# GuLF DREAM: A Model to Estimate Dermal Exposure Among Oil Spill Response and Clean-up Workers

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## Abstract

Tens of thousands of individuals performed oil spill response and clean-up (OSRC) activities following the 'Deepwater Horizon' oil drilling rig explosion in 2010. Many were exposed to oil residues and dispersants. The US National Institute of Environmental Health Sciences assembled a cohort of nearly 33 000 workers to investigate potential adverse health effects of oil spill exposures. Estimates of dermal and inhalation exposure are required for those individuals. Ambient breathing-zone measurements taken at the time of the spill were used to estimate inhalation exposures for participants in the GuLF STUDY (Gulf Long-term Follow-up Study), but no dermal measurements were collected. Consequently, a modelling approach was used to estimate dermal exposures. We sought to modify DREAM (DeRmal Exposure Assessment Method) to optimize the model for assessing exposure to various oil spill-related substances and to incorporate advances in dermal exposure research. Each DREAM parameter was reviewed in the context of literature published since 2000 and modified where appropriate. To reflect the environment in which the OSRC work took place, the model treatment of evaporation was expanded to include vapour pressure and wind speed, and the effect of seawater on exposure was added. The modified model is called GuLF DREAM and exposure is estimated in GuLF DREAM units (GDU). An external validation to assess the performance of the model for oils, tars, and fuels was conducted using available published dermal wipe measurements of heavy fuel oil (HFO) and dermal hand wash measurements of asphalt. Overall, measured exposures had moderate correlations with GDU estimates ($r = 0.59$) with specific correlations of –0.48 for HFO and 0.68 for asphalt. The GuLF DREAM model described in this article has been used to generate dermal exposure estimates for the GuLF STUDY. Many of the updates made were generic, so the updated model may be useful for other dermal exposure scenarios.

**Keywords:** Deepwater Horizon; dermal exposure; dermal exposure modelling; determinants of exposure; exposure assessment, GuLF STUDY

## Introduction

The US National Institute of Environmental Health Sciences is conducting the Gulf Long-term Follow-up Study (GuLF STUDY) to evaluate the health of workers involved in oil spill response and clean-up (OSRC) of the ~4.9 million barrels of oil in the Gulf of Mexico in 2010 released following the 'Deepwater Horizon' oil drilling rig explosion and ensuing spill (Engel *et al.*, 2017; Kwok *et al.*, 2017). As part of the study, inhalation and dermal exposures to hazardous substances associated with the response and clean-up are being assessed (Arnold *et al.*, 2021; Huynh *et al.*, 2021a,b,c; Ramachandran *et al.*, 2021; Pratt *et al.*, 2021; Stenzel *et al.*, 2021; Stewart *et al.*, 2021). This article describes the methods used to estimate dermal exposure in this population.

Many of the response and clean-up activities for the Gulf oil spill involved potential dermal contact with oils and tars, and some involved contact with dispersants and gasoline and diesel fuel (referred to here as fuel). These exposures, which were of interest to the GuLF STUDY, were assessed for the following components total hydrocarbons (THC), benzene, toluene, ethyl benzene, xylene, n-hexane, and polycyclic aromatic hydrocarbons. Despite the potential importance of the dermal route of exposure no dermal exposure measurements were made during the OSRC effort in the GULF STUDY and no surface contamination measurements taken from which dermal exposure could be extrapolated. Owing to the lack of measurements, exposure assessment for spill-related exposures was carried out using a modelling approach.

Several dermal assessment models were considered as possible approaches to estimate dermal exposure for the GuLF STUDY cohort: RISK assessment OF Occupational DERMal exposure to chemicals (RISKOFDERM; Van Hemmen *et al.*, 2003), DREAM (DeRmal Exposure Assessment Method; Van Wendel de Joode *et al.*, 2003), and European CEntre for Ecotoxicology and Toxicology Of Chemicals Targeted Risk Assessment (ECETOC TRA; ECETOC, 2009). DREAM was selected as the most appropriate model for the GuLF STUDY because its structure allows the use of information on dermal exposure scenario characteristics and personal protective equipment (PPE) use, which were available from the GuLF STUDY questionnaires. DREAM uses the information to estimate exposures on a semi-quantitative scale (DREAM units). In previous DREAM assessments, estimated DREAM units correlated well with exposure measurements for hands ($r = 0.78$) across a wide range of scenarios and exposure agents. Correlation coefficients for other parts of the body were lower, for example $r = 0.48$ for the legs (Van Wendel de Joode, Vermeulen, Van Hemmen *et al.*, 2005). Side-by-side DREAM assessments by multiple assessors indicated that the estimates were quite robust across different assessors. Intra-class correlation coefficients between 29 assessors ranged from 0.68 to 0.87 (Van Wendel de Joode, Vermeulen, Van Hemmen *et al.*, 2005).

Although the published validation and reliability testing suggested that DREAM was a promising tool, there were some limitations for use in the GuLF STUDY. Since DREAM was developed, further research has been published on the mechanisms of dermal exposure. A review of this research was necessary to ensure that the version of DREAM used for the GuLF STUDY reflected the most recent understanding of dermal exposure. Although the DREAM validation work included exposure to benzene and toluene, it did not include exposures to oils and tars. Two recent studies, however, have evaluated DREAM estimates for similar substances (McClean *et al.*, 2004; Agostini *et al.*, 2011). DREAM was used by Agostini *et al.* (2011) to estimate dermal exposure to bitumen condensate among asphalt workers. Although quantitative exposure measurements were not taken for those workers, the DREAM assessment identified differences in DREAM units between tasks similar to the exposure differences between the same tasks measured by McClean *et al.* (2004). Christopher *et al.* (2007) conducted a DREAM exposure assessment for heavy fuel oil (HFO) in several industries and found no correlation between DREAM units and exposure measurements taken on the same workers. There is, therefore, uncertainty regarding DREAM's ability to assess exposure for oils and tars. Furthermore, DREAM was intended as a tool for prospective exposure assessment and involves direct observation of subjects, but the GuLF STUDY required retrospective exposure assessment from information that could be provided by study participants. The aim of this research was to create a dermal exposure assessment method for the GuLF STUDY. We used the structure of DREAM to create a model that makes use of the available information in the GuLF STUDY. We also aimed to incorporate advances in dermal exposure research. A validation assessment was also conducted to ensure that the modified model was suitable for retrospective exposure assessment.

