Surface dust criteria for dioxin and dioxin-like compounds for re-entry to buildings

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Introduction. Building reentry criteria for dioxin TEQ, as measured by surface wipes, vary greatly, from as low as 1 ng/m^2 to as high as 125 ng/m^2 [1]. Recently, the World Trade Center Indoor Air Taskforce calculated a reentry criterion of 2 ng TEQ/m^2 for a residential exposure[2]. This number was based on the EPA's draft cancer slope factor (CSF) of 1x 10^6 (mg/kg-day)$^{-1}$, and various exposure parameters, dermal absorption values, and a cancer risk criterion of 1x 10^{-4} [2]. An indoor 'degradation' parameter was also included in the calculations. However, a single criterion based on a single set of assumptions cannot be universally applied to all sites with contaminated surfaces. Reentry criteria that consider a wider range of exposure scenarios, exposure pathways, bioavailability, and behavioral parameters would be very useful to risk managers who may have to address multiple diverse situations in the coming years. This paper describes our recommended reentry "building surface" criteria for four exposure scenarios: 1) adult occupational, 2) adult residential, 3) childhood "occupational" (i.e., school), and 4) childhood residential.

Materials and Methods. Given the diversity in exposure factors, age-specific development and health effects, we separated receptors into child and adult and exposure scenarios into residential and occupational, resulting in the four potential exposure scenarios described above. Using a cancer risk criterion of 1x10^{-5}, EPA's current CSF of 1.56x10^5 (mg/kg-day)$^{-1}$ [3], and updated exposure and bioavailability parameters (Tables 1 & 2), we used equations 1-6 to calculate re-entry criteria for surface dust, and lifetime average daily doses (LADD) based on those criteria. For children, a number of these parameters varied on a yearly basis, based on age and size.

After calculating the re-entry criteria as point estimates, we performed a sensitivity analysis on the two childhood scenarios using a Monte Carlo model (Crystal Ball, Decisioneering, Inc., Denver, CO). We used the point estimates to make an initial determination of which input parameters were likely to have the greatest effect. The probabilistic model was run for 10,000 iterations and a sensitivity analysis was performed during each model run. The sensitivity analysis helped identify which of the selected model parameters had the greatest effect on the output parameter—initial dioxin concentration in dust—by determining the input parameter's contribution to the variance of the output parameter. While the data for the input parameters were insufficient to use the curve fitting algorithms of the software, they did allow us to identify the minimum, maximum and, in some cases, the 'most likely' values for the input parameters (Tables 1 & 2). If a 'most likely' value was identified for a parameter, a triangular distribution was fit to the data; otherwise, the

parameter was represented with a uniform distribution. Half-life values for TCDD in buildings were 2, 22, and 12 months (min. max. and most likely).

Results and Discussion. Figure 1 shows calculated re-entry criteria for each scenario. Figure 2 compares the calculated LADDs to the Tolerable Daily Intake (TDI) promulgated by JECFA[6] and the average concentrations of TCDD found in eggs[10]. Figures 3 shows the change in re-entry criteria for each scenario as exposure duration is increased in 1-year intervals. Figure 3 clearly demonstrates that for each scenario, the vast majority of the dose is received in the first five years. Thus, the driver in this equation is the decay rate of TCDD. This was also supported by the sensitivity analysis. Thus, although we used the conservative exposure durations of 25, 30, 12, and 18 years for the four scenarios, the outcome would not have changed if we had used exposure durations half that long.

There are four main factors to be considered when looking at the results of this analysis. First, for deterministic estimates, the decay rate used in this equation is 22 months, and is meant to include degradation of the chemical, dilution through deposition of "non-contaminated" dust, and, dissipation through cleaning. This number is based on results from the Binghamton State Office fire[4 as cited in 2] and is likely highly conservative as it derived from levels of PCDD/Fs on the top of ceiling lights—a location that is rarely cleaned. Clearly, the surface of a desk or other horizontal surface within reach would be cleaned more often and thus have a shorter half-life. However, there is surprisingly little information on indoor dissipation levels of chemicals. Use of the half-life from the Binghamton State Office fire may overestimate exposure. This issue was addressed in the Monte Carlo model, where the decay rate was modeled as a triangular distribution with a maximum value of 22 months. Second, our equations do not account for "contaminated" dust that is reintroduced to the indoor environment after cleaning. Some redeposition from outside sources will likely occur. However, due to the conservatism of the dissipation constant, and the likelihood of gradual decline of the source over time, we do not feel redeposition would be significant. Third, the re-entry criteria are only based on surface dust concentrations, not on concentrations of dust in air. While some resuspension of dust is likely, according to the U.S. Nuclear Regulatory Commission[5], the ratio of resuspended dust to surface dust is fairly small. Including concentrations from air (based on this ratio) did not substantially change the re-entry criteria or doses (data not shown). Finally, we chose to use the cancer slope factor from the 1985 dioxin assessment[3] because we believe it is scientifically more valid. The risk of actual health effects is more likely to be driven by the non-cancer reproductive and developmental effects and use of the 1985 slope factor results in doses 2-3 orders of magnitude below doses that are protective for reproductive and developmental effects[3,11].

