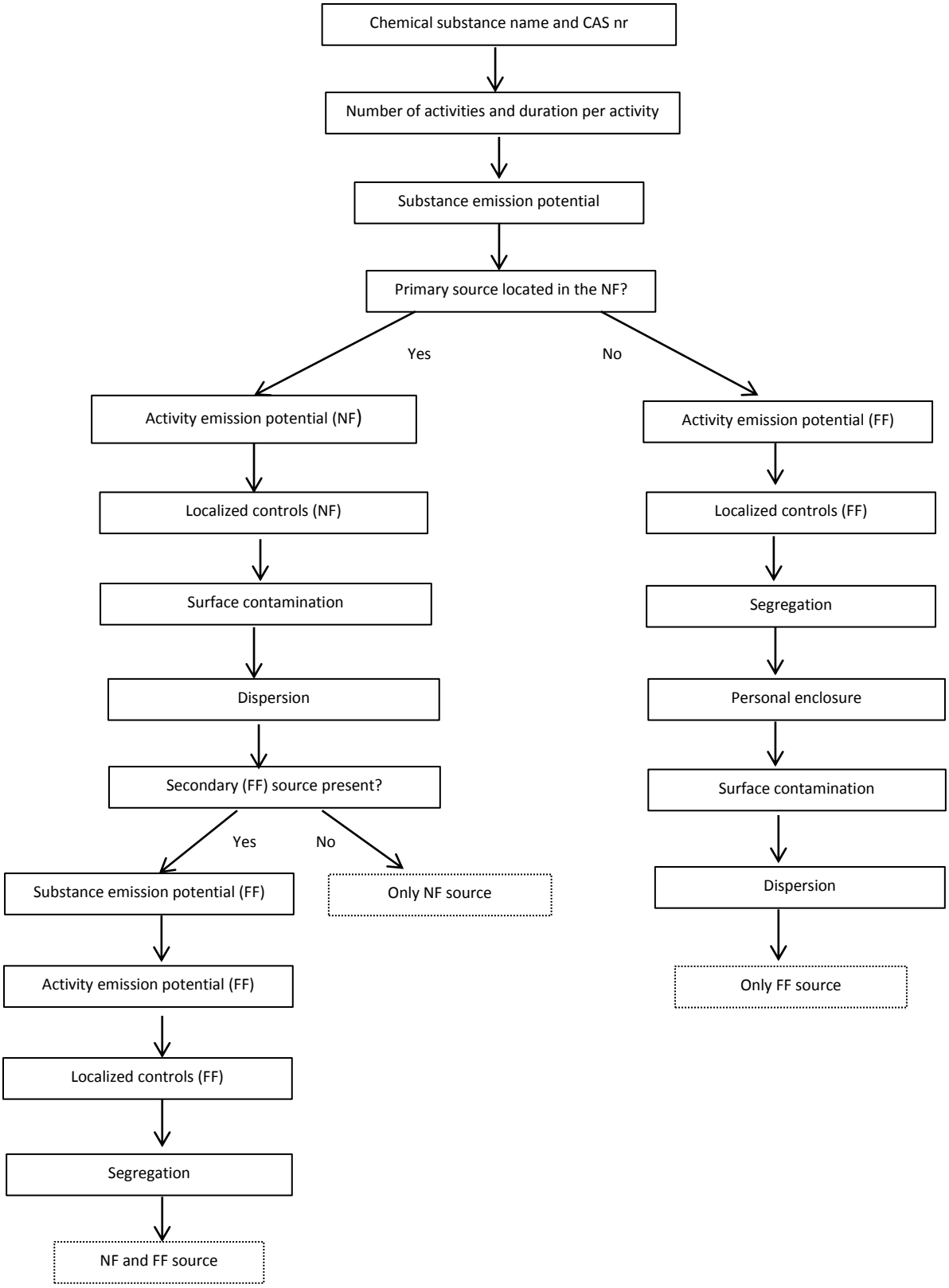

Figure 2.2 Workflow of the ART mechanistic model (from the ART report)

For each activity information on exposure determinants is selected to allow the modifying factors to be calculated. As shown in Table 2.2.

Table 2.2 Input for configuration of each activity (from the ART guidance[5])

Product type	Various product types can be used at the workplace. In ART the following types can be selected: - Powders, granules, or pellitized material - Solid objects - Liquids - Powder dissolved in a liquid or incorporated in a liquid matrix - Paste, slurry or clearly (soaked) wet powder
Substance emission	Based on the above selected product type, the user has to indicate the intrinsic emission potential of a substance, e.g. dustiness for powders and volatility for liquids.
Activity Class (AC)	Subsequently, the user has to select an AC. An AC is a generic group of activities with similar underlying determinants for the emission potential of an activity (e.g., spray applications; handling of contaminated objects, etc.). The list of possible AC depends on the product type. One to four questions then follow that determine the exposure emission potential of the activity. Each AC has a unique set of questions.
Localised controls	The user can choose from a generic list of types of localized controls (e.g., suppression techniques, containment, type of local exhaust ventilation).
Surface contamination	Questions relating to the level of general housekeeping give an indication of the contribution to exposure from re-suspension of deposited contaminants on surrounding surfaces.
Dispersion	ART will estimate the effect of dispersion for indoor, outdoor, spray room or downward laminar flow booth environments. For example, for indoor environments the level of dispersion is based on the room size and number of air changes per hour.
Segregation	The user can select from a list of types of isolation of the source from the work environment.
Separation	The user can select from a list of types of personal enclosure within a work environment.

With the exception of segregation and separation, which only apply to the far-field, all other exposure determinants have to be considered for both near-field and far-field.

[5] https://www.advancedreachtool.com/support.aspx

Once all activities have been configured, the mechanistic model can be run. At this stage it is possible to go back and revise the input parameters and re-run the model.

Exposure estimates can then be updated using the Bayesian model and measured exposure data (either the user's own or from the ART exposure measurement database).

Exposure concentrations vary within an exposure scenario either due to variability which reflects true differences in exposure situations or uncertainty which reflects lack of knowledge about the situation and/or limitations of the model. Both can be accounted for in the ART model. Variability is accounted for by selecting different percentiles of the exposure distribution (50th, 75th, 90th, 95th or 99th). The level of uncertainty around the percentile is accounted for by selecting different confidence intervals around that percentile (inter-quartile, 80%, 90% or 95% confidence interval).

Two different exposure predictions are produced: full-shift exposure and long-term average exposure. Both are represented by the 90th percentile

B.2.4 Further development of the ART exposure database

ART can currently be used to assess exposure to a wide variety of substances: inhalable dust; vapours and mists. Due to lack of suitable calibration data, ART currently cannot be used for the assessment of fumes, fibres, gases, and dust resulting from emissions during hot metallurgical processes. However, the model is continually evolving and developing, although it is not anticipated that such developments will happen within the lifetime of this project.

As yet, there may not be any analogous scenarios in the database for a user's particular scenario. However, it is anticipated that as more exposure measurement scenarios are added to the ART exposure database, the applicability of ART will increase.

Proposed future developments will allow users to upload their own data with standardised exposure data specification and template, screening system and appropriate guidance being developed (Schinkel *et al,* 2013). This will not happen within the lifetime of this project.

B.2.5 Respiratory protection

ART provides output in the form of the concentration (mg/m^3) outside respiratory protective equipment (RPE). As yet, there is no provision in ART to account for the effect of RPE and some adjustment will have to be made to account for the reduction in uptake from its use.

Cherrie *et al* (2011) carried out a limited literature review of the effectiveness of respiratory protection. The degree of protection provided by a respirator in terms of the effectiveness to reduce exposure is usually presented a protection factor (PF), i.e. the ratio of the exposure level outside the device to that inside the facepiece. PFs can easily be converted to efficiencies, for example, a PF of 10 implies that a respirator is 90% efficient and a PF of 100 is equivalent to 99% efficiency in reducing exposure. The assignment of PFs is described in various national standards and the approach is generally based on the 95th percentile of the distribution of PFs rather than a measure of the average protection afforded (Howie, 2005). It is therefore argued that assigned PFs are a poor guide to the typical protection provided by respirators.

PFs obtained from experimental or semi experimental situations often suggest greater reductions in exposure are possible than is the case in real work situations. In a summary of a small number of studies, Howie (2005) suggested that there could be a difference of up to two orders of magnitude in PF, i.e. a change in efficiency from 98.2% to 99.99%.

Nicas and Neuhaus (2004) reported a statistical methodology to assess the appropriate assigned PF, taking into account information about within and between worker variation in PF data from research studies. They assessed their method using data from nine research studies reported in the literature: seven for half-mask respirators and two powered air purifying respirators (PAPR). Cherrie *et al* (2011) used the information presented in this review and reported geometric mean PF and APF as shown in Table 2.3.

