Use of Dioxin TEFs in Calculating Dioxin TEQs at CERCLA and RCRA Sites

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Purpose

This fact sheet provides information on the use of the 2005 World Health Organization (WHO) dioxin toxicity equivalence factors (TEFs) to calculate dioxin toxicity equivalence (TEQ) at Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and Resource Conservation and Recovery Act (RCRA) sites contaminated with dioxins, furans, and polychlorinated biphenyls (PCBs). The approach provided in this fact sheet is for use at newly evaluated sites as well as for re-evaluating sites that have been previously cleaned up or screened from further consideration.

Background

Dioxins are a group of compounds that share distinct chemical structures and characteristics. The term dioxin commonly refers to the compound in this group considered most toxic, 2,3,7,8-tetrachlorodibenzo-para-dioxin (TCDD). Dioxin-like is a description used for compounds that have chemical structures, physico-chemical properties, and toxic responses similar to TCDD. Dioxin-like compounds (DLCs), including polychlorinated dibenzo-*p*-dioxins (PCDDs), polychlorinated dibenzofurans (PCDFs), and dioxin-like polychlorinated biphenyls (PCBs), typically are found in mixtures with TCDD at CERCLA and RCRA sites and other contaminated properties. The EPA Toxics Release Inventory Program issued a final rule (EPA 2007) requiring that facilities report the released mass (grams) of individual DLCs in addition to reporting the released mass of TCDD.

The evaluation of TCDD and DLCs at CERCLA and RCRA sites includes consideration of the toxicity (i.e., cancer risks and non-cancer effects) of these contaminants. In the absence of toxicity values for DLCs, TEFs are used as a measure of the toxicity of the DLCs relative to TCDD. Concentrations of DLCs measured in media are modified by TEFs to determine the dose of each DLC in a medium that is equivalent to a dose of TCDD. The modified DLC doses are expressed in terms of TCDD toxicity equivalence (TEQ). The DLC TEQ concentrations are used, rather than the DLC concentrations measured in media, for site evaluations including site characterization, risk assessment, cleanup level development and confirmatory sampling.

The U.S. Environmental Protection Agency (EPA) Office of Research and Development released the *Recommended Toxicity Equivalence Factors (TEFs) for Human Health Risk Assessments of 2,3,7,8-Tetrachlorodibenzo-p-dioxin and Dioxin-Like Compounds* (EPA 2010), recommending the use of the 2005 human and mammalian WHO TEF values for DLCs. For additional information on the use of the 2005 WHO TEFs at CERCLA and RCRA sites, refer to EPA's 2010 TEF document.

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substitute for statutes that EPA administers or their implementing regulations, nor is it a regulation itself. Thus, this document does not impose legally binding requirements on EPA, the states, or the regulated community, and may not apply to a particular situation based upon the specific circumstances. Rather, the document provides information that may be used at particular sites, as appropriate, given site-specific circumstances.

Frequently Asked Questions

Q: What are toxicity equivalence factors (TEFs)?

A: 2,3,7,8-tetrachlorodibenzo-p-dioxin (or TCDD) and DLCs, including polychlorinated dibenzo-*p*-dioxins (PCDDs), polychlorinated dibenzofurans (PCDFs), and dioxin-like polychlorinated biphenyls (PCBs), typically occur as mixtures in environmental media. The toxicity of DLCs can be addressed by considering their toxicity relative to TCDD. EPA recommends using updated TEFs to assess human health risks from exposure to dioxin-like compounds (EPA 2010). A TEF for a DLC is a measure of the compound's toxicity relative to TCDD, which is assigned a TEF of 1. For example, 1,2,3,4,7,8-hexachloro-dibenzo-*p*-dioxin is considered one tenth as toxic as TCDD and has therefore been given a TEF of 0.1.

Q: For which media are the TEFs used?

A: The TEFs are most appropriate for dioxin exposures via the oral exposure route. Generally, the ingestion pathway for TCDD drives risk CERCLA and RCRA assessments. The TEFs can be used for evaluating the risk posed by the ingestion of soil, sediments, water, and fish contaminated with TCDD and DLCs.

Q: What is the basis for using the TEF approach for DLCs?

A: The TEF approach is based on the concept of dose addition, under which it is assumed that the toxicokinetics and toxicodynamics for all DLCs are similar, and that the DLCs act by a common toxic mode of action (i.e., for all DLCs, effects are mediated through aryl hydrocarbon receptor binding). Further, this approach assumes that toxicological interactions do not occur among the DLCs within the environmental mixtures being assessed (e.g., synergism and antagonism do not occur).