Based on the point estimates, we calculated reentry criteria of approximately 85, 46, 15, and 4 ng TEQ/m^2, for the four scenarios respectively. These criteria result in dose levels of approximately 1-30 fg TEQ/kg-day and thus could produce daily intakes in the vicinity of 1/100 to 1/1000 of the 70 pg/kg-month level (based on non-cancer endpoints) considered acceptable by the joint FAO/WHO committee[6]. Therefore, they should be protective for both cancer and non-cancer effects. The childhood reentry criteria based on the Monte Carlo analysis encompassed the reentry criteria from the point analysis. For the childhood occupational scenario, the reentry criteria for the 5^{th} to 95^{th} percentile are 19and 3 ng/m^2, respectively. The 50^{th} percentile reentry criterion is 7 ng/m^2. For the residential scenario, the 5^{th}, 95^{th}, and 50^{th} percentiles were 9, 1, and 3 ng/m^2,

respectively. The fact that the median values from the Monte Carlo analysis are lower than the point estimates is in part an artifact of our reliance on uniform and triangular distributions, and in part due to the fact that several of the original exposure assumptions were equal to or lower than the lower end of the range used in the sensitivity analysis.

Thus, we conclude that 1) it is reasonable to calculate different re-entry criteria based on age and activity, 2) our calculated re-entry criteria are 2-50 times greater than those calculated by the Working Group, 3) our calculated re-entry criteria result in doses 1/100 to 1/1000 of the TDI, and 4) the re-entry criteria calculation is driven by the dissipation constant for the compound.

References

1. Michaud, J.M., S.L. Huntley, R.A. Sherer, M.N. Gray, and D.J. Paustenbach. 1994. J. Exp. Anal. Environ. Epidemiol. 4(2):197–227.
2. WG. 2003. World Trade Center indoor environment assessment: Selecting contaminants of potential concern and setting health-based benchmarks. World Trade Center Indoor Air Task Force Working Group. http://www.epa.gov/wtc/copc_benchmark.pdf
3. U.S. EPA. 1985. Health effects assessment document for polychlorinated dibenzo-*p*-dioxins. EPA/600/8-84/014F. U.S. Environmental Protection Agency, Cincinnati, OH.
4. New York State Department of Health. 2002. Binghamton State Office Building: Post-occupancy Environmental Sampling, Final Round. Center for Environmental Health, Troy, NY.
5. U.S. NUREG. 2002. Re-evaluation of the indoor resuspension factor for the screening analysis of the building occupancy scenario for NRC's license termination rule. NUREG-1720. U.S. Nuclear Regulatory Commission. Office of Nuclear Material Safety and Safeguards. Washington, DC.
6. JECFA. 2001. Joint FAO/WHO Expert Committee on Food Additives: Summary and conclusions. Food and Agriculture Organization of the United Nations World Health Organization, Rome, 5-14 June.
7. U.S. EPA. 1997. Exposure factors handbook. EPA/600/P95/002. U.S. EPA, Washington, DC.
8. Rodes, C., R. Newsome, R. Vanderpool, J. Antley, and R. Lewis. 2001. J. Exp. Anal. Environ. Epidemiol. 11:123–139.
9.U.S. EPA. 2000. Draft exposure and human health reassessment of 2,3,7,8-TCDD and related compounds. EPA/600/P-00/001. U.S. Environmental Protection Agency, Washington, DC.
10. Schecter, A., P. Cramer, K. Boggess, J. Stanley, O. Papke, J. Olson, A. Silver, M. Schmitz. J Toxicol. Environ. Health A. 63:1-18.
11. Greene, J., S. Hays, D. Paustenbach. 2003. J. Toxicol. Environ. Health B. 6: 115-159.