Table 2.3 Summary of geometric mean PF and APF from the review (Nicas & Neuhaus, 2004)

Respirator type	Scenario	GM PF	GM efficiency (%)	APF	Lower bound efficacy (%)
Half-mask	Mercury vapour	28	96	5	80
	Styrene	80	99	5	80
	Dust	17	94	1	-
	Dust in foundry operations	74	99	1	-
	Dust in steel-mill work	260	99.6	12	91.7
	Paint spraying	4000	99.98	170	99.4
	Styrene	38	97	4	75
PAPR	Secondary lead smelter	170	99	6	83
	Lead battery manufacturing	120	99	8	87

Cherrie *et al* concluded that the typical effectiveness of half-mask respirators is about 95%, with the lower bound of effectiveness being about 75%. PAPRs were generally 99% effective, with a lower bound of 85%. Where necessary these figures could be used to adjust estimates of exposure from ART by applying multiplicatively. In the current study it is recommended the use of geometric mean PFs to adjust exposure. RPE is often only used for one task. In that case exposure may need to be estimated for each task separately in ART, the results exported, correction for RPE applied to the relevant task and a new time weighted average calculated.

C. Dermal exposure models

C.1 General review of available occupational dermal exposure models

The ART Consortium have been funded by the British and Dutch governments to develop an add-on to the existing ART software tool to estimate hand dermal exposure for low-volatility liquids; whole body exposure and the incorporation of other physical forms of contaminant being delayed to a later phase of the project.

The concept and model are based on the conceptual dermal model of Scheider *et al* (1999), the DeRmal Exposure Assessment Method (DREAM) (van Wendel de Joode *et al,* 2003) and the ART

inhalation model (Fransman *et al,* 2011). ART will form the backbone of DART, which will be implemented as an extension of the current version of ART. Initially the model will only consider hand exposure.

The model will consist of a set of Principal MFs that describe the inter-relation of the different compartments, similar to the ART approach, these are outlined in Table 3.1. To simplify, the dermal MFs will be described for each major mass transport processes and the magnitude of the parameters will be estimated on the basis of a literature review and/or expert opinion.

Table 3.1 Principle modifying factors (MF) and underlying determinants proposed for dART

Mass transport processes	Principle Modifying Factor (MF)	Description
Air emission & deposition (D_{BP})	MFs from ART (Tielemans *et al,* 2008). Apply the ART scores from the C_{nf} / C_{ff} estimates	Air concentration (in near-field or far-field) is assumed to be correlated with dermal exposure (via deposition). The relative contribution of *deposition* to dermal exposure will be investigated during calibration.
Direct emission (E_{BP})*``	Substance (direct) emission potential (E_I)	The intrinsic bulk emission potential of a substance, e.g. viscosity of liquids and moistness of solids.
	Activity (direct) emission Potential (H_b)	The potential of the activity to (i) result in direct contact with the source (e.g. immersion of hands in substance), or (ii) to generate direct emissions like splashes and spillages onto the skin. Determinants include the (i) type and amount of energy transfer, (ii) scale (e.g. amount product used) and (iii) product-to-air interface (e.g. level of containment). Also, the frequency of contacts with the source (e.g. immersion of hands) and orientation or direction of work, and distance between the source and worker is considered (assuming the absence of direct emissions in the far-field)
	Localized control (LC)	Control measures in close proximity of the source intended to prevent direct emission (splashes) reaching the worker, or measures to prevent the worker to immerse hands into the source (e.g. using screens).
	Affected surface area of body part – from bulk emission (BP_E)	The potential surface area of a specified body part that is affected by bulk emissions, e.g. hand palms.
Surface contact (T_{BP})	Surface contamination levels (Su)	The potential that surfaces areas are contaminated. It is a combination of air-to-surface deposition (using $C_{nf/ff}$ estimate) and the bulk-to-surface emission estimate (E_{BP}).

Mass transport processes	Principle Modifying Factor (MF)	Description
		It includes surface decontamination / cleaning and removal from surfaces through evaporation.
	Frequency of contacts (P_T)	The potential frequency of worker contacts (intentional and incidental) with different surfaces^, e.g. the number of containers used.
	Transfer efficiency (C_f)	The potential that a substance is transferred from a surface to the skin or clothing, considering substance properties (e.g. viscosity, particle size, stickiness), surface type (e.g. smooth) and contact type (e.g. grasp) etc.
	Affected surface area of body part – from surface contact (BP_T)	The potential surface area of a specified body part that is affected by surface contacts, e.g. hand palms.
Decontamination (*WH*)	Decontamination of skin or clothing / worker hygiene	The potential decontamination or cleaning of either the skin or clothing, e.g. hand washing, washing of clothes.
Removal (*R*)	Removal from skin or clothing	The potential removal of, or retention/adherence of a substance on/from the skin or clothing, e.g. sticky or waxy substances. It also considers removal of substance from the hands when contacting uncontaminated surfaces. In all, removal will account for the 'level of challenge' of a substance on the skin or clothing. In each instance, a distinction is made between unprotected skin and clothing for a particular body part. This parameter is also linked removal associated with different dermal sampling techniques.
Protective clothing	Effectiveness of protective clothing	The protection provided by different types of protective clothing for different body parts. Where appropriate, these protection values can be used to include exposure data of actual sampling techniques.

** direct emission is defined as (1) dripping, spilling or splashes (liquids/suspensions) and impaction (solids) of a substance where the airborne transfer of the product is not affected by air movement, or (2) immersion of a body part in a substance*

^ a distinction is made between different surface areas, e.g. equipment/tools, treated surfaces, work surfaces

As in ART, it will be possible to assess different tasks to obtain a shift exposure. The proposed equations and model inputs for DART are outlined in Appendix 3.

However, the DART developments are still at an early stage and it seems unlikely that there will be even a prototype tool available before the end of 2014. In the meantime IOM have been adapting and improving the DREAM tool for use in an epidemiological study of oil spill clean-up workers being undertaken in the USA – the GuLF study, which is funded by NIEHS. In this report we concentrate on the latter tool, partly because it is already available and partly because it will provide a reasonable intermediate step before the final developments of DART. It may therefore allow the ultimate incorporation of the DART tool in INTEGRA without any major restructuring.

C.2 The GuLF DREAM tool

The GuLF DREAM Tool was developed to assess dermal exposure to the components of oils and tars and to dispersants among clean-up workers in the 2010 Deepwater Horizon spill in the Gulf of Mexico. It is based on the DREAM modelling tool which was identified by the GuLF exposure assessment team as the best available generic method for reconstructing dermal exposures (van Wendel de Joode, 2003).

C.2.1 The DeRmal Exposure Assessment Method (DREAM)

DREAM is a generic observational tool which is designed for dermal assessment in epidemiological studies and occupational hygiene studies. It estimates the dermal exposure for each of nine body parts (hands, forearms, upper arms, head, front torso, back torso, lower abdomen to the knees, lower legs and feet) and then corrects the estimated value to account for the effect of any personal protective equipment (PPE) or clothing.

Dermal exposure for each body part is calculated as the sum of exposure from three key pathways of dermal exposure that were identified by Schneider *et al* (1999):

1. *Immersion*: direct contact between the body part and the substance. This could be from placing a body part in or on the source, or from spills or splashes;
2. *Surface Transfer*: contact between the body part and a surface contaminated with the substance, and subsequent transfer of the substance to the body part;
3. *Deposition*: deposition of an airborne substance onto the body part.

The variables in the DREAM model are summarised in Appendix 4. These follow a pathway from source (emission) to the receptor (skin contamination layer). In each case the DREAM model assigns a numeric factor to the exposure determinant based on a categorical grouping scheme. The determinants, within a pathway, are generally combined in a multiplicative way and then are added together for each of the pathways.

Potential dermal exposure for each pathway is calculated as the product of subjective assessment of the frequency (identified as probability in the original model) and intensity of exposure by that pathway for each body part, multiplied by an estimate of the 'intrinsic emission' of the substance and an exposure route factor that weights some pathways more heavily than others (van Wendel de Joode *et al,* 2003). *Actual dermal exposure* is then estimated by dividing *Potential Dermal Exposure* by clothing protection factors.

The output from the tool is an assessment of exposure as a continuous variable in an arbitrary set of dimensionless DREAM Units, i.e. the tool predicts relative exposure rather than absolute exposure. The full set of model equations is provided in van Wendel de Joode *et al* (2003).

The accuracy and reliability of the DREAM tool were assessed in two further papers (van Wendel de Joode, 2005a; van Wendel de Joode, 2005b).

To assess accuracy the estimated exposures were compared with quantitative dermal exposure measurements obtained from several occupational settings. The input parameters for the model were derived from observations of workers performing a certain task obtained as the exposures were being measured. Data were obtained for work with metal working fluids (MWF), organic solvents, cyclophosphamide while handling of antineoplastic drugs in hospitals, di-ethyl-glycol-butyl-ether (DEGBE), benzene, and toluene. A variety of measurement approaches were used, including interception, removal and direct assessments.

The Spearman correlation coefficients between measured and estimated exposures for individual observations within a scenario ranged from 0.19 to 0.82. Estimates of exposure levels on clothing layer were only predicted reliably when information on the concentration of the contaminant in the formulation was included in the model. No attempt was made to calibrate the DREAM units in terms of mass loading on the skin or any other quantitative measure of skin exposure.