## Methods

### Model review and amendments

The structure of DREAM was described in detail by Van Wendel de Joode *et al.* (2003). DREAM estimates the 'potential dermal exposure' on nine body parts and reduces those values to account for the expected effect of any PPE or clothing to develop an estimate of the 'actual dermal exposure' on the skin. If PPE or clothing is not worn on the body part, actual dermal exposure is identical to potential dermal exposure. It is important to note that DREAM estimates exposure on the skin in terms of mass of contaminant (assessed on an arbitrary scale—DREAM units), not uptake through the skin.

Potential dermal exposure for each body part is calculated as the sum of exposure from each of three pathways of dermal exposure:

- *Emission*: direct contact between the body part and the substance. This could be from placing a body part in, such as a container of a liquid, or on the source, such as from spills or splashes.
- *Surface Transfer*: contact between the body part and a surface contaminated with the substance and subsequent transfer of the substance to the body part.
- *Deposition*: deposition of an airborne substance onto the body part.

Potential dermal exposure for each pathway is calculated as the product of the 'frequency' 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 of the three pathways more heavily than others (Van Wendel de Joode *et al.*, 2003). The 'intrinsic emission' refers to the effect on exposure of the agent's characteristics (for example 'concentration' or 'vapour pressure').

The magnitude of each of the aforementioned parameters is assessed from data or subjectively by exposure assessors familiar with the exposure scenario on a categorical scale. Each category is associated with a weighting that reflects the expected relative effect of the category on the exposure level (Table 1).

To modify DREAM for the GuLF STUDY, each of the DREAM parameters was independently reviewed by two of us experienced in dermal exposure assessment (J.W.C. and M.G.N.). These reviews assessed the robustness of the DREAM approach to each parameter and considered whether there was evidence to suggest a need for modifying the parameters for the GuLF STUDY. Not included in the original model but also reviewed was the impact of seawater on the model. The DREAM review generally focussed on literature published since 2000, since literature published before this time would have been considered in the original development of DREAM. The updated model was called GuLF DREAM and exposure is estimated in GuLF DREAM units (GDU). Model parameters from DREAM and corresponding parameters from GuLF DREAM are summarized in Table 1. The rationale behind the changes that have been made to DREAM are summarized later. Detailed descriptions are available in the Supplementary material (available at *Annals of Work Exposures and Health* online).

#### Intrinsic emission

The intrinsic emission of the substance in DREAM is determined from the characteristics of the substance. For liquids intrinsic emission is the product of values assigned to the concentration ($C$), 'evaporation' (EV), and 'viscosity' ($V$). The GuLF STUDY dermal exposure assessment focussed on components of oil, tar, fuel, and liquid dispersants; the estimation of solids or vapours was not considered. Vapours were not considered because the dispersants were in liquid form at ambient exposure temperatures. In DREAM, concentration was a categorical variable. During validation of DREAM, Van Wendel de Joode, Vermeulen, Van Hemmen *et al.* (2005) and Van Wendel de Joode, Van Hemmen, Meijster *et al.* (2005) found that entering concentration as a continuous variable resulted in stronger correlation between model estimates and measurement values. In GuLF DREAM, concentration is entered as a continuous variable.

**Table 1.** Summary of DREAM and corresponding GuLF DREAM parameters and weightings

| Parameter | Original DREAM weightings | GuLF STUDY DREAM weightings | Changes for GuLF STUDY |
|---|---|---|---|
| Intrinsic emission (substance/environmental factors) | | | |
| Concentration | Value between 0 and 1 (categorical) | Value between 0 and 1 (continuous) | Entered as a continuous variable rather than categorical as this resulted in stronger correlation with measurement values in DREAM validation (Van Wendel de Joode, Vermeulen, Van Hemmen *et al.*, 2005 and Van Wendel de Joode, Van Hemmen, Meijster *et al.* (2005).) |
| Viscosity*/emission | Low = 1<br>Medium =1.75<br>High =3 | Low = 1<br>Medium low = 2.0<br>Medium = 3<br>Medium high = 6.0<br>High = 9 | Increased weighting of high category to reflect increased retention with increased viscosity (Cinalli *et al.*, 1992 and Gorman Ng *et al.,* 2013). Intermediate levels (medium low and medium high) added to increase differentiation among GuLF STUDY participants. The effect of viscosity was attenuated when cotton clothing was used as Gorman Ng *et al.* (2013) found that viscosity had a limited effect on uptake by cotton materials (see supplementary materials). |
| Viscosity/surface transfer | Low = 1<br>Medium = 1.75<br>High = 3 | Low = 1<br>Medium low = 1.375<br>Medium = 1.75<br>Medium high = 2.375<br>High = 3 | No changes made. Cinalli *et al.*, (1992) and Gorman Ng *et al.*, (2013) found no difference in surface transfer with increasing viscosity. Intermediate levels (medium low and medium high) added to increase differentiation among GuLF STUDY participants |
| Viscosity/deposition | Low = 1<br>Medium = 1.75<br>High = 3 | Low = 1<br>Medium low = 1.375<br>Medium = 1.75<br>Medium low = 1.375<br>High = 3 | No changes made. Gorman Ng *et al.* (2013) found no evidence that viscosity influences exposure by deposition if air concentrations are held constant. Intermediate levels (medium low and medium high) added to increase differentiation among GuLF STUDY participants |
| Evaporation | <50°C = 3<br>50–150°C = 1<br>>150°C = 0.3 | Not included | To refine the effect of evaporation this variable was replaced by two factors that influence the rate of evaporation: vapour pressure and wind speed |
| Vapour pressure | Not included | <50 Pa = 1<br>50–100 Pa = 0.75<br>100–1000 Pa = 0.1<br>1000–10000 Pa = 0.01<br>>10000 Pa = 0.005 | Evaluated using both IH SkinPerm and the NIOSH Skin Permeation Calculator. Both calculators showed an increasing rate of evaporation with increasing vapour pressure, as reflected in the weightings |
| Velocity of air | Not included | Dispersants:<br><1–3 mph = 1<br>3–10 mph = 0.75<br>>10 mph = 0.5<br>Oils and tars: any wind speed = 1 | Evaluated using both IH SkinPerm and the NIOSH Skin Permeation Calculator. The weightings are based on the more conservative estimates from the NIOSH model |