Q: What is toxicity equivalence (TEQ)?

A: For a single DLC, dioxin toxicity equivalence (TCDD TEQ) is the product of the concentration of the DLC in an environmental mixture and its corresponding TEF; total TEQ for the mixture is the sum of the individual TCDD TEQs across the DLCs. The TCDD TEQ provides a means for determining the toxicity of a mixture of DLCs, in the absence of toxicity values for these DLCs.

The EPA's *Recommended Toxicity Equivalence Factors (TEFs) for Human Health Risk Assessments of 2,3,7,8- Tetrachlorodibenzo-p-dioxin and Dioxin-Like Compounds* (EPA

2010) provides a formula (reproduced below) for calculating the exposure concentration for *n* DLCs in a mixture, in TCDD TEQ. Exposure to the *ith* individual PCDD, PCDF, or PCB compound is expressed in terms of an equivalent exposure of TCDD by computing the product of the concentration of the individual compound (*Ci*) and its assigned *TEFi*. TEQ is then calculated by summing these products across the *n* DLCs present in the mixture.

$$TEQ = \sum_{i=1}^{n} (C_i \times TEF_i)$$

- C_i *Individual TCDD or DLC concentration in environmental media.*
- TEF_i *Toxicity Equivalence Factor assigned for TCDD or the DLC.*
- *TEQ TCDD toxicity equivalence.*

Sample calculation:

Using the 2005 WHO TEFs (Van den Berg et. al. 2006), the TEQ for each DLC is estimated by multiplying the measured DLC concentration by the TEF corresponding to the DLC. The TEQ for the media sample is determined by summing the individual TEQ for TCDD with DLCs in the mixture. For example:

Individual concentration of TCDD and DLCs in an environmental sample:
2,3,7,8 TCDD……10 ppt (parts per trillion)
2,3,4,7,8- PeCDF ……..30 ppt
PCB 126……..... 20 ppt

TEFs:
2,3,7,8 TCDD……...…1
2,3,4,7,8- PeCDF …….…….....0.5
PCB 126……..…0.1

Individual TEQ:
2,3,7,8 TCDD……...10 ppt × 1 = 10 ppt TEQ
2,3,4,7,8- PeCDF …….30 ppt × 0.5 = 15 ppt TEQ
PCB 126……....20 ppt × 0.1 = 2 ppt TEQ

Total TEQ
10 ppt + 15 ppt + 2 ppt = 27 ppt TEQ

Q: For which exposure pathways are the TEFs used?

A: In addition to the ingestion pathway, the TEFs may be applied to other exposure routes (i.e., dermal or inhalation), as an estimate, assuming exposures to DLCs via these routes can be quantified. When included in an assessment, the fractional contribution of oral, dermal, and inhalation route exposures to the predicted TEQ should be identified.

In the absence of dermal toxicity values, a route-to-route (oral to dermal) extrapolation can be done using the oral toxicity value and adjusting for absorption through skin. This Office of Solid Waste and Emergency Response policy is described in Section 4.1 of the *Risk Assessment Guidance for Superfund Volume I: Human Health Evaluation Manual (Part E, Supplemental Guidance for Dermal Risk Assessment) Final* (EPA 2004). The availability of a dermal absorption factor for TCDD allows for the use of the TEFs in evaluating dermal exposure.

The EPA Integrated Risk Information System (IRIS) does not include toxicity values for estimating the risk posed by the inhalation of TCDD (either via particulates or volatiles). The EPA Regional Screening Tables (EPA 2012) provide dioxin soil screening levels for the inhalation pathway based on the California EPA reference concentration (RfC) and unit risk factor for TCDD. Inhalation risk based on particulate emissions from soil, estimated using the California EPA RfC for TCDD, shows that the contribution of the inhalation pathway compared to the ingestion pathway is well below 1%.

Q: Are dioxin TEFs applied in assessing both cancer risks and non-cancer health effects?

A: The EPA 2010 TEF document (EPA 2010) recommends that the TEFs be used for all effects mediated through aryl hydrocarbon receptor binding by the DLCs, including cancer and noncancer effects.

Q: How is the EPA 2010 report *Recommended Toxicity Equivalence Factors (TEFs) for Human Health Risk Assessments of 2,3,7,8-Tetrachlorodibenzo-p-dioxin and Dioxin-Like Compounds* to be applied at CERCLA and RCRA sites?