Van Wende de Joode (2005b) investigated the reliability of DREAM by (i) studying inter-observer agreement, (ii) assessing the effect of individual observers on dermal exposure estimates for different tasks, and (iii) comparing inter-observer agreement for ranking of body parts according to their exposure level. Four studies were performed with 29 observers (different number of individuals contributing to each study) assessing dermal exposures to liquids, solids, and vapours. The assessors were either present at the time of the study or watches a video of the work task. Intra-class correlation coefficients ranged from 0.68 to 0.87 for total dermal exposure estimates, indicating generally good or excellent inter-observer agreement. Differences between individual observers on task estimates were relatively small and on average observers differed by less than a factor of two. Inter-observer agreement for ranking of dermal exposure of nine body parts was moderate to good (median Spearman correlation coefficients for pairs of observers ranged from 0.29 to 0.93).

The authors concluded that the DREAM method could be successfully applied for semi-quantitative dermal exposure assessments for groups of workers with considerable contrast in dermal exposure levels, i.e. where the difference in average level between groups was large.

C.2.2 Modification of DREAM to produce GuLF DREAM

Since the original development of the DREAM tool further relevant research has been published that can inform the model structure and determinant parameter values. In addition, the study team wished to ensure that the full range of conditions that were encountered by the clean-up workers were adequately covered by the model.

A series of focussed mini-reviews were undertaken to address aspects of the model where further development was considered appropriate. These reviews covered:

- Recent work on intrinsic emission, particularly related to viscosity and evaporation of volatile agents;

- New information on frequency and intensity of exposure, particularly in relation to 'saturation' of the skin contamination layer with contaminant and the relative importance of different exposure pathways;
- The effectiveness of gloves and protective clothing;
- The use of skin creams and lotions as barrier creams;
- The potential effects of contact with seawater and sweat on dermal exposure.

The DREAM model was then updated based on these literature reviews.

C.2.3 Viscosity

In the DREAM model the intrinsic emission of the substance is determined from the substance characteristics. For liquids intrinsic emission is the product of physical state (PS) concentration (C), evaporation (EV) and viscosity (V). The magnitude of each of the above determinants is assessed on a categorical scale by the exposure assessor. Van Wendel de Joode *et al* (2003) reported that increased viscosity was expected to result in increased exposure as 'higher viscosity results in decreased removal from (covered) skin', citing a study by Cinalli *et al* (1992) using three different oils to investigate the effect of viscosity on dermal exposure by immersion and surface transfer (hands gripping an oil soaked cloth) to support this decision.

However, the oils studied by Cinalli *et al* all fall into the 'medium viscosity' category so the viscosity multiplier values in the DREAM model were not based directly on the differences between these oils, but were instead based on the general trend displayed of increasing retention with increasing viscosity.

A recent study carried out by Gorman Ng *et al* (2013) investigated the effect of viscosity on dermal exposure by immersion, surface transfer and deposition using a range of glycerol solutions: 20% glycerol (2 mPa.s), 50% glycerol (7 mPa.s), and 87% glycerol (109 mPa.s). Similar to the earlier findings, Gorman Ng *et al* found that the effect of viscosity on exposure varied with the pathway of exposure. In summary, the findings of Gorman Ng *et al* were as follows:

Surface Transfer: There did not appear to be a relationship between viscosity and dermal exposure by surface transfer.

Immersion: For immersion exposure, the mass of 87% glycerol on the skin following contact was three times higher than the mass of 50% glycerol which, in turn, was three times higher than the mass of 20% glycerol.

Deposition: For deposition exposure the effect of viscosity on exposure was the opposite of the effect on immersion. The highest dermal exposures were measured for the least viscous solution, 20% glycerol. These exposures were over three times higher than the exposures measured for the other two solutions. After normalizing for the air concentration of glycerol, there continued to be an inverse relationship between viscosity and deposition. The dermal exposures measured following deposition of the two higher viscosity solutions were, on average, 70 and 50% of the exposures measured following deposition of the least viscous glycerol solution.

Roff *et al* (1997) also observed a similar negative effect of substance viscosity on exposure by deposition. They found that dermal exposures were 3.7 times higher when using a spirit-based fluid than with a more viscous water-based fluid.

C.2.4 Evaporation

In the original DREAM model the magnitude of the evaporation determinant was based on the liquid boiling point:

<50 ºC	=	3
50 - 150 ºC	=	1
>150 ºC	=	0.3

The rationale given for this classification is that 'Volatile liquids result in lower dermal exposure due to increased removal' and a study by Garrod *et al* (1999) of dermal exposure to timber preservatives among timber pre-treatment operators is cited to support this decision.

However, Garrod *et al* do not make this conclusion and instead state that the observed higher exposure to water based preservatives may have arisen due to an observation that timber treated with solvent based preservatives were dryer when emerging from the enclosed treatment vessel resulting in decreased opportunity for exposure by the surface transfer pathway.

The multipliers for evaporation in the DREAM model therefore appear to be based mainly on professional judgement.

We have evaluated the evaporation equations for two dermal absorption predictive models: IH SkinPerm and the NIOSH Skin Permeation Calculator.

C.2.4.1 IH SkinPerm

IH SkinPerm is a tool for estimating dermal absorption that is based on a model developed by ten Berge (2009). This model estimates both the amount of a substance deposited on the skin that is absorbed into the *stratum corneum*, and the amount that is lost to evaporation. The evaporation rate equations are based on the REACH technical guidance for occupational exposure estimation (ECHA, 2010). These equations are:

$$Evaporation\ rate(LF) = \frac{\beta * MW * VP}{R * T * 10} \quad (1)$$

Where:

MW = Molecular weight
VP = Vapor pressure of the liquid at skin temperature in Pascal
R = Gas constant in J/Mol/ºK
T = Skin temperature in ºK (303ºK = approximate skin temperature)
β = Coefficient of mass transfer in the vapour phase in meter/hour

And the empirical formulation for β is given as:

$$\beta = \frac{0.0111 * V^{0.96} * D_g^{0.19}}{v^{0.15} * X^{0.04}} \quad (2)$$

Where

V = velocity of air (REACH guidance suggests assuming 0.3 m/s)

D_g = Diffusivity of the liquid in the gas phase (range 0.03 to 0.06 m^2/hr) (REACH guidance suggests assuming 0.05 m^2/hr)

ν = kinematic viscosity of air (REACH guidance suggests literature value of 0.054 m^2/hr)

X = Length of the area of evaporation in the direction of the air stream (REACH guidance suggests assuming 0.1 meter)

Of these, only V, MW and VP may vary.

C.2.4.2 NIOSH Skin Permeation Calculator

The NIOSH Skin Permeation Calculator also estimates the amount of material deposited on the skin that is absorbed into the stratum corneum and the amount that is lost to evaporation. It is based on the work of Kasting and Miller (2006).

This model estimates the rate of evaporation from the vapour pressure, the temperature, the molecular weight and the wind speed.

$$Evaporation\ Rate = \frac{6320 * V^{0.78} * VP * MW}{0.76 * R * T * \sqrt[3]{MW}} \qquad (3)$$

Both models give similar predictions of evaporation rate, but the effect of molecular weight on evaporation was lower in the model used by the NIOSH calculator and the effect of wind speed was more pronounced in the equation from the IH SkinPerm model. It was concluded that either model would be a suitable basis for estimation of the evaporation determinant in the modified DREAM tool.

Whilst these equations are probably reliable for non-viscous liquids there are further complexities for viscous mixtures because the contaminant must diffuse to the surface of the liquid to evaporate. In substances such as oils and tars the absence of fluid mixing results in a reduced evaporation rate compared to the predicted values.

C.2.5 Frequency and intensity of exposure

Since the development of the DREAM model, the available research indicates that duration of exposure is related to level of exposure (e.g. Hughson and Aitken, 2004; Liden *et al,* 2008). Liden *et al* (2008) measured dermal exposure to nickel, chromium and cobalt among carpenters, locksmiths, cashiers and secretaries who handled metallic items including coins, locks, and tools. The highest exposures were seen for nickel, and among all occupations, locksmiths had the highest exposure (arithmetic mean = 0.358 µg/cm^2 for nickel) and secretaries had the lowest exposure (arithmetic mean = 0.018 µg/cm^2 for nickel). Among all the job categories, secretaries had the least frequent contact with metallic objects. The duration of exposure was also about half the exposure for the other job categories but the measured exposure for secretaries was less than half the exposure for the next lowest exposed job group (carpenters: arithmetic mean nickel exposure = 0.077 µg/cm^2 for 161 minutes of exposure) suggesting an effect of frequency of contact on exposure.

There is evidence of skin becoming 'saturated' with dusts. Hughson and Cherrie (2003) conducted experiments in which subjects immersed their hands into bags of zinc dust and zinc oxide and found that the maximum skin surface loading for zinc dust was an average of 4840 µg/cm^2 and for zinc oxide was an average of 733 µg/cm^2. Once skin has become saturated, further contacts will not lead to increased exposure. It is also likely that the skin has a maximum carrying capacity for liquids. In the DREAM model repeated exposure by emission and deposition (10 – 50% of task

duration) increases the exposure estimate by a factor of three while constant exposure by these pathways (>50% of task duration) results in a factor of 10. For deposition these values may be appropriate, but for immersion, the skin may become saturated after just one or two contacts so it is unlikely that constant exposure by immersion would result in such a large increase in exposure.

In summary, the available evidence does suggest a relationship between frequency of exposure events and dermal exposure, but it also suggests that the assigned value for the category "Almost constantly" may be too high for the emission pathway where the skin may become saturated. We suggest retaining the original DREAM values for the deposition pathway, but decreasing the value for the "almost constantly" category for the emission pathway.