**Table 1.** Continued

| Parameter | Original DREAM weightings | GuLF STUDY DREAM weightings | Changes for GuLF STUDY |
|---|---|---|---|
| Exposure route factor | | | |
| Exposure Route Factor | Emission = 3<br>Surface transfer = 1<br>Deposition = 1 | Emission = 5<br>Surface transfer = 3<br>Deposition =1 | Emission and surface transfer weightings were increased to reflect the evidence that suggests 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 *et al.*, 2002; Pronk *et al.*, 2006; Links *et al.*, 2007) |
| Frequency and intensity of exposure | | | |
| Frequency of exposure by emission and surface transfer | <1% of task duration = 0<br><10% of task duration = 1<br>10–50% of task duration = 3<br>≥50% of task duration = 10 | <1% of task duration = 0<br><10% of task duration = 1<br>10–50% of task duration = 3<br>≥50% of task duration = 5 | The weightings for the highest frequency category were reduced. Hughson and Cherrie (2003) found that skin becomes saturated following emission or surface transfer exposure. It is unlikely that there would be such a big difference between exposure for <50 and >50% of the task |
| Frequency of exposure by deposition | <1% of task duration = 0<br><10% of task duration = 1<br>10–50% of task duration = 3<br>≥50% of task duration = 10 | <1% of task duration = 0<br><10% of task duration = 1<br>10–50% of task duration = 3<br>≥50% of task duration = 10 | No change made<br>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<br>10–50% of body part = 3<br>≥50% of body part = 10 | <10% of body part = 1<br>10–50% of body part = 3<br>≥50% of body part = 10 | No change made<br>The available evidence suggests a linear relationship between body surface area exposed and exposure (Brouwer, Lansink *et al.*, 2000, and Brouwer, de Vreede *et al.*, 2000) supporting the original DREAM values |
| Intensity of surface transfer: contamination level of surface | Not contaminated = 0<br>Possibly contaminated = 1<br><50% of surface = 3<br>≥50% of surface = 10 | Not contaminated = 0<br>Possibly contaminated = 1<br><50% of surface = 3<br>≥50% of surface = 10 | No change made<br>Brouwer *et al.* (1999), Cohen Hubal *et al.* (2005), and Christopher (2008) found a relationship between the loading of material on surfaces and the mass transferred to the skin following contact supporting the original DREAM values |
| Gloves and protective clothing | | | |
| Glove or clothing material by body part | No glove or body part not covered = 1<br>Woven clothing = 0.3<br>Non-woven permeable = 0.1<br>Non-woven impermeable = 0.03 | No glove or body part not covered = 1<br>Woven or permeable clothing or inappropriate materials = 0.9<br>Non-woven impermeable gloves or clothing = 0.5 | The impact of gloves and clothing on exposure was reduced. The literature on glove effectiveness suggested that the original DREAM model overestimated the effect of gloves on exposure. (Scheepers *et al.*, 2009; Weiss *et al.*, 2011; Wang *et al.*, 2006) |

**Table 1.** Continued

| Parameter | Original DREAM weightings | GuLF STUDY DREAM weightings | Changes for GuLF STUDY |
|---|---|---|---|
| Pressure and friction on gloves | Gloves = 1<br>Clothing = 0.3 | Not included | No evidence was found that 'pressure or friction on gloves' plays a role in glove effectiveness |
| Replacement frequency | Replaced after use = 0.3<br>Daily = 1<br>Weekly = 3<br>Monthly = 10 | Replaced within a work shift = 0.3<br>Replaced daily = 1<br>Replaced < 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 STUDY questionnaire |
| Non-woven gloves connect well with clothing | No = 3<br>Yes = 1 | No = 1.3<br>Yes = 1 | The weighting was modified to reflect the lower overall protection assumed from wearing gloves. Creely and Cherrie (2001) support the importance of this factor, although there is no quantitative data to substantiate the magnitude |
| Non-woven gloves wear time | 0–25% of time = 10<br>25–99% of time = 3<br>100% of time = 1 | 0–25% of the time = 2<br>25–99% of time = 1.2<br>100% of time = 1 | The magnitude of the parameters was reduced based on the lower effectiveness assumed for clothing and gloves |
| Under gloves worn with impermeable gloves | No = 1<br>Yes = 0.3 | Not included | No evidence was found that under gloves have any impact on exposure |
| Replacement frequency of under gloves | Single use = 1<br>Daily = 3<br>Weekly or monthly = 10 | Not included | No evidence was found that under gloves have any impact on exposure |
| Barrier cream | Not used = 1<br>Used = 0.3 | Not included | Barrier creams were not used by remediation workers in the GuLF study |
| Seawater | Not included | Dispersants = 1<br>Oils and tars = 2 | This variable was added to reflect the effect of seawater exposure on dermal uptake. Exposure to water can damage the skin and can increase uptake of chemicals by a factor of up to 4 (Yoshizawa *et al.*, 2001). The effect was not applied to dispersants as they are water soluble and would be washed away by water, counteracting the effect of increased uptake |

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

***Viscosity.*** In DREAM, dermal exposure is expected to increase with increased viscosity. Viscosity can affect dermal exposure in two ways: transfer and retention. Cinalli *et al.* (1992) and Gorman Ng *et al.* (2013) both studied the effect of viscosity on dermal exposure in laboratory simulations using consumer oils and glycerine solutions, respectively. Both found that the effect of viscosity on exposure varied, depending on the exposure pathway. In both studies, for exposure by 'surface transfer' and deposition, there was no relationship between viscosity and the transfer of liquid to the skin, but the amount of liquid transferred to the skin increased with increasing viscosity by the emission pathway. For retention, Cinalli *et al.* found that after oil was wiped from the skin, the highest viscosity oil (mineral oil) left more residue on the skin than lower viscosity oils (vegetable oil and bath oil), thus retention of oils on the skin was greater the more viscous the oil. In GuLF DREAM, the DREAM weightings were retained for exposure by surface transfer and deposition to reflect the finding that

**Table 2** The effect of varying VP, MW, $V^a$, and $T$ on the evaporation rate using IH SkinPerm and the NIOSH Skin Permeation Calculator

| Variable | Values | Evaporation Rate IH SkinPerm (mg cm$^{-2}$ h$^{-1}$) | Ratio of evaporation rate to rate at lowest value IH SkinPerm | Evaporation rate NIOSH (mg cm$^{-2}$ h$^{-1}$) | Ratio of evaporation rate to rate at lowest value NIOSH |
|---|---|---|---|---|---|
| VP$^b$ (Pa) | 50 | 2 | 1 | 2 | 1 |
| | 100 | 4 | 2 | 4 | 2 |
| | 1000 | 42 | 20 | 45 | 20 |
| | 5000 | 208 | 100 | 224 | 100 |
| | 10000 | 415 | 200 | 447 | 200 |
| | 25000 | 1038 | 500 | 1119 | 500 |
| MW$^c$ (g mol$^{-1}$) | 75 | 26 | 1 | 33 | 1 |
| | 100 | 35 | 1.3 | 40 | 1.2 |
| | 120 | 42 | 1.6 | 45 | 1.4 |
| $V^d$ (mph) | 0.67 | 42 | 1 | 45 | 1 |
| | 3 | 175 | 4.2 | 144 | 3.2 |
| | 5 | 286 | 6.8 | 215 | 4.8 |
| | 10 | 555 | 13.2 | 368 | 8.2 |
| | 15 | 820 | 19.5 | 506 | 11.2 |
| $T^e$ (K) | 303 | 42 | 1 | 45 | 1 |
| | 313 | 40 | 0.97 | 43 | 0.97 |
| | 323 | 39 | 0.94 | 42 | 0.94 |