A: The TEF approach has previously been used at CERCLA and RCRA sites. The EPA is now recommending the use of the 2005 human and mammalian WHO TEF values for DLCs, as discussed in the EPA 2010 TEF report (EPA 2010). This report provides updates to the 1998 WHO TEF values (Van den Berg et al 1998), based on a number of factors, including new toxicity values and the need to consider impurities in test compounds.

Some of the 2005 WHO TEFs have increased and some have decreased in value, compared to the 1998 WHO TEFs. The relative importance of the TEF changes largely depends on the mixture being evaluated. For example, the TEF for 2,3,4,7,8-pentachloro-dibenzofuran was reduced from 0.5 to 0.3 and the TEF for PCB 169 increased from 0.01 to 0.03. See Attachment A for a comparison of the WHO 1998 and 2005 TEFs.

Underlying assumptions of the TEF method include: a) the toxicokinetics and the toxicodynamics of TCDD and DLCs are similar; b) the dose-response curves of TCDD and DLCs are similarly shaped; c) the aryl hydrocarbon receptor mediates most if not all of the biologic and toxic effects of the DLCs; and d) the kinetics and potency of various DLCs are generally similar between species (EPA 2000, EPA 2008). EPA recommends that risk assessors identify the fraction of the total TEQ attributable to TCDD (for which

uncertainty is relative low) and attributable to DLCs (for which uncertainty is somewhat higher).

Q: The EPA issued a report in 2010 on the use of dioxin TEFs for human health risk assessments. Does the Agency have information on the use of TEFs for ecological risk assessments?

A: Yes. In 2008, the EPA issued the *Framework for Application of the Toxicity Equivalence Methodology* for *Polychlorinated Dioxins, Furans, and Biphenyls in Ecological Risk Assessment* (EPA 2008).

Q: How are the dioxin TEFs used at PCB sites?

A: There are 209 PCB chemical compounds, or congeners; 12 of the 209 PCB congeners are considered dioxin-like. If dioxin-like PCBs are of concern at a PCB site, the PCB cleanup level will need to meet a site-specific dioxin TEQ cleanup level. In this case, two PCB cleanup levels are calculated. One cleanup level is calculated for total PCBs (i.e., for all PCB congeners present), based on toxicity values for total PCBs. The other PCB cleanup level is calculated so that it meets a site-specific dioxin TEQ cleanup level. This second PCB cleanup level depends on the TEQ (i.e., concentration x TEF) of dioxin-like PCBs in the PCB-contaminated media along with any TCDD and other DLCs present, and considers toxicity values for TCDD. The more stringent of the two PCB cleanup levels is selected.

For example, the PCB soil cleanup level that will meet a site-specific dioxin TEQ soil cleanup level can be calculated as:

$$PCB_{\text{cleanup level for TCDD/DLCs}} = PCB_{\text{soil concentration}} \times TEQ_{\text{cleanup level}} / TEQ_{\text{soil concentration}}$$

Where:

- $PCB_{\text{cleanup level for TCDD/DLCs}}$ — PCB soil cleanup level that meets the dioxin TEQ soil cleanup level.
- $PCB_{\text{soil concentration}}$ — Soil concentration of total PCBs.
- $TEQ_{\text{cleanup level}}$ — Dioxin TEQ soil cleanup level.
- $TEQ_{\text{soil concentration}}$ — Soil TEQ concentration of TCDD and DLCs, (i.e. other dioxins, furans and dioxin-like PCBs).

The PCB soil cleanup level that will meet a site-specific dioxin TEQ soil cleanup level is compared to the site-specific soil cleanup level for total PCBs to select the more stringent of the two, ensuring that the remedy will be protective for both PCB and dioxin-like PCB (along with any TCDD and other DLC) exposures.

The following is a sample calculation:

$$PCB_{\text{cleanup level for TCDD/DLCs}} = 5{,}000 \text{ ppt PCBs} \times 50 \text{ ppt TEQ} / 500 \text{ ppt TEQ}$$

$PCB_{\text{cleanup level for TCDD/DLCs}}$ = 500 ppt PCBs

In this example, one tenth of the total PCB concentration is due to dioxin-like PCBs, as well as any TCDD and other DLCs present (i.e., the dioxin-like PCB TEQ concentration, along with any TCDD and other DCLs present, is 500 ppt TEQ). For a soil dioxin cleanup level of 50 ppt TEQ, the corresponding PCB soil cleanup level that would not exceed the soil dioxin cleanup level is 500 ppt PCBs.

