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Human Health Risk Evaluation of Structural Surfaces Contaminated with Metals

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ABSTRACT

Contaminated surfaces, such as the walls and/or floors inside a former manufacturing facility, on occasion generate concern for potential human health risks. A responsible party may seek the consensus of a regulatory environmental agency on the potential human health risks and hazards from exposures to indoor structural surfaces by workers, or children residents as a conservative screening tool. The involvement of the Human and Ecological Risk Division (HERD) in such cases has resulted in the development of spreadsheets to evaluate risks and hazards and calculate site-specific chemical-specific surface screening goals. The spreadsheets utilize exposure parameters based on professional judgment, since no regulatory guidance currently exists on the subject. The exposure parameters developed include skin surface area for dermal exposures as well as for inadvertent oral exposure, contact frequency, transfer efficiency from surface to skin, and fraction of contaminant transferred from skin to mouth. Analytical chemistry results from wipe samples of indoor building surfaces were the source of the exposure point concentrations and toxicity criteria recommended by the California Environmental Protection Agency were employed. The chemicals evaluated were arsenic, cadmium, chromium, copper, cyanide, nickel and zinc. The risk evaluations did not include potential exposures via other sources, such as soil or groundwater. Further research quantifying exposure parameters from contact with structural surfaces will reduce the uncertainty in the risk estimates and likely generate less conservative structural surface screening goals.

METHODS

Spreadsheets were developed for computing human health hazard indices and excess cancer risks from exposures to contaminants on building surfaces, as well as the corresponding human health risk-based structural surface screening goals, using modifications of the standard risk equations published by U.S. EPA (1989). No regulatory guidance currently exists for assessing human health risks from exposure to contaminated surfaces.

FACILITIES / RECEPTORS

Facility A had operated as a metal-polishing and metal-plating facility. The building was a concrete structure. The potential chemicals of human health concern were cadmium, chromium, copper, cyanide, nickel, and zinc. The HERD developed chemical-specific screening goals for the building surfaces. Since these potential chemicals of concern are not considered to be carcinogenic by the oral or dermal routes and inhalation of these non-volatile chemicals from residues on the walls or floor was deemed to be inconsequential, exposures, risks, and risk-based surface screening goals were based on non-carcinogenic effects to children. Children in a residential setting represent the highest exposed individuals on a body weight basis; accordingly, the child resident was selected to protect the most sensitive receptor which may potentially come in contact with the building surfaces if future land/facility use is unrestricted.

Facility B employed waste materials generated from metal plating operations and etching solutions as the raw materials in manufacturing inorganic chemicals, primarily copper carbonate. The surfaces investigated at Facility B were metal or fiber reinforced plastic tanks and lined containment areas. The potential chemicals of human health concern were arsenic, cadmium, chromium, copper and nickel. Once again, inhalation of these non-volatile chemicals from residues on the surfaces of tanks or containment areas was deemed to be inconsequential. Therefore, dermal and oral exposures were evaluated; arsenic was the sole carcinogenic chemical of concern via either of these routes. Accordingly, the HERD developed chemical-specific surface screening goals based on non-carcinogenic effects for each chemical, as well as the carcinogenicity of arsenic. It was assumed that the facility use would continue as industrial/commercial, thus the surface screening goals were based on potential health effects to workers.

EXPOSURE ASSESSMENT

Exposure Point Concentrations (EPC) were calculated from analytical data obtained from surface wipe samples (C_{wipe}) from an area of 100 cm^2 . A non-depleting source was assumed. A wipe removal efficiency of 50% was assumed; that is, it was assumed that half of the contaminant on the surface was removed and quantified via analytical chemistry. The evaluation does not include potential exposures from soil or groundwater, and therefore assumes that concentrations in these media are 0 mg/kg .

EXPOSURE POINT CONCENTRATION CALCULATION

C_s = Concentration of surface contaminant, $\mu\text{g}/\text{cm}^2$ = EPC

$$C_s = \frac{C_{\text{wipe}} \times 2}{100}$$

C_{wipe} = Concentration of the contaminant on the surface ($\mu\text{g}/100\text{ cm}^2$)

Routes of Exposure: The two exposure pathways evaluated were:

- dermal contact with a contaminated surface and subsequent transdermal uptake;
- dermal contact with a contaminated surface followed by inadvertent ingestion of contaminants transferred to skin.