[a] Velocity of air is comparable to wind speed in GuLF DREAM.
[b] MW = 120 g, velocity of air = 0.67 mph, $T$ = 303 K.
[c] VP = 1000 Pa, velocity of air = 0.67 mph, $T$ = 303 K.
[d] VP = 1000 Pa, MW = 120 g, $T$ = 303 K.
[e] VP = 1000 Pa, MW = 120 g, velocity of air = 0.67 mph.

higher viscosity oils had greater retention on the skin. For the emission pathway, the weightings for medium and high viscosity were increased as both transfer and retention were influenced by viscosity for this pathway (Table 1). DREAM had three categories of viscosity (low, medium, and high). We have added two intermediate categories (low medium, and medium high) to reflect the range of viscosities of the chemicals in the GuLF STUDY. The weightings for the intermediate categories were set at the midpoints between the low, medium, and high categories. The effect of viscosity was attenuated when cotton clothing was used as Gorman Ng *et al.* (2013) found that viscosity had a limited effect on uptake by cotton materials (see supplementary materials).

***Evaporation.*** DREAM took a direct approach to account for the effect of evaporation of liquids from the skin on exposure. Greater evaporation was expected for substances with lower boiling points, resulting in lower exposure. However, as the OSRC workers were exposed to high ambient temperatures it was hypothesized that evaporation may have had a substantial effect on exposure. To investigate this possible effect, evaporation equations used in two dermal absorption predictive models were evaluated: IH SkinPerm (Tibaldi *et al.*, 2014) and the NIOSH Skin Permeation Calculator (NIOSH, 2013). These models use similar equations to estimate evaporation from the skin. In both models the variable parameters are velocity of air ($V$), molecular weight (MW), and vapour pressure (VP). Skin temperature ($T$) is included in both models and in most work environments is expected to remain relatively constant as ambient temperatures are typically lower than skin temperature (~303 K or 30°C, Tibaldi *et al.*, 2014). However, in the GuLF STUDY, ambient temperatures often exceeded skin temperatures (up to 323 K or 50°C) and may play a greater role in evaporation, so we evaluated the effect of values of $T$ greater than 303 K.

To evaluate the effect of these parameters on the evaporation rate in a sensitivity analysis, evaporation rates were calculated with both equations, holding all equation parameters constant while individually varying $V$, MW, VP, or $T$ within the range of the expected values for the GuLF STUDY (Table 2). In an outdoor context, velocity of air is determined by 'wind speed' and in GuLF DREAM we refer to 'wind speed' rather than 'velocity of air'. Typical wind speeds were expected to range from 0.3 to 6.7 ms$^{-1}$ (0.67–15 miles per h). The expected $T$ ranged from 303 K (30°C, typical skin temperature, Tibaldi *et al.*, 2014) to 323 K (50°C).

In both models the evaporation rate increased with VP, MW, and $V$. Parameters for vapour pressure and wind speed were added to GuLF DREAM. The model estimates of evaporation rates were used to calculate ratios between the evaporation rates at the minimum expected values of vapour pressure and wind speed, and the evaporation rates at increasing intervals of these parameters (Table 2). The weightings assigned to vapour pressure and wind speed were based on these ratios. In the case of vapour pressure, both models resulted in similar estimated ratios. In the case of wind speed, the NIOSH model estimated a more modest increase in evaporation with increasing wind speed, and the GuLF DREAM weightings were based on these more conservative estimates.

Counter-intuitively, the rate of evaporation decreased with increasing $T$ in both models as $T$ is in the denominator in both models. Our sensitivity analysis indicated that within the range of expected $T$ in the GuLF STUDY, $T$ alone should not have heavily influenced the rate of evaporation. Vapour pressure varies with temperature, and the degree of variation can be determined using the Antoine and Clausius–Clapeyron equations that are derived from thermodynamic principles (Perkins, 1997). If a VP is used that corresponds to the relevant temperature, it is not necessary to include both in the model. The effect of MW within the expected range was also minimal. Consequently $T$ and MW were excluded from GuLF DREAM. The equation for intrinsic emission of liquids was changed to reflect these findings (equation 1):

$$\begin{aligned}\text{Intrinsic Emission}_{(\text{Liquids})} = {} & \text{Concentration} \\ & \times \text{Vapour Pressure} \\ & \times \text{Wind Speed} \times \text{Viscosity}\end{aligned} \tag{1}$$

To fit the structure of DREAM each parameter was categorized and weightings were assigned to each category to reflect the expected impact on exposure (Table 1).

Fingas (2011) described experimental work that studied the rate of evaporation of water and oil with wind of varying speeds. He found that the rate of evaporation of water increased with increasing wind speed, but that wind speed had no effect on the rates of evaporation of oil or gasoline. He concluded that this is because the evaporation rates of the volatile components of oils and fuels are limited by the diffusion rate of the molecules inside the liquid to the surface of the liquid, and they evaporate too slowly to saturate the air. The rates of evaporation of oil and gasoline and their constituents are, therefore, unaffected by wind speed. Because dispersants contain surfactants, however, they have a low surface tension. This results in the components having a vapour pressures that approximate saturation; therefore, dispersants would be affected by wind speed. Consequently, in GuLF DREAM, wind speed has no effect on evaporation of oils, tars, and fuels, and their components and affects only evaporation of dispersants.