Table 1. Parameters for reentry criteria calculations

Parameter		Value[a]	Units	Source
CR	cancer risk	$1x10^{-5}$	unitless	
LADD	lifetime average daily dose	See eq. 1	mg/kg-day	
CSF	cancer slope factor	$1x10^{5}$	$(mg/kg\text{-}day)^{-1}$	3
CSL	contaminant surface load	See eq. 3	ng/m^2	2
k	dissipation rate constant	0.38	$years^{-1}$	4
t	time	See eq. 3	years	2
ET_{hard}	exposure to hard surfaces	See Table 2	hours/day	7
$FTSS_{\mathbf{hard}}$	fraction transferred from surface to skin	0.2 (0.3-0.5)	unitless	1
ET_{soft}	exposure to soft surfaces	See Table 2	hours/day	7
$FTSS_{\mathbf{soft}}$	fraction transferred from surface to skin	0.1 (0.03-0.09)	unitless	8
SA	surface area of three fingers	See Table 2	cm^2/event	2
FQ	frequency of hand-to-mouth events	See Table 2	events/hour	2
SE	saliva extraction factor	0.5	unitless	2
ABS_o	oral absorption fraction	0.3 (0.03,0.65, 1)	unitless	1
EF	exposure frequency	See Table 2	days/year	7
ED[b]	exposure duration	30, 25, 12, 18	years	7
BW	body weight	See Table 2	kg	7
AT	averaging time	70	years	7
TC[c]	transfer coefficient	See Table 2	cm^2/hour	7
ABS_d	dermal absorption fraction	0.03 (0.01, 0.03, 0.14)	unitless	9

[a]Parenthetical values are min. and max. values (uniform distribution) or min., most likely, and max. values (triangular distribution) for Monte Carlo analysis. [b] ED is 30, 25, 12, and 18 years for the four scenarios, respectively. [c] Approximate area of skin reexposed to dust/ hour (children 0–8: palms, forearms, bottom of feet; children 8–13: palms and bottom of feet; children 13–18 and adults: palms).

Table 2. Age-specific parameters for reentry criteria calculations

		Parameter[a]											
		Age (years)	SA (cm^2/ev)	FQ (ev/hr)	BW (kg)	ET_{hard} (hr/day)		ET_{soft} (hr/day)		EF (days/year)		TC (cm^2/hr)	
Scenario						Occ.	Res.	Occ.	Res.	Occ.	Res.	Adult	Child
		0–1	11	9.5 (1,20)	9.1		4 (2,6)		8 (4,12)		350		800
		1–2	13	9.5 (1,20)	11.3		4 (2,6)		8 (4,12)		350		800
		2–3	15	9.5 (1,20)	13.3		4 (2,6)		8 (4,12)		350		800
		3–4	17	9.5 (1,20)	15.3		4 (2,6)		8 (4,12)		350		800
		4–5	19	9.5 (1,20)	17.4		4 (2,6)		8 (4,12)		350		800
		5–6	21	9.5 (1,20)	19.7		4 (2,6)		8 (4,12)		350		800
Child Occupational	Child Residential	6–7	23	5 (1,10)	22.6	6 (4,8)	2 (1,3)	2 (1,3)	6 (4,8)	180	350		800
		7–8	25	5 (1,10)	24.9	6 (4,8)	2 (1,3)	2 (1,3)	6 (4,8)	180	350		800
		8–9	27	5 (1,10)	28.1	6 (4,8)	2 (1,3)	2 (1,3)	6 (4,8)	180	350		800
		9–10	29	5 (1,10)	31.5	6 (4,8)	2 (1,3)	2 (1,3)	6 (4,8)	180	350		800
		10–11	31	5 (1,10)	36.3	6 (4,8)	2 (1,3)	2 (1,3)	6 (4,8)	180	350		800
		11–12	33	5 (1,10)	41.1	6 (4,8)	2 (1,3)	2 (1,3)	6 (4,8)	180	350		800
		12–13	35	5 (1,10)	45.3	6 (4,8)	2 (1,3)	2 (1,3)	6 (4,8)	180	350		800
		13–14	37	2 (1,4)	50.4	6 (4,8)	2 (1,3)	2 (1,3)	6 (4,8)	180	350		800
		14–15	39	2 (1,4)	56	6 (4,8)	2 (1,3)	2 (1,3)	6 (4,8)	180	350		800
		15–16	41	2 (1,4)	58.1	6 (4,8)	2 (1,3)	2 (1,3)	6 (4,8)	180	350		800
		16–17	43	2 (1,4)	62.6	6 (4,8)	2 (1,3)	2 (1,3)	6 (4,8)	180	350		800
		17–18	45	2 (1,4)	63.2	6 (4,8)	2 (1,3)	2 (1,3)	6 (4,8)	180	350		800
Adult		18–70	45	0.2	70	4	4	4	8	250	350	500	

[a]Parenthetical values are min. and max. values for Monte Carlo analysis. The original point estimate was used as the most likely value in these triangular distributions.