MODIFIED EXPOSURE EQUATIONS

The modified equations for estimating intakes from contaminated surface are:

Average Daily Intake for non-carcinogenic effects via dermal contact (*ADId_{der}*)

$$ADId_{\text{der}} = \frac{C_s \times SA_{\text{d}} \times CF \times TE \times EF \times ED \times ABS_{\text{der}}}{BW \times AT \times UCF}$$

Average Daily Intake for non-carcinogen effects via incidental ingestion (*ADIng*)

$$ADIng = \frac{C_s \times SA_{\text{i}} \times CF \times TE \times f_{\text{do}} \times f_{\text{gi}} \times EF \times ED}{BW \times AT \times UCF}$$

Lifetime Average Daily Intake for a carcinogen via dermal contact (*LADId_{der}*)

$$LADId_{\text{der}} = \frac{C_s \times SA_{\text{d}} \times CF \times TE \times EF \times ED \times ABS_{\text{der}}}{BW \times AT_{\text{c}} \times UCF}$$

Lifetime average daily intake for a carcinogen via incidental ingestion (*LADIng*)

$$LADIng = \frac{C_s \times SA_{\text{i}} \times CF \times TE \times f_{\text{do}} \times f_{\text{gi}} \times EF \times ED}{BW \times AT_{\text{c}} \times UCF}$$

Where: *ABS_{der}* = Dermal Absorption (fraction), chemical specific
UCF = Unit Conversion Factor, 1000 $\mu\text{g}/\text{mg}$

The remainder of the parameters are as defined above or in Tables 1 and 2, which also contain the exposure assumptions employed and the references for the assumptions.

Exposure Constants: Combining the non-chemical specific exposure assumptions yield the following exposure constants for non-carcinogens and carcinogens, respectively via dermal and ingestion (from skin) routes.

CNST_{der}

CNST_{ing}

cCNST_{der}

cCNST_{ing}

EXPOSURE CONSTANTS

$$\frac{\text{CNST}_{\text{der}}}{\text{BW} \times \text{AT} \times \text{UCF}} = \frac{\text{SAd} \times \text{CF} \times \text{TE} \times \text{EF} \times \text{ED}}{\text{BW} \times \text{AT} \times \text{UCF}}$$

$$\frac{\text{CNST}_{\text{ing}}}{\text{BW} \times \text{AT} \times \text{UCF}} = \frac{\text{SAi} \times \text{CF} \times \text{TE} \times \text{fdo} \times \text{fgi} \times \text{EF} \times \text{ED}}{\text{BW} \times \text{AT} \times \text{UCF}}$$

$$\frac{\text{cCNST}_{\text{der}}}{\text{BW} \times \text{ATc} \times \text{UCF}} = \frac{\text{SAd} \times \text{CF} \times \text{TE} \times \text{EF} \times \text{ED}}{\text{BW} \times \text{ATc} \times \text{UCF}}$$

$$\frac{\text{cCNST}_{\text{ing}}}{\text{BW} \times \text{ATc} \times \text{UCF}} = \frac{\text{SAi} \times \text{CF} \times \text{TE} \times \text{fdo} \times \text{fgi} \times \text{EF} \times \text{ED}}{\text{BW} \times \text{ATc} \times \text{UCF}}$$

Exposure Parameters: Limited research has been conducted to quantify some of the parameters used in calculating the surface screening goals. This is the case for the contact frequency (CF), the skin area available for dermal contact with the contaminated surface (SAd), the skin area available for oral exposure after dermal contact with the surface (SAi), and the fraction of contaminant transferred from the dermal-to-oral route (fdo).

Fraction of contaminant transferred from the dermal-to-oral route (fdo): Because quantitative values have not been established for the fdo, we used the most conservative value, 100 percent, for this parameter for the evaluation of exposure by children to contaminated surfaces, which is consistent with a screening level approach. However, for the worker, the fraction of contaminant transferred from skin to mouth was assumed to be 0.04, consistent with Michaud, et al. (1994) and U.S. EPA (1991, 1999).

Michaud, et al. (1994) assumed all of the contaminant on the surface area of the fingertips is ingested twice each day, although the total skin surface area of the hands is assumed to be available for oral exposure and contacting the contaminated surface once per hour, or 8 times per work day. Consequently, the fraction ultimately ingested was computed as follows. The surface area of the fingertips is assumed to represent 14 percent of the hands, that is, 790 cm² times 0.14 or 111 cm²; this area is multiplied by two events per day to get 222 cm². The total skin surface area of the hands available for oral exposure is 790 cm² per event, times eight events per day, or 6320 cm². The fraction ultimately ingested is then equal to 222 cm² divided by 6320 cm² for a fdo of 0.04.