### Exposure pathways

In DREAM, exposure by the emission is weighted three times as heavily as exposure by surface transfer or deposition. There is evidence that supports this increased weighting of the emission pathway. Hughson and Cherrie (2003) conducted laboratory experiments to assess dermal exposure to zinc following emission or surface transfer. Measured exposures from emission were over three times higher than exposures following surface transfer. Gorman Ng *et al.* (2013) also carried out laboratory experiments comparing dermal exposure pathways. They assessed exposure to liquids (glycerol solutions) and dusts (calcium acetate, zinc oxide, and magnesium sulphate) by emission, surface transfer and deposition. For liquids and dusts, the masses of material that transferred to the skin were higher for the emission pathway than the surface transfer or deposition pathways by at least a factor of 10. Exposures following surface transfer were higher than exposures from deposition by at least a factor of 3, despite measured air concentrations up to 44 mg m$^{-3}$ for dust and up to 67 mg m$^{-3}$ for liquids. Several studies have demonstrated a correlation between measured air concentration and dermal exposure (Vermeulen *et al.*, 2000; Burstyn *et al.*, 2002; Pronk *et al.*, 2006; Links *et al.*, 2007) suggesting that deposition plays a role in dermal exposure. However, in some of these studies, the correlation between air concentration and dermal exposure was weaker among workers who directly handled materials or had contact with contaminated surfaces. This further suggests that emission and surface transfer both play a larger role in dermal exposure than deposition. In GULF DREAM, the exposure route weighting for emission was, therefore, increased to 5. This relatively conservative weighting for emission was selected to avoid overstating its effect or overshadowing the effect of all other contributing factors to dermal exposure. The weighting for surface transfer was increased to 3 as the evidence suggests that it is associated with higher exposures than deposition (Table 1). No change was made to deposition.

### Frequency of exposure

The DREAM parameter frequency relates to rate of dermal contact with the substance expressed as the proportion of the task duration in which exposure occurs. DREAM assumes increasing exposure with increasing duration. Studies identified in the review have supported this reasoning (Hughson and Aitken, 2004; Liden *et al.*, 2008). However, there is also some evidence of the skin becoming 'saturated' (Hughson and Cherrie, 2003). Once skin has become saturated, further duration of exposure will not lead to increased exposure. Saturation is most likely to occur during exposure by emission and may occur after only one or two emission episodes. The original weightings for frequency from DREAM were retained in GuLF DREAM for deposition and surface transfer because saturation is less likely by these pathways, but the weighting associated with the highest frequency category was reduced for the emission pathway to account for saturation (Table 1).

### Intensity of exposure

The DREAM parameter intensity relates to the proportion of the affected body part(s) that is exposed by the emission and deposition pathways. Dermal exposure levels are typically recorded as mass per unit area, and the greater the area involved, the greater the total mass exposure. Measurements using fluorescent methods have indicated that greater exposed surface areas are related to higher mass exposures (Brouwer, Lansink *et al.*, 2000). As these findings support the original DREAM classification and weightings used for intensity of emission and deposition, they were retained in GuLF DREAM (Table 1).

Intensity is defined differently for the surface transfer pathway; for this pathway, it relates to the contamination level of the contacted surface. There was evidence cited by the authors of DREAM to support the weightings used (Van Wendel de Joode, 2003). More recent studies also support them (Brouwer *et al.*, 1999; Vermeulen *et al.*, 2000; Cohen Hubal *et al.*, 2005; Christopher, 2008). The classification and weightings for intensity of surface transfer were retained in GuLF DREAM (Table 1).

### Gloves and protective clothing

There are eight DREAM parameters that affect estimates of protection provided by gloves or clothing. These are the following: (i) 'glove or clothing material', (ii) 'pressure and friction on gloves/clothing', (iii) 'replacement frequency', (iv) 'glove connection with clothing', (v) 'percentage of time during the task that glove/clothing was worn', (vi) 'use of under gloves', (vii) 'replacement frequency of under gloves', and (viii) 'use of barrier cream'. When DREAM was developed there was little objective information to define the magnitude of the weightings for these parameters.

***Glove or clothing material.*** In DREAM gloves or protective clothing decrease exposure using weightings ranging from 0.3 to 0.03 depending on the glove or clothing material (Table 1). Our review suggested that these values may be optimistic about the effectiveness of gloves and protective clothing. Although studies show that gloves and protective clothing can reduce dermal exposure by 80–95% (Popendorf *et al.*, 1995; Roff, 1997; Garrod *et al.*, 1999; Brouwer, de Vreede *et al.*, 2000; Driver *et al.*, 2007), these studies were often based on measures of external exposure or were undertaken in closely controlled experimental situations. Studies where biological monitoring was used to assess exposures generally showed that protective gloves reduced exposure by ~50–60% (Wang *et al.*, 2006; Scheepers *et al.*, 2009; Weiss *et al.*, 2011). The results of these biological monitoring studies may be more realistic as they were carried out in real workplaces rather than experimental situations and they take account of uptake from the whole body rather than from isolated sampling areas. Thus, the impact of glove and clothing material on exposure was reduced in GuLF DREAM to 0.5 for impermeable gloves or clothing to reflect the reductions observed in biological monitoring studies. Woven, permeable, or inappropriate materials were assigned a weighting of 0.9, reflecting minimal protection (Table 1).

***Pressure and friction on gloves/clothing.*** No studies were found that provided information on the impact of 'pressure or friction on gloves' on the effectiveness of gloves. This parameter was removed from the model.

***Replacement frequency.*** There is evidence to suggest that reusing gloves over one or more work shifts can result in diminished protection. Lee *et al.* (2009) conducted laboratory tests of glove permeation of the pesticide, malathion. They found that gloves that had been used for up to 14 days had greater permeation than new gloves, even with no discernible wear to the gloves. The apparent increased permeation may have been due to changes in the glove material properties due to use or to transfer of the substance to the interior of the gloves when the gloves were put on and removed. The latter has been documented by Rawson *et al.* (2005) who found that, without training, 90% of glove wearers had contamination inside their gloves when they reused them. Although this evidence supported retaining the replacement frequency parameter in GuLF DREAM, there were insufficient data to determine the magnitude of the weightings. In DREAM, reuse of clothing and gloves can result in exposures thirty times higher than scenarios in which they are not reused; we think this is likely to be an overestimate of the effect of reuse, and the impact was consequently reduced in GuLF DREAM (Table 1).

***Glove connection with clothing.*** Creely and Cherrie (2001) carried out simulated laboratory tests on the effectiveness of three glove types during pesticide spraying. All gloves tested were made of materials that were impermeable to the pesticide for up to eight h. The poorest protection was with shorter, thicker gloves, i.e. those that were difficult to manipulate and did not fully cover the forearm. Despite this evidence of an effect of glove connection with clothing, there is no published information about the relative importance of this factor. The DREAM parameter was retained in GuLF DREAM and extended to apply to all glove materials as there is no reason to assume that it applies only to non-permeable gloves (Table 1). The weightings were modified to take account of the lower overall protectiveness from gloves discussed earlier (Glove or clothing material).