The parameters related to frequency of exposure by surface transfer are similar to the parameters for emission and deposition. The same categories and assigned values are used. But, the literature cited in support of the categorisation is different. For emission and deposition only the study by Lansink *et al* (1998) is cited in support of the categorisation. For surface transfer three papers are cited in support of the categorisation (Brouwer *et al,* 1999; Spencer *et al,* 1995; and Kissel *et al,* 1996) and one is cited because it does not support the categorisation (Llewellyn *et al,* 1996).

Gorman Ng *et al,* (2012) conducted a systematic literature review of research that investigated the transfer of powders and liquids from surfaces to the skin. The twenty-eight identified papers were reviewed and the data were collated into a database. Among the identified studies, some investigated the effect of multiple contacts on exposure. Cohen Hubal *et al* (2005) studied the transfer of riboflavin from carpet or laminate material to hands following contact in laboratory experiments. Their experiments indicated that the hands reached maximum loading after the fifth contact and that subsequent contacts did not increase exposure and, in some cases, resulted in removal of material from the skin. The Brouwer *et al* (1999) study cited by van Wendel de Joode had a similar finding. They also conducted laboratory experiments to assess the transfer of Tinopal from glass surfaces to the hand following contact. They used a fluorescent imaging method to assess the area exposed and the loading of the skin after one to twelve successive contacts. They found that surface area exposed and the loading of the skin did increase with increasing exposure but that the relationship between number of contacts and increasing exposure was not linear. The amount of material that transferred to the skin was smaller after a greater number of contacts. They also observed removal of material from the skin following contact with a blank glass plate. Hughson and Cherrie (2003) conducted laboratory experiments involving contact between hands and aluminium surfaces loaded with zinc oxide. They found no significant difference in dermal loading of zinc oxide from 1, 2, 4 or 8 contacts.

The available evidence supports increasing exposure with increasing frequency of contact; however, the reviewed studies also suggest that this relationship is not linear. The existing DREAM parameters are based on a log-linear distribution. The evidence from the reviewed studies suggests that exposures are likely to be over-estimated in the 'almost constantly' category in the original model.

C.2.6 Exposure routes

In DREAM exposure by the emission route is weighted three times as heavily exposure by surface contact or deposition. The justification for this weighting is that, 'emission is defined as mass transport of substances by direct release from a source onto clothing and uncovered skin, whereas deposition and transfer result from indirect mass transfer of substances after interference with air or surface compartments, where loss of mass is likely to occur. In addition, absolute mass being

released due to emission is likely to be higher than due to transfer or deposition' (van Wendel de Joode, 2003). The reasoning seems to be logical but no literature is cited to support this weighting.

Hughson and Cherrie (2003) conducted laboratory experiments to assess dermal exposure to zinc following immersion and contact with contaminated surfaces. The measured exposures following immersion were over three times higher than exposures following surface contact. For zinc oxide the maximum skin loading measured following immersion exposure was 733 µg/cm^2 and the range of exposures following surface contact was 163 – 237 µg/cm^2. This data supports a higher weighting for immersion exposure.

Gorman Ng *et al* (2013) carried out laboratory experiments to determine the effect of dustiness and viscosity on dermal exposure by each of the three dermal exposure pathways. The test substances used were glycerol solutions (20%, 50% and 87% glycerol), calcium acetate, zinc oxide and magnesium sulphate. They investigated immersion, surface contacts and deposition from a chamber atmosphere. The masses of material that transferred to the skin were highest in the immersion experiments. Exposures following surface contact were lower than exposures from immersion, but were higher than exposures from deposition, despite measured air concentrations up to 44 mg/m^3. These results support a higher weighting for immersion exposure, but also suggest that exposures from surface contact are higher than exposure from deposition.

Several research studies have identified a correlation between measured air concentration and dermal exposure (Vermeulen *et al,* 2000; Burstyn, 2002; Pronk *et al,* 2006; Links *et al,* 2007), but the correlations were typically found in some job groups and not in others. Other studies found no correlation (Makinen and Linnainmaa, 2004a and 2004b). Workers who were involved in direct handling of materials or contact with contaminated surfaces appear to be less likely to have demonstrated correlations between air concentration and dermal exposure (Burstyn, 2002; Pronk *et al,* 2006; Links *et al,* 2007). This suggests that deposition can and does play a role in dermal exposure, but that surface contact and immersion play larger roles when present. Vermeulen *et al* (2000) found that air concentration ('near field' and 'far field') and surface loading were all significantly ($p<0.01$) correlated with dermal exposure ($r = 0.22$, 0.17 and 0.22) respectively, but that there was a stronger correlation between 'far field' air concentration and surface loading ($r = 0.41$). It is possible that the surface contact pathway could contribute to some of the correlations observed between air concentration and dermal exposure.

In summary, the available evidence supports a higher weighting for the immersion pathway, but also suggest that the surface contact pathway should be weighted higher than the deposition pathway. The evidence suggests that exposure by emission results in exposures far greater than the other pathways so the value for this pathway could be increased.

C.2.7 Gloves and clothing

There are seven DREAM parameters that affect estimates of protection provided by gloves or clothing. There is an additional term for the protective effects of barrier or pre-work creams (discussed in the next section). The model applies these factors separately to each of the nine body parts, e.g. head, hands etc. The developers of DREAM cited eleven papers in support of their model parameterization.

It is important to be clear at a conceptual level how protective clothing and gloves work. Brouwer *et al* (2005) described the processes by which substances may contaminate the skin when protective clothing is worn as:

- Permeation, i.e. diffusion-driven transport through the clothing membrane;
- Penetration, the macroscopic transport through small holes in a fabric or through the seams or other physical gaps;
- Transfer, by contact of the inside of the glove or clothing or the skin underneath with contaminated surfaces, including the outer surface of skin protective equipment;
- Deposition, which is the transport of a contaminant onto the skin not covered by clothing or gloves.

Ideally, research to assess the effectiveness of protective clothing should include all aspects and should be carried out in realistic situations to ensure that any behavioural issues, particularly those related to transfer or deposition, are incorporated.

Brouwer *et al* (2001) noted that, in general, biological monitoring studies show lesser reduction in internal exposure from wearing protective clothing than might be expected from measurements of external exposure inside and outside protective clothing. It is unclear why this may be the case but it could reflect the more carefully controlled conditions that often prevail in experimental studies or it may be that biological monitoring provides a more "integrated" assessment of exposure, taking account of differential absorption of contaminants from exposure on different parts of the body. Whatever the reason, this observation reinforces the importance of assessments based on realistic workplace studies.

It is generally unclear which exposure process is most important, e.g. transfer, permeation etc. in the studies carried out, although it is assumed that with correctly selected gloves, i.e. made from glove material that is capable of resisting permeation from the challenge chemicals, with appropriate training and frequent replacement, permeation is negligible. However, Lee *et al* (2009) noted that in laboratory tests of permeation, higher temperatures (37^{o}C vs 22^{o}C) markedly increased permeation of a pesticide (increased by two orders of magnitude from about 0.01 to about 2 µg/cm^2/minute), although breakthrough time remained fairly similar at about 15 to 24 hr. These authors also showed that the gloves that had been used for prolonged periods (up to 14 days) had greater measured permeation and shorter breakthrough time than new gloves. They were not able to identify the reason for this finding because there was no discernable wear in the glove materials, although the authors speculated that use had affected the glove material properties. It is also possible that the gloves had retained some of the contaminant in the glove material or the substance was transferred inside the glove from taking off and putting on contaminated gloves.

Rawson *et al* (2005) noted that, without training, 90% of glove wearers had contamination inside their gloves when they reused them, whereas after training this was reduced to 10%.

The impact of glove design on effectiveness was investigated by Creely and Cherrie (2001). They carried out simulated laboratory tests of a pesticide spraying operation using a novel interception sampling strategy (i.e. cotton gloves worn inside the protective glove on one hand and outside on the other hand; glove arrangement swapped half-way through the experiment). Three protective gloves were selected for testing. For all three the manufacturer certified that there was no permeation for the selected pesticide for use of periods up to 8 hours. The gloves reduced hand exposure to between 0.2% and 1% of the potential exposure without gloves depending on the

glove design (the poorest protection was with shorter thicker gloves, i.e. those that were difficult to manipulate and did not fully cover the forearm). Behaviour was an important determinant of protection. Protection was about half for "messy" workers who splashed the pesticide during use compared to "tidy" workers (exposures were highest in circumstances when the paint spray equipment failed to work correctly: "pump failure"). If the person took the gloves off and then puts them back on then the protection was much reduced (to 3% of potential exposure if gloves not worn). There was large variation in protection offered by the gloves, which was mostly associated with the worker behaviour (Table 3.2).

Table 3.2 Mass of permethrin detected on cotton gloves with task variability

Category	N	GM	GSD
Pump failure	5	0.076	2.3
Messy workers	14	0.015	5.5
Tidy workers	11	0.0056	9.6

Studies for exposure measurements inside and outside clothing are often uninformative because of different measurement methods used inside and outside the clothing, e.g. the studies by Machera *et al* (2009) and Fenske *et al* (2002). Studies of this type were not considered in this review.