U.S. EPA (1991) recommends 50 mg/day as the default soil ingestion rate for an occupational exposure scenario (U.S. EPA, 1991) with a dermal dust loading of 0.2 mg dust /cm² skin (U.S. EPA, 1999). Using the total contact area of 6320 cm² (total skin surface area of the hands available for oral exposure, 790 cm² per event times eight events per day), the total dermal contact load would be 1264 mg/day (0.2 mg/cm² x 6320 cm²). The fraction ultimately ingested is then equal to 50 mg/day divided by 1264 mg/day total contacted for a fdo of 0.04.

Table 1. Exposure Parameters

		<i>Child Resident</i> ^a		<i>Worker</i> ^b	
Body Weight (kg)	BW	15	U.S. EPA, 1989	70	U.S. EPA, 1989
Averaging Time (days) – non-cancer	AT	2190	U.S. EPA, 1989	9,125	U.S. EPA, 1989
Averaging Time (days) – cancer	ATc			25,550	
Exposure Frequency (days/yr)	EF	350	U.S. EPA, 1989	250	U.S. EPA, 1989
Exposure Duration (yr)	ED	6	U.S. EPA, 1989	25	U.S. EPA, 1989
Contact Frequency (events/day)	CF	8	Michaud et al., 1994 Paull, 1997	8	Michaud et al., 1994 Paull, 1997
Skin Surface Area (cm ²)	SAd	3200 ^c	U.S. EPA, 1997	5070 ^f	U.S. EPA, 1997
Skin Surface Area, Ingestion (cm ²)	SAi	390 ^d	U.S. EPA, 1997	790 ^g	U.S. EPA, 1997
Surface-to-skin transfer efficiency	TE	0.1 ^e	Paull, 1997	0.1 ^e	Paull, 1997
Fraction transferred from dermal-to-oral	fdo	1		0.04	Michaud et al., 1994
Fractional GI absorption	fgi	1		1	

- ^a For Facility A, a child was assumed to spend 8 hours/day outside of the structure, 8 hours/day awake indoors, and 8 hours/day asleep in the structure.
- ^b For Facility B, workers were assumed to spend an 8 hr workday in the structure.
- ^c The dermal portions of the child assumed to be available for contact with the concrete surface are the head, forearms, hands, lower legs, and feet.
- ^d For the surface-to-dermal-to-oral pathway, the average dermal surface area of a 0 to 6 yr old child's hands was assumed to be available for contact with the interior building surfaces and subsequent oral ingestion.
- ^e 10% of the surface contamination was assumed to be transferred to the skin.
- ^f The dermal portions of the worker assumed to be available for contact with the concrete surface are the adult male and female mean of the head, forearms, hands, and lower legs.
- ^g The skin surface area available for oral exposure by the worker was assumed to be the average of adult males and females, both hands.

Table 2. Chemical-Specific Assumptions / Toxicity Criteria

Chemical	Dermal Absorption (fraction) ^a	Reference Dose (mg/kg/day)	Source	Oral Cancer Slope Factor (mg/kg/day) ⁻¹	Source
Arsenic	0.03	0.0003	IRIS ^b	1.5	IRIS
Cadmium	0.001	0.0005	IRIS	NA ^c	
Chromium III	0.01	1.5	IRIS	NA ^d	
Chromium VI	0	0.003	IRIS	NA ^c	
Copper	0.01	0.0371	HEAST ^e	NA ^d	
Cyanide	.01	0.02	IRIS	NA ^d	
Nickel	0.01	0.02	IRIS	NA ^c	
Zinc	0.01	0.3	IRIS	NA ^d	

^a Source: DTSC, 1999

^b U.S. EPA Integrated Risk Information System (IRIS)

^c Non-applicable – not a carcinogen by the oral route

^d Non-applicable – not a carcinogen

^e Health Effects Assessment Summary Tables (HEAST)

RISK CHARACTERIZATION / SURFACE SCREENING GOALS

The equations used to calculate the ADI and LADI in mg/kg-day and the subsequent hazard or risk may be rearranged and used to calculate the target surface concentration ($\mu\text{g}/100\text{ cm}^2$) that would represent a non-carcinogenic Hazard Index of 1.0 or a theoretical excess cancer risk of one-in-a-million (1×10^{-6}) for an individual chemical, assuming no exposures from other sources. Although not presented here, cumulative surface screening goals may be obtained by equally apportioning the target HI or Risk among the individual chemicals; however, there is no singular method for apportioning single-media screening levels in order to achieve a cumulative target HI or risk.