***Percentage of time during task that glove/clothing was worn.*** We found no evidence related to this parameter. However, logically, if there is exposure during a task and gloves are not worn for some of the time, then the protection offered by the gloves will be less than if they had been worn throughout the task. This parameter was retained in GuLF DREAM and extended to all glove materials as nothing suggests that the logic applies to some glove materials and not others. In line with the lower glove effectiveness discussed earlier (Glove or clothing material), the magnitude of this parameter was reduced (Table 1).

***Under gloves.*** We found no research on the effect of under gloves and no evidence that the use of under gloves has any impact on exposure. Both parameters related to under gloves were removed from GuLF DREAM.

***Barrier cream.*** On the basis of a review of the literature and supporting documents, there is no evidence that the OSRC workers used barrier creams. This parameter was removed from GuLF DREAM.

### Seawater

Contact with seawater was prevalent amongst the OSRC workers so its effects on dermal exposure and uptake were reviewed. Water is a weak dermal irritant that can damage the skin by gradually removing the horny layer, denaturing the keratin, removing stratum corneum lipids, and altering the water retention capacity of the skin (Tsai and Maibach, 1999; English, 2004). Exposure to seawater may, therefore, disrupt the skin barrier, which can increase the uptake of chemicals through the skin (Kezic *et al.*, 2009). The extent of the enhanced penetration depends on the degree of skin damage and the chemicals concerned. Kezic *et al.* (2009) found that skin barrier disruption from contact with water increased dermal uptake by ≤4 times in 16 of 21 studies reviewed, so the maximum effect of exposure to seawater is likely to increase the uptake of chemicals by a factor of 4 times. There is evidence to suggest that seawater is less damaging than pure water (Yoshizawa *et al.*, 2001).

In general, water is effective at removing water-soluble chemicals from the skin (Hui *et al.*, 2013). The dispersant used by the OSRC workers was water soluble, so although the presence of seawater may have damaged the dermal barrier, increased uptake would also probably be counteracted by the chemical being washed away. Consequently, in GuLF DREAM seawater has no effect on exposure to dispersants. In the case of oils, tars, and fuels, which are not water soluble, uptake is expected to be increased by exposure to seawater. To account for this difference, the GuLF DREAM exposure estimate for these substances is multiplied by two (half the maximum likely effect of exposure to seawater) when workers are exposed to seawater, whereas for dispersants seawater has no effect in the model.

## Validation

We reviewed dermal exposure studies to identify those that could be used for validation of the GuLF DREAM model. We found only two studies, one on HFO and one on asphalt (Christopher *et al.*, 2007, 2011; Cavallari *et al.*, 2012). Original data sets were obtained from the study authors and contextual information from the studies was used to calculate GuLF DREAM estimates for exposure scenarios. Only hand exposure could be evaluated because of the lack of sufficient measurement data for the other body parts.

Cavallari *et al.* (2012) assessed the effect that source and work practices had on dermal exposure to polycyclic aromatic compounds (PACs) among hot-mix asphalt paving workers. Asphalt or bitumen is a sticky, black and highly viscous liquid or semi-solid form of petroleum and is similar to the tar in the GuLF STUDY. It is a complex mixture of organic compounds including PACs. Measurements ($n$ = 8) were made using a hand washing procedure.

HFO components are a group of heavy petroleum streams produced in oil refineries from crude oil. As HFOs have low volatility, inhalation exposure is likely to be low in most circumstances. However, there is the potential for dermal exposure, particularly during transfer, cleaning, and maintenance activities. Christopher *et al.* (2007, 2011) developed a wipe sampling method to assess HFO levels using either phenanthrene or naphthalene as markers of HFO exposure. Measurements ($n$ = 16) were carried out in four different types of facilities: oil refineries, distribution terminals, energy providers, and an engine building and repair company.

GDU hand exposure estimates were generated by two exposure assessors experienced in dermal exposure assessment (J.W.C. and A.S.) and compared to the dermal wipe and wash measurements expressed in micrograms per square centimetre of skin (μg cm$^{-2}$). Exposure measurements below the limit of detection (LOD) were substituted with randomly generated values between zero and the LOD. The data were log-transformed prior to analysis. Pearson's correlation coefficients were calculated to compare measured and GuLF DREAM estimated exposures by substance. Analysis was conducted with Intercooled Stata, version 13.1 for Mac (Stata Corp LP, College Station, TX, USA)

## Results

### Updated model

The GuLF DREAM model has the same general structure as DREAM, except for the changes in weights that are described earlier and summarized in Table 1. A total of 23 variables were evaluated. Of these, eight were modified, seven were not modified, three were added, and five were removed. The equations used in the modified model are described in equations 2–9. The full model algorithm is available in the Supplementary material (available at *Annals of Work Exposures and Health* online). The tool has been implemented in Excel and is freely available upon request to the authors (M.G.N.).

Gulf DREAM uses the values selected by the exposure assessor to estimate exposure. First, the variable 'Substance' is calculated. This variable only needs to be calculated once.

$$\begin{aligned} \mathit{Substance} &= \mathit{Concentration} \times \mathit{Vapor\ Pressure} \\ &\quad \times \mathit{Wind\ Speed} \end{aligned} \tag{2}$$

The exposure for each body part is estimated by three pathways: emission, deposition, and surface transfer.

$$\begin{aligned} \mathit{Emission} &= \mathit{Emission\ Frequency} \times \mathit{Emission\ Intensity} \\ &\quad \times \mathit{Viscosity} \times \mathit{Substance} \times 5 \end{aligned} \tag{3}$$

$$\begin{aligned} \mathit{Deposition} &= \mathit{Deposition\ Frequency} \times \mathit{Deposition\ Intensity} \\ &\quad \times \mathit{Viscosity} \times \mathit{Substance} \times 1 \end{aligned} \tag{4}$$

$$\begin{aligned} \mathit{Surface\ Transfer} &= \mathit{Surface\ Transfer\ Frequency} \\ &\quad \times \mathit{Surface\ Transfer\ Intensity} \\ &\quad \times \mathit{Viscosity} \times \mathit{Substance} \times 3 \end{aligned} \tag{5}$$

'Potential Exposure' for each body part is then estimated, where SA = Surface Area:

$$\begin{aligned} \mathit{Potential\ Exposure} &= (\mathit{Emission} + \mathit{Deposition} + \mathit{Surface\ Transfer}) \\ &\quad \times \mathit{Body\ Part\ SA} \end{aligned} \tag{6}$$