Driver *et al* (2007) present an analysis of the US EPA Pesticide Handlers Exposure Database, a database of a large number of studies where there were mostly simultaneous measurements inside and outside the clothing using the same type of interception (patch) samplers (2029 sample pairs from inside/outside patches and 100 whole-body dosimeter pairs, from 40 different studies). These authors showed that single layer clothing (i.e., long-sleeved shirt, long pants; gloves are not included) reduced measured exposure by about 90% on average compared to what exposure might have been without protective clothing, although there was considerable variation in the effectiveness. They showed that the percent penetration decreased as outer loading decreased (mg/cm^2). This finding highlights the difficulty in assessing the effectiveness of clothing as a percentage of the challenge because the process of transfer from outside to inside the clothing is independent of the external loading, i.e. the penetration is being normalized to a value that is unrelated to the process by which contaminant penetrates clothing. For example, with permeation the rate of transfer is dependent mainly on the concentration of the contaminant on the surface of the clothing rather than the mass loading.

Fenske (1988) described a semi-experimental study to assess the relative effectiveness of different clothing types and gloves during spraying of pesticides. He used a fluorescent tracer to assess skin exposure and then compared the amount of contamination detected with workers wearing:

- A work shirt made from woven cotton/polyester fabric;
- A coverall made from woven cotton polyester;
- A non-woven coverall made from Tyvek.

There was considerable variability in the measured exposure levels and in his data analysis Fenske adjusted the data to normalize to the contamination found on an uncovered part of the head. This analysis suggested that the type of clothing did not affect the amount of contamination on the torso, but there were statistically significant differences for the forearm and upper arms. The

main reason for these differences appears to be openings in the garment, e.g. at the neck and sleeve. There was also contamination on the hands although the authors asserted that the tracer could not have permeated through the glove material, i.e. it must have been transferred there by some mechanism.

The main findings from Fenske's study were that coveralls gave more protection than a work shirt (47%-77% additional reduction in exposure) and that the main source of exposure was openings in the clothing.

Shih *et al* (2009) carried out a small study to measure air and dermal exposure to 2-ethoxyethyl acetate for 20 workers over five working days. Tape stripping was used for the dermal assessments. Gloves of unspecified type and material were worn by about a quarter of the workers and the comparison of effectiveness was between those who wore gloves and those that did not. The levels measured on the palms of the hands were about 25% lower when gloves were worn (a statistically significant difference) compared to when they weren't. The levels on the back of the hands and uncovered forearms were not significantly different on the two groups, suggesting the gloves had a limited impact on protecting workers. Also the major route of exposure may not be the hand per se but the palms.

There are three studies where biological monitoring was used to assess the effectiveness of protective clothing. Scheepers *et al* (2009) studied exposures of dermatology nurses while they were applying ointments containing polycyclic aromatic hydrocarbons (PAH) with the aim of evaluating the effectiveness of improved skin protection systems. Nurses performed a treatment with loose-fit polyethylene gloves followed by a second treatment without gloves (the time between the ointment applications is not described by the authors). The use of gloves produced a median reduction of 51% in the excretion of 1-hydroxypyrene in urine compared to not wearing gloves (skin contamination was not measured in this part of the study). They then tested the use of vinyl gloves and Tyvek sleeves, which showed a 97% reduction in skin contamination with pyrene and benzo(a)pyrene and a lowering in urinary excretion of 1-hydroxypyrene of 57% compared to no protection.

Weiss *et al* (2011) measured inhalation and internal exposure to 4,4'-methylenedianiline (MDA) of workers making rotor blades for helicopters. Air levels were very low (around the limit of quantification), although MDA was found in 89% of post-shift urine samples implying dermal exposure was important (median concentration was 4.2 mg/l, which approximately corresponds to an inhalation exposure of 40 mg/m^3 over 8-hr, i.e. about half of the ACGIH TLV). Three personal protective equipment interventions were tried but only MDA-impermeable overalls and nitrile gloves reduced internal exposure – mean body burden was reduced by about 60%.

Wang *et al* (2000) investigated the effect of neoprene gloves (and barrier cream) amongst workers exposed to N,N-dimethylformamide (DMF) using biological monitoring. They saw that the biological monitoring levels were reduced by about 50% when wearing gloves, compared to not wearing gloves, and by a similar amount with both gloves and respirator, implying that the main route of exposure was by skin contact.

One further study is informative in assessing the effectiveness of protective clothing and gloves (i.e. a hat and neck cloth, and clean trousers, and long-sleeved shirts, plus cotton gloves with latex-coated palm and fingertips), that of Cavallari *et al* (2012), who carried out measurements of external exposure on hot-mix asphalt paving operators. The paper describes a semi-experimental investigation of exposure where dermal exposure to phenanthrene and pyrene was monitored

using post-shift hand washing and using a new Passive Organic Dermal (POD) sampler. Data were collected for two temperatures of hot-mix (149°C and 127°C) and two types of cleaning agents (either diesel or biodiesel. Note in the paper "biodiesel unrestricted" is equivalent to diesel use). They found that exposures were reduced by frequent glove use (not further specified in the paper) compared to no glove use: 47% to 67% reduction for analysis of pyrene and 29% to 37% reduction for analysis of phenanthrene. In addition, the higher process temperature resulted in increased exposure compared to the lower temperature operation. It is not clear why there was a difference in the effectiveness due to the substance analysed.

C.2.8 Other determinants

The original DREAM model included parameters for barrier cream. However, a review of the literature (Cherrie, personal communication) found little evidence that barrier creams, which are generally designed to repel water-based irritant chemicals, are effective in protecting the skin from dermatitis. Human studies mostly show negligible long-term benefits of barrier creams to skin health in comparison with other emollient type creams. However, all of these creams may have a positive effect on the skin condition because they promote repair and restore the barrier function of the stratum corneum. This factor has been excluded from GuLF DREAM.

The review for the GuLF DREAM tool also considered the effect of seawater on skin and skin contamination (washing off), but these issues are not considered further here.

C.2.9 Development of the GuLF DREAM tool

The DREAM tool was updated based on this information to better reflect current knowledge. The revised model parameters are shown in Table 3.3 along with the original DREAM parameters

Table 3.3 Summary of DREAM variables and parameters with corresponding GuLF DREAM

Variable	Original DREAM parameters	GuLF STUDY DREAM parameters	Comments
Exposure Route Factor	Emission = 3 Surface Transfer = 1 Deposition = 1	Emission = 5 Surface Transfer = 3 Deposition = 1	The evidence suggest that emission results in exposures far greater than the other pathways (Gorman Ng *et al*, 2013), and surface transfer typically results in exposures higher than deposition (Burstyn, 2002; Pronk *et al*, 2006; Links *et al*, 2007)
Viscosity*/ immersion	Low = 1 Medium =1.75 High =3	Low = 1 Medium = 3 High = 9	Cinalli *et al* (1992) and Gorman Ng *et al* (2013), showed increasing retention with increasing viscosity.
Viscosity/ surface transfer	Low = 1 Medium = 1.75 High = 3	Low = 1 Medium = 1.75 High = 3	Cinalli *et al* and Gorman Ng *et al* (2013) found no difference. No change.

Variable	Original DREAM parameters	GuLF STUDY DREAM parameters	Comments
Viscosity/ Deposition	Low = 1 Medium = 1.75 High = 3	Low = 1 Medium = 1.75 High = 3	No evidence that viscosity has an effect on exposure by deposition if air concentrations are held constant (Gorman Ng *et al*, 2013). No change.
Evaporation	<50 ºC = 3 50 - 150 ºC = 1 >150 ºC = 0.3	NA	Evaluated both IHSkin Perm and the NIOSH model. Broke out evaporation into: Vapour pressure Molecular weight Wind speed See below.
Vapour Pressure	NA	<100 = 1 100 – 1000 = 0.5 1000 – 10000 = 0.1 >10000 = 0.05	Both models showed an increasing rate of evaporation with increasing vapour pressure
Molecular weight	NA	<100 = 1 100 – 120 = 1.3 >120 = 1.8	Evaluated both IHSkin Perm and the NIOSH model. The multipliers are based on the more conservative estimates from the NIOSH model
Wind speed	NA		Evaluated both IHSkin Perm and the NIOSH model. The multipliers are based on the more conservative estimates from the NIOSH model
Barrier Cream	Not used = 1 Used = 0.3	REMOVED	Barrier creams were not used by clean-up workers in the GuLF study. Little evidence that they are effective.
Glove or clothing material by body part	No glove or body part not covered = 1 Woven clothing = 0.3 Non-woven permeable = 0.1 Non-woven impermeable = 0.03	No glove or body part not covered = 1 Woven or permeable clothing or inappropriate glove materials = 0.9 Non-woven impermeable gloves or clothing = 0.5	Reviewed literature on glove effectiveness and concluded that the original DREAM model was over-estimated the effect of gloves on exposure.