RISK CHARACTERIZATION EQUATIONS

$$HI = ADI/RfD$$

$$Risk = LADI \times CSF$$

Where:

HI = Hazard Index
 ADI = Average Daily Dose
 RfD = Reference Dose

Risk = Carcinogenic Risk
 LADI = Lifetime Average Daily Dose
 CSF = Cancer Slope Factor

CALCULATION OF SURFACE SCREENING GOALS

Hazard-Based Screening Goals

$$\text{Ingestion} \quad C_{wipe} = \frac{oRfD \times HI \times UCF \times 100\text{cm}^2/\text{wipe}}{2 \times CNSTing}$$

$$\text{Dermal} \quad C_{wipe} = \frac{oRfD \times HI \times UCF \times 100\text{cm}^2/\text{wipe}}{2 \times ABSder \times CNSTder}$$

$$\text{Ingestion + Dermal} \quad C_{wipe} = \frac{oRfD \times HI \times UCF \times 100\text{cm}^2/\text{wipe}}{2 \times [(ABSder \times CNSTder) + (CNSTing)]}$$

Risk-Based Screening Goals

$$\text{Ingestion} \quad C_{wipe} = \frac{RISK \times UCF \times 100\text{cm}^2/\text{wipe}}{2 \times cCNSTing \times CSF}$$

$$\text{Dermal} \quad C_{wipe} = \frac{RISK \times UCF \times 100\text{cm}^2/\text{wipe}}{2 \times ABSder \times cCNSTder \times CSF}$$

$$\text{Ingestion + Dermal} \quad C_{wipe} = \frac{RISK \times UCF \times 100\text{cm}^2/\text{wipe}}{CSF \times 2 \times [(ABSder \times cCNSTder) + (cCNSTing)]}$$

Where: HI = Target Hazard Index, 1.0
 oRfD = Oral Reference Dose
 Risk = Target risk, 1×10^{-6}
 CSF = Oral Cancer Slope Factor

RESULTS

Table 3. Surface Screening Goals ($\mu\text{g}/100\text{cm}^2$)

Chemical	Facility A Child Resident Surface Wipe Concentration	Facility B Worker Surface Wipe Concentration
Arsenic (carcinogen)	NA	0.06
Arsenic (systemic toxicant)	NA	10
Cadmium	1.2	86
Chromium III	3500	120,000
Chromium VI	7.5	600
Copper	86	2900
Cyanide	28	NA
Nickel	46	1600
Zinc	700	NA

NA = Not applicable, not a contaminant at the Facility.

Note: These chemical-specific goals were developed specifically for Facilities A and B, respectively, and are not to be applied to any other site.

DISCUSSION

There are numerous uncertainties associated with performing human health risk assessments for contact with contaminated surfaces of buildings or other structures due to lack of exposure data. These main areas of uncertainty in human exposure assessment for contaminants on surfaces include:

Wipe Sample Results – In this assessment, a wipe removal efficiency of 50% was assumed. If the removal efficiency is actually greater than 50% the surface concentration would be overestimated by up to 2-fold. If the efficiency is less than 50%, the surface concentration would be underestimated; possibly by up to 10-fold if the actual removal efficiency was only 5%. The removal efficiency is dependent on:

- surface material (concrete, wood, wallboard, glass, metal)
- type of material used to collect the sample (glass wool, cotton gauze, filter paper)
- wetting solution used (none, water, hexane, ethanol)
- degree of pressure applied when taking the sample
- number of times the surface is wiped with the collection material.

Skin Surface Area (SAd) (potentially affected) – In this assessment, the head, forearms, hands and lower legs (and feet for the child) were assumed to be in contact with the contaminated surface at a contact frequency (CF) of eight times a day on a daily basis; this is likely extremely conservative, especially for the worker.

Transfer Efficiency (contaminants from surface to skin) – Although the transfer efficiency from surface to skin was assumed to be 10%, the actual efficiency may vary widely, depending on:

- amount of pressure and movement of the body against the surface
- duration of each skin-to-surface contact
- affinity of the contaminant for the skin
- structural and biochemical differences of skin contacting the surface (palm of hand vs. forearm)
- degree of skin hydration
- surface porosity (concrete, wood) or imperviousness (glass, metal)

CONCLUSIONS

1. The results demonstrate that using exposure parameters protective of children produces hazard-based surface screening goals that are at least an order of magnitude more stringent than those designed to protect workers.
2. Arsenic, the sole chemical that is carcinogenic via the routes evaluated, yielded results for worker surface screening goals consistent with expectations; the risk-based goal is substantially lower than the hazard-based goal.
3. Additional research is needed to more accurately estimate exposure to contaminants on surfaces. Further refining exposure parameters and standardizing surface wipe sampling methodology will reduce the uncertainties in human health risk assessments of indoor structural surfaces.

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