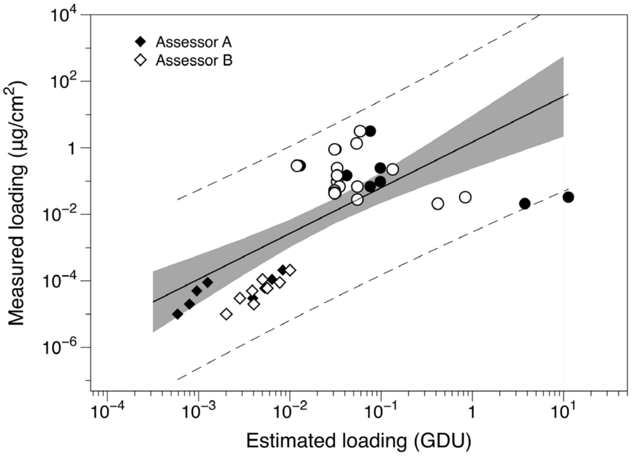

**Figure 1** Scatter plot of hand wipe estimates against GDU hand exposure estimates for exposure to asphalt and HFO, $r$ = 0.59. Asphalt measurements are depicted as circles and HFO measurements are depicted as diamonds.

The effect of protective clothing for each body part is then calculated. This is calculated differently for the hands (*Hand Clothing*) than for the rest of the body (*Body Clothing)*

$$\begin{aligned}\mathit{Hand\ Clothing} &= \mathit{Clothing\ Material} \\ &\quad \times \mathit{Clothing\ Replacement\ Frequency} \\ &\quad \times \mathit{Glove\ Connection} \\ &\quad \times \mathit{TimeGloves\ Worn}\end{aligned} \tag{7}$$

$$\begin{aligned}\mathit{Body\ Clothing} &= \mathit{Clothing\ Material} \\ &\quad \times \mathit{Clothing\ Replacement\ Frequency}\end{aligned} \tag{8}$$

'*Actual Exposure*' for each body part is then calculated. In equation 9 Hand Clothing and Body Clothing are referred to collectively as 'Clothing'. The calculated value for Hand Clothing is used in calculations pertaining to the hands; the calculated value for each body part from *Body Clothing* is used in calculations pertaining to the other body parts.

$$\begin{aligned}\mathit{Actual\ Exposure}\ (\mathit{Body\ Part}) &= \mathit{Potential\ Exposure} \\ &\quad \times \mathit{Clothing}\ \times \mathit{Seawater}\end{aligned} \tag{9}$$

'Overall Actual Exposure' for the entire body is calculated by summing the 'Actual Exposure' value across all body parts.

### Validation

Across all exposure measurements, there was a moderate correlation ($r = 0.59$) between measured hand exposures and GuLF DREAM estimates (Fig. 1). Measured HFO exposures were higher than asphalt measurements by at least two orders of magnitude and this is generally reflected by higher GDU estimates for HFO exposures. Measured HFO exposures ranged from 0.015 to 3.19 µg cm$^{-2}$ whereas measurements of asphalt exposure ranged from $1 \times 10^{-5}$ to $2.1 \times 10^{-4}$ µg cm$^{-2}$. The within-substance correlation between measured and modelled exposure was 0.68 for asphalt and −0.48 for HFO. Twelve (75%) of the HFO measurements were below the limits of analytical detection. All of the asphalt measurements were detectable.

## Discussion

This review and modification of DREAM has been tailored specifically for the needs of the GuLF STUDY. GuLF DREAM provides a systematic and transparent approach to develop expert exposure assessment in the absence of dermal exposure measurements. It allows the use of contextual information (including questionnaire responses and other documents) to rank or categorize GuLF OSRC workers by dermal exposure level. The model was used in conjunction with self-reported participant-specific information to generate exposure estimates for OSRC workers in the GuLF STUDY (Stewart *et al.*, 2021). Although this exposure assessment approach is likely subject to misclassification of variable weightings by the exposure assessors, it is a more systematic, transparent and quantitative approach than a retrospective occupational exposure assessment approach in which an assessor uses professional judgement to assign an exposure value without supporting information as to how the values were derived.

In the development of the model, we were interested in the impact of the determinants of exposures to oils, tars, fuels, and the mixture of COREXIT EC9500®/EC9527® dispersants. We did this by not assessing exposures to these mixtures, but rather components of these mixtures, i.e. THC, benzene, toluene, ethyl benzene, xylene, n-hexane, and polycyclic aromatic hydrocarbons. Estimation of exposure to these components will be accomplished by the assignment of concentration, vapour pressure, and viscosity in each of these mixtures.

The major limitation of both DREAM and GuLF DREAM is that although they provide exposure estimates on a quantitative scale, they do not quantify the mass of the substance on the skin. This means that it is not possible to quantify the uptake through the skin (the dose). Nevertheless, GuLF DREAM is useful as a transparent and systematic method for ranking workers and activities by exposure level. It provides a relative ranking which can be used in epidemiologic analyses. Furthermore, although the mass of exposure is not estimated by GuLF DREAM, dermal absorption is limited by the flux of materials through the skin, so the surface area exposed may be more important to dose absorbed than the absolute mass present on the skin (Kissel *et al.*, 2011; Frasch *et al.*, 2014). GuLF DREAM also includes estimates of the exposed body surface area.

Although much of GuLF DREAM is data-driven, there are still areas where the data are insufficient to fully define the model. This was particularly apparent for some of the parameters related to gloves and protective clothing. This underscores the need for continued research on dermal exposure to provide data needed to update dermal modelling approaches. Future work may allow the addition of other parameters that could refine the exposure estimates. For example, there is some evidence that increased temperature can increase penetration of chemicals through the stratum corneum and that ambient temperature can alter the effectiveness of gloves (Lee *et al.*, 2009; Cavallari *et al.*, 2012; Oliveira *et al.*, 2014), but we concluded that there was insufficient evidence for these to be included in GuLF DREAM at this time.

It is also important to note that DREAM was designed to be used as an observational model. It was anticipated that exposure assessors would observe work activities and then develop DREAM exposure estimates. The two experienced industrial hygienists (IHs) with the most knowledge of the Deepwater Horizon OSRC operations were able to observe only a limited number of OSRC activities because most OSRC operations had been completed when the GuLF STUDY got into the field.

Another limitation in the application of the model to the GuLF STUDY is that although some parameters (e.g. concentration, vapour pressure, glove material) were objective, others, such as frequency and intensity, were subjective. In the absence of measurements, there was no way to quantify the percentage of the body part, the surface affected or the frequency of exposure.