Variable	Original DREAM parameters	GuLF STUDY DREAM parameters	Comments
Pressure and friction on gloves	Gloves = 1 Clothing = 0.3	REMOVED	No evidence that "pressure or friction on gloves" play a role in glove effectiveness.
Replacement frequency	Replaced after use = 0.3 Daily = 1 Weekly = 3 Monthly = 10	Replaced within a work shift = 0.3 Daily = 1 >Daily = 3	The original DREAM values may have overestimated the effect of reuse of clothing and gloves. These categories were also changed to match the GuLF questionnaire.
Non-woven gloves connect well with clothing	No = 3 Yes = 1	No = 1.3 Yes = 1	Creely and Cherrie (2001) support the importance of this factor, although there is no quantitative data to substantiate the magnitude of the parameter. The value was modified to reflect the lower overall protection assumed from wearing gloves.
Non-woven gloves wear time	0 – 25% of time = 10 25 – 99% of time = 3 100% of time = 1	0 – 25% of the time on tasks where there may be exposure = 2 25 – 99% of time = 1.2 100% of time = 1	Reduce the magnitude of the parameters based on judgment and the lower effectiveness assumed for clothing and gloves.
Under gloves worn with impermeable gloves	No = 1 Yes = 0.3	REMOVED	No evidence that under gloves have any impact on exposure.
Replacement frequency of under gloves	Single use = 1 Daily = 3 Weekly or monthly = 10	REMOVED	No evidence that under gloves have any impact on exposure.
Frequency of exposure by emission and surface contact	<1% of task = 0 <10% of task = 1 10-50% of task = 3 ≥50% of task = 10	<1% of task = 0 <10% of task = 1 10-50% of task = 3 ≥50% of task = 5	Hughson and Cherrie (2003) found that skin becomes saturated following emission or surface contact exposure. It is unlikely that there would be a big difference between exposure for 10 – 50% of the task and exposure for more than 50% of the task so these parameters have been revised down.

Variable	Original DREAM parameters	GuLF STUDY DREAM parameters	Comments
Frequency of exposure by deposition	<1% of task = 0 <10% of task = 1 10-50% of task = 3 ≥50% of task = 10	<1% of task = 0 <10% of task = 1 10-50% of task = 3 ≥50% of task = 10	Exposure levels from deposition are typically not high enough to result in saturation (Gorman Ng *et al*, 2013) so the original values have been retained.
Intensity of emission or deposition exposure (amount of body part exposed)	<10% of body part = 1 10-50% of body part = 3 ≥50% of body part = 10	<10% of body part = 1 10-50% of body part = 3 ≥50% of body part = 10	The available evidence suggests a linear relationship between body surface area exposed and exposure (Brouwer *et al*, 2000) supporting the original DREAM values.
Intensity of surface transfer: contamination level of surface	Not contaminated = 0 Possibly contaminated = 1 <50% of surface = 3 ≥50% of surface = 10	Not contaminated = 0 Possibly contaminated = 1 <50% of surface = 3 ≥50% of surface = 10	Brouwer *et al* (1999), Cohen Hubal *et al* (2005) and Christopher *et al* (2008) all found a relationship between the loading of material on surfaces and the mass transferred to the skin following contact supporting the original DREAM values.

Low: e.g., water, centipoise=1. Medium: e.g., sweet LA crude oil, centipoise=35-40. High viscosity: e.g., tar, centipoise=~several thousands)

C.3 Comparison of the GuLF DREAM assessments with measured dermal exposure

The GuLF DREAM model is currently implemented in Microsoft Excel. The tool reliability is being assessed using four datasets: timber spraying using hand-held equipment in buildings (Soutar *et al,* 2000); asphalt paving (Cavallari *et al,* 2012); processing of heavy fuel oil in various locations (Christopher *et al,* 2011) and spraying pigs with phosmet (Stewart *et al,* 1999). Assessments have been independently carried out by two people (JWC and AS) using the available descriptive information for each set of measurements, but as far as possible blinded to the measurement data. After an initial assessment the two assessors shared and discussed their results (training activity) and then repeated the assessments taking account of their increased understanding. Although assessments have been carried out for the whole body, only the data for hands is summarised here.

The available measurements for the four datasets have been collected using different methodologies: either removal techniques (washing or wiping) or interception techniques (absorbent gloves). It is generally accepted that these approaches may provide different metrics

and that in particular the retention capacity of interception samplers is much greater than the skin and so where there is an excess of contaminant material available then the interception samplers will be positively biased compared to removal methodologies. Table 3.4 summarises the available measurement data.

Table 3.4 Dermal exposure data available for the assessment of GuLF DREAM

Dataset	Number of hand sample data	Sampling methods	Analyte assessed	Comments
Timber spraying	11	Cotton gloves	Permethrin or boron	Good descriptions for assessment
Asphalt paving	17*	Hand washing	Pyrene	Limited descriptive information, but a semi-experimental study
Processing of heavy fuel oil	16	Moist hand wipes	Naphthalene or phenanthrene	Good descriptive information
Spraying pigs with phosmet	10	Cotton gloves and	Phosmet	Some tasks had very limited descriptive information

* We are still awaiting further details of the measurement data from the authors for this study and so have presented a subset of our results

The quality of information for assessment was variable. For timber spraying good observational records were available and there were 11 measurements. The assessment of asphalt paving used generic descriptions from a paper and there were eight scenarios for which we currently have data. There were good descriptions for processing of heavy fuel oil, but eight of the 16 measurements were below the limit of detection. Descriptions of spraying of pigs with phosmet varied in quality, with three having very poor descriptions.

This work is ongoing and progress to date is summarised below. In particular, the preliminary data presented here is still undergoing further analysis and checking.

The data for the first assessor (AS) in GuLF DREAM Units (GDU) versus dermal loading are shown below in Figure 3.1, with the data for the second assessor being shown in Figure 3.2.

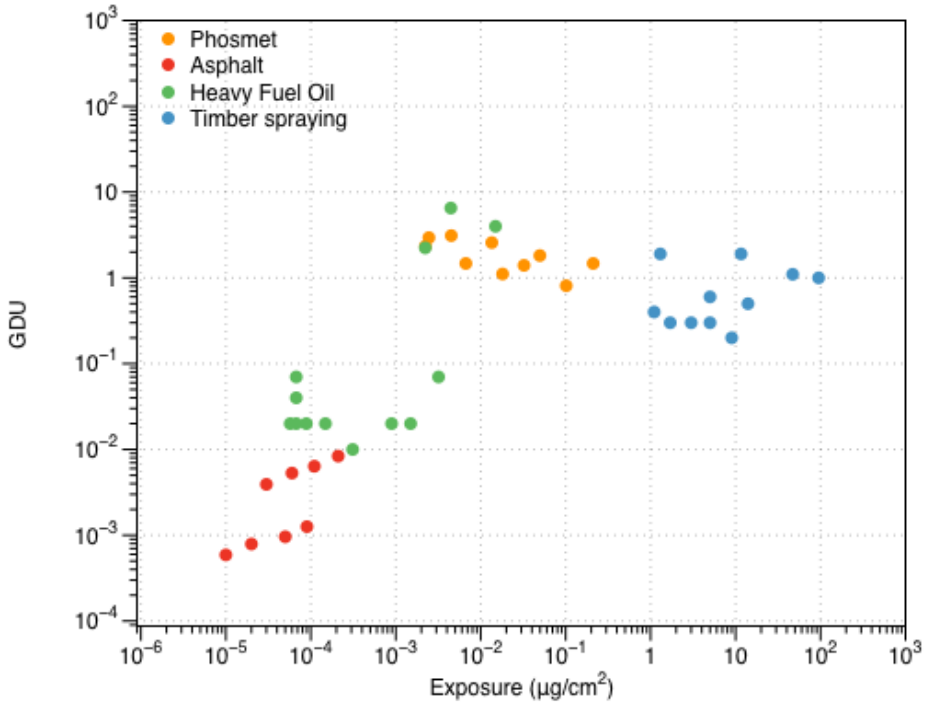

Figure 3.1 Comparison of GuLF DREAM assessment and dermal loading for Assessor 1

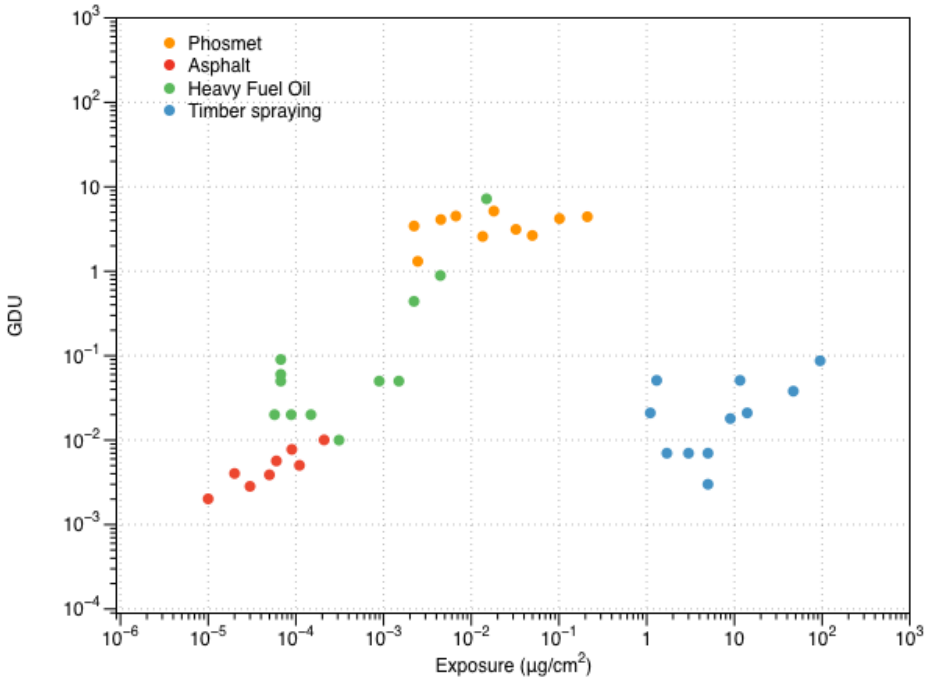

Figure 3.2 Comparison of GuLF DREAM assessment (GDU) and dermal loading for Assessor 2