Figure 1. Calculated TCDD re-entry criteria

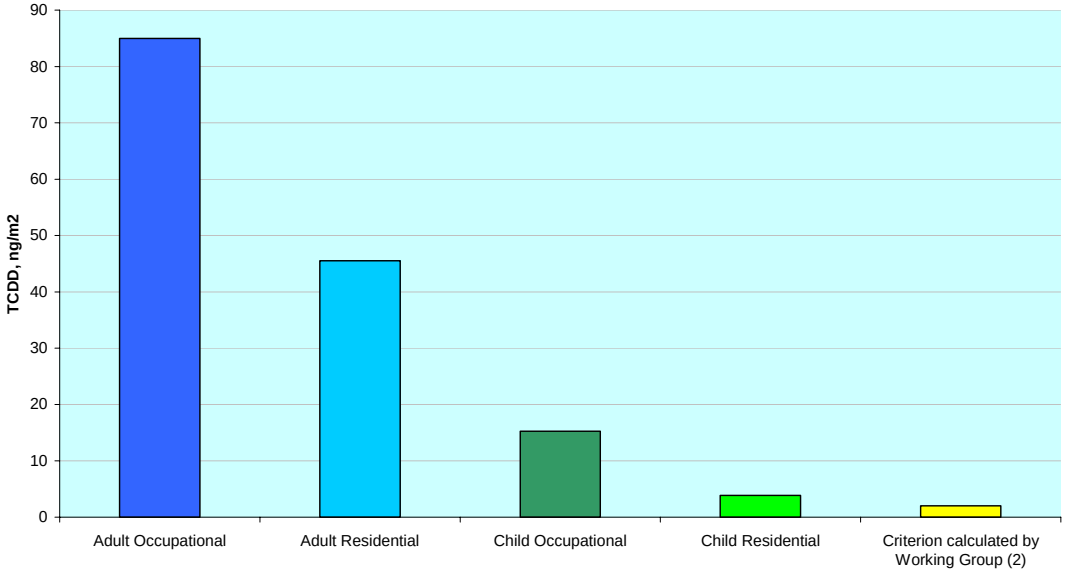


Figure 2. LADD based on re-entry criteria, food, and regulatory levels

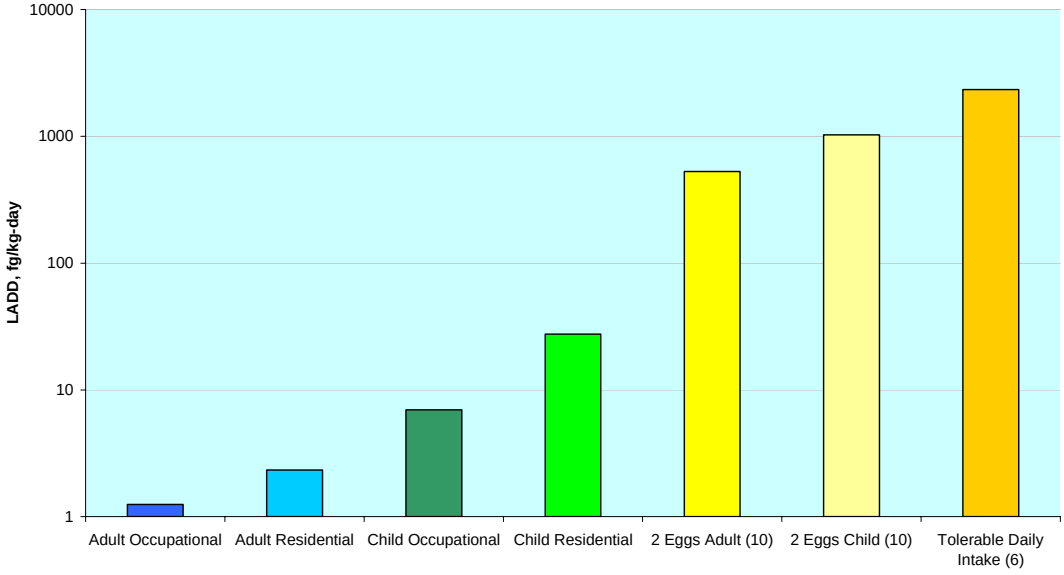
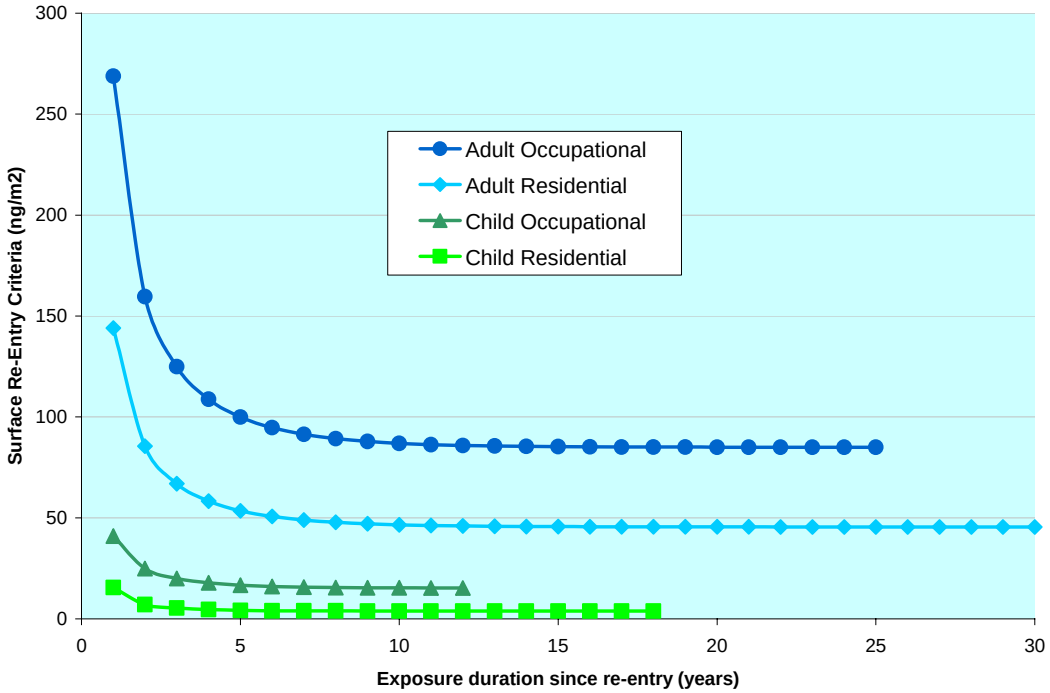


Figure 3. Cumulative change in re-entry criteria over time



Equations

$$\text{Cancer Risk} = \text{LADD} \times \text{CSF} \qquad \text{Eq. 1}$$

$$\text{LADD} = \text{LADD}_{\text{Incidental ingestion}} + \text{LADD}_{\text{Dermal contact}} \qquad \text{Eq. 2}$$

$$\text{CSL} = \text{CSL}_{\text{initial}}\, e^{-kt} \qquad \text{Eq. 3}$$

$$\text{LADD}_{\text{Incidental ingestion}} = \frac{\left[\left(\text{ET}_{\text{hard}} \times \text{FTSS}_{\text{hard}} \times \text{CSL}\right) + \left(\text{ET}_{\text{soft}} \times \text{FTSS}_{\text{soft}} \times \text{CSL}\right)\right] \times \text{SA} \times \text{FQ} \times \text{SE} \times \text{ABS}_{\text{o}} \times \text{EF} \times \text{ED}\right)}{\text{BW} \times \text{AT}}$$

Eq.4

$$\text{LADD}_{\text{Dermal contact}} = \frac{\left(\left(\text{TC} \times \text{ET}_{\text{hard}} \times \text{FTSS}_{\text{hard}} \times \text{CSL}\right) + \left(\text{TC} \times \text{ET}_{\text{soft}} \times \text{FTSS}_{\text{soft}} \times \text{CSL}\right)\right) \times \text{ABSd} \times \text{EF} \times \text{ED}}{\text{BW} \times \text{AT}}$$

Eq. 5

$$\text{Re}-\textit{entry Criterion} = \frac{\textit{Hypothetical CSL}_{\textit{initial}} \times \textit{T arg et Risk Level}}{\textit{Hypothetical Risk}} \qquad \text{Eq. 6}$$