There were no external documents that described all the jobs/activities performed, much less dermal contact in these jobs. Moreover, the questionnaire was developed before GuLF DREAM, and questions were included only if the study participants were judged likely to provide reasonably accurate responses. The questionnaires were deficient in some critical questions necessary for the DREAM architecture. For example, the questionnaire asked for the amount of time exposure occurred to a chemical (but not by body part) and the body part exposed (but not by chemical). Expert judgement based on the questionnaire information and general knowledge about the work activities was, therefore, used to assign weightings for some parameters.

For the specific jobs/activities carried out, we relied on study participants' self-reports for contact with the four mixtures of interest (oil, tar, fuel, and dispersants) and use of PPE. Although over or under-reporting of jobs/activities (the basis for the assessment) by the participants may have occurred, the frequency of the contact and the use of PPE are expected to be the main possible sources of bias from the study participants. It is likely that there were changes over time in contact and PPE use due to increased experience performing the job/task, varying weather conditions (less extreme heat and humidity in the spring and fall versus the summer), and increased enforcement of PPE use. However, there were no questions that asked about changes over time. A possible source of error may have arisen from the assessor. In particular, intensity of exposure was estimated from industrial hygiene knowledge of the jobs/activities and chemicals. The complexity of both the model and the exposure situations makes it difficult to identify an overall direction of error and bias or its effect on risk estimates

GuLF DREAM was subjected to validity evaluations. We were unable to collect measurement data for the GuLF STUDY as clean-up activities had been completed by the time the study began. To validate GuLF DREAM, therefore, we relied on previously published data either the peer-reviewed or the grey literature. We required data that fit a set of constraints that further limited the pool of data. First, the data had to be accompanied by sufficient descriptive information to allow generation of GuLF DREAM estimates. Second, we required data on dermal exposure to oils, tars, fuels, and dispersants. We were unable to locate data on the specific oils, tars, fuels, and dispersants encountered by the OSRC workers. Asphalt and HFO were the most similar compounds for which data were available, but we were unable to locate data on compounds that would approximate the behaviour of dispersants. Thus, we were disappointed both by the lack of studies with which to evaluate the model and the limitation of these studies (for our purposes), i.e. the small number of measurements and the high number of HFO measurements below the LOD. Because the components of interest to the GuLF STUDY (THC, benzene, toluene, ethylbenzene, xylene, n-hexane, and polycyclic aromatic hydrocarbons) were entrained within at least one of the agents of interest (i.e. the oils, tars, fuels, and dispersants) we assumed that the performance of the model would be similar for these components individually as for the mixtures. For consistency, we excluded data from interception (glove or patch) sampling methods as they have been shown to greatly overestimate exposure relative to removal (wipe or wash) methods (Gorman Ng *et al.*, 2014). Dermal measurements of OSRC work are clearly needed to better quantify the exposure levels related to this work. When such data are available GuLF DREAM would benefit from further validation.

Nonetheless, overall, the validation results demonstrate a moderate correlation ($r = 0.59$) between GuLF DREAM exposure estimates and hand wash and wipe measurements. The overall model correlation was lower than the overall model correlation calculated for DREAM in other situations ($r = 0.78$; Van Wendel de Joode, Vermeulen, Van Hemmen *et al.*, 2005). Perhaps this is not surprising because the DREAM validation by Van Wendel de Joode, Vermeulen, Van Hemmen, *et al.* (2005) involved exposure assessors who directly observed the workers when the exposure measurements were carried out. GuLF DREAM was validated against previously collected data sets involving exposures to hydrocarbons without the opportunity to observe the workers.

When stratified by material, GuLF DREAM performed well for exposure to asphalt ($r = 0.68$), but less so for exposure to HFO ($r = -0.48$). Seventy-five percent of the HFO measurements were less than the LOD and this could explain the poorer performance of the model for HFO. With so many non-detectable measurements we are unable to differentiate among different exposure scenarios.

Despite the poorer performance for HFO, the overall moderate performance between all estimated and measured exposures indicates that GuLF DREAM can differentiate between lower and higher exposures. The stronger correlation seen for asphalt is further evidence of the model's potential. In general, dermal exposure arises from more haphazard processes than for inhalation exposure, e.g. repeated contacts with surfaces that may or may not be contaminated. This makes assessing dermal exposure more difficult than for inhalation exposure. Yet dermal exposure can be important to the overall level of exposure in many work situations and may be particularly so in the GuLF STUDY.

Before using GuLF DREAM in the GuLF STUDY we conducted a preliminary evaluation. The purpose of the evaluation was several-fold: to learn if the retrospective nature of the GuLF STUDY allowed assessment of exposures from the information available to the investigators; to have multiple raters' review the very complicated coding instructions for errors and ambiguities, and make recommendations for improvement of the instructions; to make changes to the instructions based on the raters' comments; and to gain experience in how to think about assessing exposures (prior to actually doing the work) by having discussions with assessors with different experiences and perspectives. The evaluation was conducted by five assessors (two experienced IHs with knowledge of the Deepwater Horizon OSRC work, two experienced IHs with knowledge of the DREAM model and one person with only industrial hygiene experience). Each assessor was provided a contextual document on each of 10 exposure scenarios selected to represent the expected range of exposures to oil. In addition, a summary was provided of all GuLF STUDY participants' responses to each of the dermal questions for each of the 10 exposure scenarios. A detailed set of guidelines was developed to indicate how to translate the responses into DREAM values, although the assessors could override the guidelines. Assessments were made for THC in oil for all exposure scenarios and THC in tar for two scenarios. Useful information was gained from this exercise and changes made to the instruction and application of the data. In the GuLF STUDY, dermal exposure estimates were generated by one of the experienced exposure assessors with knowledge of the Deepwater Horizon OSRC work (Stewart *et al.*, 2021).

Although the development of GuLF DREAM was focussed on creating an exposure assessment tool for the GuLF STUDY, many of the updates that were made to the DREAM framework were generic in nature. The limited validation suggests that GuLF DREAM can be useful as a retrospective exposure assessment tool. With further evaluation, this model could be adapted for use in other contexts. The model is being used to develop job-exposure matrices of dermal exposure to oils, tars, fuels, and dispersants for the GuLF STUDY.

## Supplementary Data

Supplementary data are available at *Annals of Work Exposures and Health* online.

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The authors declare no conflict of interest relating to the material presented in this Article. Its contents, including any opinions and/or conclusions expressed, are solely those of the authors.

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