The GuLF DREAM tool assessments produced correlations with measurements in each dataset that ranged from poor to good (between -0.69 for JWC for phosmet and 0.9 for JWC for asphalt, but for the three studies where there was measurement data collected using recovery methods (i.e. washing or wiping) the correlation for the three datasets combined was good (r = 0.88 for AS and 0.82 for JWC, log-transformed data for hands). Where interception samplers were used (i.e.

absorbent gloves in timber spraying) the measurements appeared to be positively biased compared to the other datasets, which probably reflects the greater ability of the sampling media to retain contaminant compared to skin. There was also a large difference between the two assessors with Assessor 2 being almost two orders of magnitude higher than Assessor 1. It is unclear why there is such a large difference, but Assessor 1 had originally collected these data and it may be that she had some unconscious perceptions of the exposure scenarios that were not contained in the written textual descriptions.

The results within a dataset are probably no worse than was originally obtained using the DREAM tool (van Wendel de Joode, 2005b). The best results were obtained for asphalt and this may in part be due to the semi-experimental nature of the measurement data where exposures were measured for a number of discrete situations, i.e. high vs low temperature asphalt plus use of disease for cleaning or no use of diesel.

The comparison of the model tool with measurements is limited by the availability of suitable datasets with sufficient accompanying contextual information to make it feasible to reconstruct exposures. However, the results from this exercise suggest that it is possible to quantitatively estimate dermal exposure. The INTEGRA platform may benefit from the GuLF DREAM tool or the DART tool if it is developed in the appropriate timescale.

D. Inadvertent Ingestion exposure models

D.1 General review of available models

Although there are a number of screening or first tier exposure models available for inhalation and dermal exposure there are currently no suitable methods for directly measuring or modelling inadvertent ingestion exposure and there is therefore an urgent need to develop tools that can be used under REACH for predicting occupational exposure by ingestion.

A conceptual model and preliminary predictive model for ingestion exposure were developed (Cherrie *et al,* 2006; Christopher *et al,* 2007).

Inadvertent ingestion exposure was defined as the ingestion (uptake) of substances through processes of which the individual is oblivious via the oral cavity. A simple validated model explaining the processes involved in inadvertent ingestion exposure was developed and its strong relation to dermal exposure was identified. The roles of hand-to-mouth and object-to-mouth events as the primary exposure processes were highlighted. Two exposure "compartments" were defined: the *peri*-oral area (i.e. the area of skin around the outside of the mouth) and the oral cavity. The role of human behaviour in determining inadvertent ingestion exposure was also investigated.

This model has recently been updated (Gorman Ng *et al,* in preparation) to produce an inadvertent ingestion exposure modelling tool called the Ingestion Exposure Assessment Tool (IEAT).

D.2 The IEAT model tool

IEAT is an inadvertent ingestion modelling tool which is freely available and can be downloaded[6].

This website also provides links to reports associated to inadvertent ingestion exposure.

- Estimates the mass loading of material on the perioral area
- Input
    - General properties of substance
    - Job profile
    - Immersion, spills and splashes onto hands
    - Personal Protective Equipment
- Output is in µg
- Also dermal for hands µg/cm^2

IEAT is intended to be used as a screening tool to estimate occupational inadvertent ingestion exposure to liquids and solids over a full shift. Information about an exposure scenario required includes substance characteristics, levels of contamination on work surfaces, tasks patterns and personal protective equipment use. Information is entered into the tool using a series of drop down menus.

Model input parameters for the Ingestion Exposure Assessment Tool are listed in Appendix 5.

The tool provides an estimate of exposure on the hands and perioral area. The perioral exposure estimate is assumed to be a surrogate for inadvertent ingestion exposure. Observations of workers showed that the majority of hand-to-mouth contacts involve contact with the perioral area rather than the direct insertion of hands or objects into the oral cavity. Substances that are present on the perioral area can be ingested when workers eat, drink or lick their lips. It is assumed that everything in the perioral area is ingested.

Output from the model is potential ingestion exposure (µg) and hand exposure (µg/cm^2) over an entire work shift. Hand exposure is also reported since it is estimated as part of the underlying calculations for the tool. It describes the amount of substance per cm^2 on the entire hand for both right and left hands. Both a geometric and upper estimate of exposure are provided as is information on how to interpret the results.

IEAT was developed as a conservative exposure screening model and it generally overestimates inadvertent ingestion exposure by a factor of 8. Currently there is limited data for calibration. However, since it is a generic model it can be used to screen exposure scenarios for a wide range of substances.

Exposure in IEAT is estimated for individual tasks, unlike the ART model for inhalation exposure which allows shift based exposure for up to four tasks to be estimated. This could be overcome by using IEAT to estimate exposure for individual tasks and combining the results. Further, IEAT is a tier 1 model whereas ART is a tier 2 model, which would result in an accurate estimate being combined with a much less accurate and more conservative estimate. Inadvertent ingestion

[6] http://www.iom-world.org/research/research-expertise/exposure-assessment/ingestion-exposure-assessment-tool/

exposure will also be heavily confounded by hand exposure and it is probably difficult to separate the two routes of exposure. The exception to this would be substances which do not penetrate the skin.

Until further development of the IEAT model has been carried out it is recommended that ingestion be excluded.

E. Proposals for an integrated modelling framework for External occupational exposure

We have assessed the suitability of the ART tool and associated dermal exposure modelling tools that could be incorporated into the INTEGRA platform. The ART is a robust model tool that could, in principal, be used for occupational inhalation exposure. The calibration that the tool authors have undertaken covers a relatively wide range of chemicals and many of the gaps are perhaps less important for the INTEGRA project, e.g. fibres.

The development of a dermal exposure model tool by the ART Consortium (DART) was originally proposed for use as the occupational dermal tool within INTEGRA, although because of delays in commencing the work it is currently not expected to be available within the current project. We therefore propose using a modified version of the DREAM tool – the GuLF DREAM, which is being developed as a method of reconstructing dermal exposure for an epidemiological study of oils spill clean-up workers being undertaken in the USA. We are confident that this tool will provide a suitable interim method for estimating dermal exposure.

Ingestion exposure is likely to be closely associated with hand dermal exposure, mainly because of the importance of hand-to-mouth contacts in inadvertent ingestion. In analysing biological monitoring data using the INTEGRA platform then it would likely be impossible to disentangle exposure arising from inadvertent ingestion and dermal exposure. The only available tool (iEAT) is just a screening level tool and it is likely to produce estimates of ingestion exposure that are conservative and likely to be inconsistent with the ART/GuLF DREAM model estimates. For these reasons, i.e. likely poor accuracy and precision, we propose excluding occupational inadvertent ingestion from the INTEGRA tool. However, we suggest that the iEAT tool is used as a sensitivity test to investigate whether ingestion could be important in specific scenarios.

Exposure by inhalation and dermal routes are likely to be correlated to a greater or lesser extent, based on conceptual model analysis and available literature. We believe that this may also make it difficult to disentangle the source of exposure from the INTEGRA analysis of biological monitoring data. In such circumstances it seems possible that the reliability of the model (accuracy and precision) may drive the association between biological monitoring and the estimate of external exposure derived from the model tools. This might suggest not including dermal exposure in the INTEGRA platform. However, we consider that there are clear advantages to include an occupational dermal tool in INTEGRA and so we propose including GuLF DREAM. The tool should ideally have a better calibration, but this would need further calibration datasets that are difficult to identify and the measurements would only need to be made using in-situ or recovery methods (not interception because of the potential bias). Further calibration of the GuLF DREAM tool is outside the scope of the present project. DART may become available during the lifetime of the INTEGRA

project and if so we recommend it is used in place of GuLF DREAM. This is particularly because we expect that DART will ultimately have a more reliable calibration dataset the GuLF DREAM.

The model inputs for ART and GuLF DREAM have some commonality and if the models are implemented within the INTEGRA platform we need to identify where there may be efficiencies for the user to avoid, if possible, needing to double enter data. However, there are practical implementation issues related to the incorporation of the ART model into the platform. This is particularly complicated since it is not written in a way that will easily facilitate combination with the INTEGRA computational platform. It is proposed to develop an input/output protocol in the INTEGRA platform so that the user will be redirected to ART, execute ART within its own user interface and export the output to the INTEGRA platform for further use within the platform (e.g. PBPK). These issues will be fully resolved in INTEGRA Work Package 3.