Additional Resources

This fact sheet provides information on the use of the 2005 WHO TEFs to calculate TEQs at CERCLA and RCRA sites. Additional information on evaluating TCDD and DLCs at these sites can be found online at: http://epa.gov/superfund/health/contaminants/dioxin/dioxinsoil.html

Attachment A "Recommended Toxicity Equivalence Factors (TEFs) for Human Health Risk Assessments of Polychlorinated Dibenzo-p-dioxins, Dibenzofurans, and Dioxin-Like Polychlorinated Biphenyls" provides the 2005 updates to the 1998 WHO TEFs.

References

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ATTACHMENT A

Recommended Toxicity Equivalence Factors (TEFs) for Human Health Risk Assessment of Polychlorinated dibenzo-*p*-dioxins, Dibenzofurans, and Dioxin-Like Polychlorinated Biphenyls[1]

Compound	1998 TEF[2]	2005 TEF[3]
Polychlorinated dibenzo-*p*-dioxins (*PCDDs*)		
2,3,7,8-Tetrachloro-dibenzo-*p*-dioxin (TCDD)	1	1
1,2,3,7,8-Pentachloro dibenzo-*p*-dioxin (PeCDD)	1	1
1,2,3,4,7,8-Hexachloro- dibenzo-*p*-dioxin (HxCDD)	0.1	0.1
1,2,3,6,7,8-Hexachloro- dibenzo-*p*-dioxin (HxCDD)	0.1	0.1
1,2,3,7,8,9-Hexachloro- dibenzo-*p*-dioxin (HxCDD)	0.1	0.1
1,2,3,7,8,9-Heptachloro- dibenzo-*p*-dioxin (HpCDD)	0.01	0.01
Octachloro-dibenzo-*p*-dioxin (OCDD)	**0.0001**	**0.0003**
Polychlorinated dibenzofurans (*PCDFs*)		
2,3,7,8-Tetrachlor-dibenzofuran (TCDF)	0.1	0.1
1,2,3,7,8-Pentachloro-dibenzofuran (PeCDF)	**0.05**	**0.03**
2,3,4,7,8-Pentachloro-dibenzofuran (PeCDF)	**0.5**	**0.3**
1,2,3,4,7,8-Hexachloro-dibenzofuran (HxCDF)	0.1	0.1
1,2,3,6,7,8-Hexachloro-dibenzofuran (HxCDF)	0.1	0.1
1,2,3,7,8,9-Hexachloro-dibenzofuran (HxCDF)	0.1	0.1
2,3,4,6,7,8-Hexachloro-dibenzofuran (HxCDF)	0.1	0.1
1,2,3,4,6,7,8-Heptachloro-dibenzofuran (HpCDF)	0.01	0.01
1,2,3,4,7,8,9-Heptachloro-dibenzofuran (HpCDF)	0.01	0.01
Octachloro-dibenzofuran (OCDF)	**0.0001**	**0.0003**
Polychlorinated biphenyls (*PCB* congener number)		
3,3',4,4'-Tetrachloro-biphenyl (77)	0.0001	0.0001
3,4,4',5-Tetrachloro-biphenyl (81)	**0.0001**	**0.0003**
3,3',4,4',5-Pentachloro-biphenyl (126)	0.1	0.1
3,3',4,4',5,5'-Hexachloro-biphenyl (169)	**0.01**	**0.03**
2,3,3',4,4'-Pentachloro-biphenyl (105)	**0.0001**	**0.00003**
2,3,4,4',5-Pentachloro-biphenyl (114)	**0.0005**	**0.00003**
2,3',4,4',5-Pentachloro-biphenyl (118)	**0.0001**	**0.00003**
2',3,4,4',5-Pentachloro-biphenyl (123)	**0.0001**	**0.00003**
2,3,3',4,4', 5-Hexachloro-biphenyl (156)	**0.0005**	**0.00003**
2,3,3',4,4',5'-Hexachloro-biphenyl (157)	**0.0005**	**0.00003**
2,3',4,4',5,5'-Hexachloro-biphenyl (167)	**0.00001**	**0.00003**
2,3,3',4,4',5,5'-Heptachloro-biphenyl (189)	**0.0001**	**0.00003**

[1] Numbers in bold indicate a change in TEF value.
[2] Source: van den Berg et al. (1998); available at: http://www.cerc.usgs.gov/pubs/center/pdfDocs/90970.pdf
[3] Source: van den Berg et al. (2006); WHO's Web site on dioxin TEFs, available at: http://www.who.int/ipcs/assessment/tef_update/en/