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Appendix 1 – Equations used by ART

The total personal exposure level (C_t) is the sum of exposure levels due to NF (C_{nf}) and FF (C_{ff}) contributions, adjusted for possible use of RPE:

$$C_t = C_{nf} + C_{ff}$$

Personal exposure due to sources in the NF (C_{nf}) is calculated as a multiplicative function of substance emission potential (E), activity emission potential (H), localized control (LC) and dilution (D). In addition, exposure may arise due to transport of substance from surfaces in the NF [surface contamination (Su)]:

$$C_{nf} = \left(E_{nf} \,.\, H_{nf} \,.\, LC_{nf} + Su_{nf}\right) .\; D_{nf}$$

Personal exposure due to sources in the FF (C_{ff}) is calculated as a multiplicative function of substance emission potential (E), activity emission potential (H), localized control (LC), segregation (Seg), dilution (D) and separation (Sep). In addition, exposure may arise due to transport of substance from surfaces in the FF [surface contamination (Su)]:

$$C_{ff} = \left(E_{ff} \,.\, H_{ff} \,.\, LC_{ff} \,.\, Seg_{ff} + Su_{ff}\right) .\; D_{ff} \,.\, Sep_{ff}$$

There are differences between equations describing exposure related to NF and FF sources. Segregation and separation are not relevant for NF sources. The factor dilution will be different for FF sources as compared to NF sources.

Appendix 2 – Input parameters for the Advanced Reach Tool (ART) v1.5

Descriptor	Example
1. General	
Branch, industry	Agricultural/petrochemical/pharmaceutical, etc.
Activities performed	Name activities; percent time an activity is performed during total sampling time (e.g. 70% spraying liquids, 30% transfer liquids)
Type of product	Antifouling paint/wood/styrene/biocide, etc.
Total sampling time	Average and/or range, full shift
2. Main activities (determinants only applies for relevant activity class) and control	
Amounts used/contamination level of surfaces (where relevant)	Average and/or range (kg) used, use rate (kg h^{-1}), or dirty/clean (contaminated) objects
Surfaces treated, handled, processed (where relevant)	Average and/or range in m^2, m^2 h^{-1}
Technique (where relevant)	Airless spraying/compressed air, etc
Type of handling (where relevant)	Manual/mechanical, e.g. sanding with hand or sander
Distance to source (where relevant)	Near-field (<1 m), far-field (>1 m)
Direction of application (where relevant)	All directions including upward/downward-horizontal/only downward
Dropping height (where relevant)	Average and/or range of heights
Open surface areas (where relevant)	Average and/or range of surface area
Localized control	
Suppression techniques (dusts)	Description wetting system
Containment (excl. extraction)	Description level of containment, e.g. enclosures around source (e.g. lids)
LEV	Types, e.g. fixed capturing, mobile capturing, fume cupboard
Vapour recovery system	Description system (top, bottom)
Mechanical ventilation systems (booths)	Type of unidirectional room ventilation
Segregation	Level of segregation, ventilation
Personal enclosure	Level of enclosure, ventilation
Fugitive sources	Housekeeping practices, cleanliness of workplace
3. Product	
Substance measured	Active ingredient (e.g. toluene) or total hydrocarbons or respirable dust
Concentration active ingredient	Average and/or range of concentration active ingredient in product
Dustiness, moistness (only applies for powders)	Fine dust/course dust/granules, flakes, pellets
	Specify if it is wet/moist or dry
Volatility (only applies for liquids)	Single component: percentage of (volatile) component

Descriptor	Example
	and vapour pressure of the component
	Mixtures: percentage of (volatile) components in the product and vapour pressure of the components in the product
	Processing temperature (where relevant)
4. Environment	
Location	Indoors/outdoors
Indoors	
Room size	Average and/or range of room sizes/description type of room
Mechanical ventilation systems	Average and/or range of ACH/description ventilation
Type general ventilation	Description type of ventilation, e.g. doors, windows, mechanical, etc.
Outdoors	
Far-field distance to source (outdoors)	Average and/or range of distances
Distance to buildings (outdoors)	Average and/or range of distances

Appendix 3 – Proposed equations and key model inputs for DART

Dermal exposure (Skin-P_{BP}) = $(D_{BP} + E_{BP} + T_{BP}) * WH * R * (1-\eta_{GLOVE})$

D_{BP} Deposition

E_{BP} Bulk emission

T_{BP} Surface contact

WH Decontamination (from skin, clothing): worker hygiene

R Removal (from skin, clothing): retention, evaporation

Deposition (D_{BP})

= ART score & calibration*

*The relative contribution of deposition will be investigated during the calibration of the model

Bulk emission (E_{BP})~

= $E_I * H * LC * BP_E$

E_I Substance (bulk) Emission Potential

H Activity (bulk) Emission Potential

LC Localized control

BP_E Affected surface area of body part

~ liquids = spilling, splashes, dripping, (body part) immersion; solids = impaction, (body part) immersion

Surface contact (T_{BP})

= $Su * P_T * C_f * BP_T$

Su Surface contamination level*

P_T Frequency of contact

C_f Transfer efficiency

BP_T Affected surface area of body part

*incl. surface decontamination/cleaning (EH)

Overall algorithm

Dermal exposure (Skin-P_{BP}) $= (D_{BP} + E_{BP} + T_{BP}) * WH * R$

$= [(D_{BP}) + (E_I * H * LC * BP_E) + (Su * P_T * C_f * BP_T)] * WH * R$

Appendix 4 – Summary of DREAM variables and parameters

Determinant	Original DREAM categories
Emission to clothing and uncovered skin	<1% of task = 0 <10% of task = 1 10-50% of task = 3 ≥50% of task = 10
Intensity of emission	<10% of body part = 1 10-50% of body part = 3 ≥50% of body part = 10
Exposure route factor	Immersion = 3 Transfer = 1 Deposition = 1
Probability (frequency) of exposure by deposition	<1% of task = 0 <10% of task = 1 10-50% of task = 3 ≥50% of task = 10
Intensity of deposition exposure	<10% of body part = 1 10-50% of body part = 3 ≥50% of body part = 10
Transfer to clothing or skin	<1% of task = 0 <10% of task = 1 10-50% of task = 3 ≥50% of task = 10
Intensity of transfer	Not contaminated = 0 Possibly contaminated = 1 < 50% of contact surface =3 ≥50% of contact surface = 10
Body surface	Head = 0.69 Upper arm = 0.67 Forearm = 0.53 Hands = 0.47 Torso front = 1.22 Torso back = 1.22

Determinant	Original DREAM categories
	Lower body part = 2.43 Lower leg = 1.15 Feet = 0.63
Physical state	Solid = 1 Liquid = 1 Vapour–gaseous = 0.3
Concentration	>90% active ingredient = 1 1–90% active ingredient = 0.3 <1% active ingredient = 0.1
Evaporation	<50 ºC = 3 50 - 150 ºC = 1 >150 ºC = 0.3
Viscosity (liquids only)	Low = 1 Medium =1.75 High =3
Formulation (solids only)	Powder/fine particulate = 3 Granules /grains/pellets = 1 Pack/bunch/bundle = 0.3
Dusty (solids)?	No = 1 Yes = 3
Sticky/Waxy/moist (solids)?	No = 1 Yes = 1.75
Glove or clothing material by body part	No glove or body part not covered = 1 Woven clothing = 0.3 Non-woven permeable = 0.1 Non-woven impermeable = 0.03
Pressure and friction on gloves	Gloves = 1 Clothing = 0.3
Replacement frequency for gloves	Replaced after use = 0.3 Daily = 1 Weekly = 3 Monthly = 10

Determinant	Original DREAM categories
Non-woven gloves connect well with clothing	No = 3 Yes = 1
Non-woven gloves wear time	0 – 25% of time = 10 25 – 99% of time = 3 100% of time = 1
Under gloves worn with impermeable gloves	No = 1 Yes = 0.3
Replacement frequency of under gloves	Single use = 1 Daily = 3 Weekly or monthly = 10
Barrier Cream	Not used = 1 Used = 0.3

Appendix 5 – Input parameters for IEAT model

Table 1 Model input parameters for the Ingestion Exposure Assessment Tool

Parameters	Options
Surface Loading Level	High (~50 µg/cm²) Medium (~15 µg/cm²), Low (~0.5 µg/cm²), Very Low (0.01 µg/cm²)
Physical State	Liquid Solid
Concentration of substance in solution/formulation	<1% 1 – <5% 5 – <25% 25 - <50% ≥50%
Are gloves worn during times when the worker is likely to come into contact with the substance?	Yes No
Are gloves worn for more than 75% of the shift?	Yes No
If gloves are worn, what type of gloves are they?	Woven (e.g. cotton) Nonwoven (e.g. nitrile)
Is RPE used for more than 50% of the shift?	Yes No
If RPE is used, what type of RPE is it?	Half face (Dust mask, Surgical mask, Half face respirator) Full face (Full face respirator, Powered respirator, SCBA)
Is emission of the substance onto skin (by immersion, spills or splashes) likely to occur frequently (more than five times per shift)?	Yes No
If there is frequent emission are gloves worn during these events?	Yes No

Parameters	Options
Which option best describes the way a typical worker's time is spent during a normal shift?	1) Labour: ≥80%; Admin/travel: <20% 2) Labour: <80%; Admin/travel: ≥20% *Labour* is defined as manual tasks, operating equipment (including machinery, instruments or control panels) or carrying out repairs. *Admin/travel* is defined as attending meetings, discussing work with other employees, conducting paperwork, or travelling from one work area to another.