Appendix D

Use of the Toxic Equivalency Factor Methodology for Dioxins and Furans, PCBs, and PAHs

D.1 Introduction

The toxicity equivalency factor (TEF) methodology was developed by the U.S. Environmental Protection Agency (USEPA) to evaluate the toxicity and assess the risks of a mixture of structurally-related chemicals with a common mechanism of action. Both USEPA and the World Health Organization (WHO) use TEFs to evaluate mixtures of polychlorinated dibenzo-*p*-dioxins and polychlorinated dibenzo-*p*-furans (PCDDs and PCDFs) and mixtures of dioxin-like polychlorinated biphenyls (PCBs). TEF methodology specific to mixtures of polycylic aromatic hydrocarbons (PAHs) are used by the California EPA, the Washington Department of Ecology, and DEQ's Cleanup Program. Further details for each of these three types of mixtures are presented below.

D.2 Polychlorinated Dibenzo-*p*-dioxins (PCDDs) and Dibenzofurans (PCDFs)

There are 7 distinct PCDD compounds and 10 distinct PCDF compounds, all of which are referred to as congeners. All 17 dioxin/furan congeners are structurally similar and have the same mechanism of toxicity. Because of their similarities, the combined toxicity of these 17 compounds can be estimated using the sum of their doses, which are scaled for potency relative to one component of the mixture for which adequate dose-response toxicity information is available (EPA 2000); this compound is referred to as an "index" chemical. Of these 17 congeners, the toxicity of 2,3,7,8-tetrachlorodibenzo-p-dioxin (commonly referred to as 2,3,7,8-TCDD) has been the most extensively studied, and is used as the index chemical.

Each of the congeners is assigned a TEF which represents the relative potency, or toxicity, of each congener to 2,3,7,8-TCDD. Thus, for 2,3,7,8-TCDD, the TEF is 1.0. The TEFs assigned to each dioxin/furan congener are presented in Table D-1.

To evaluate cumulative risk, the concentrations of each of the 17 congeners is multiplied by its specific TEF. Then those 17 adjusted concentrations are summed to produce a Toxicity Equivalency Quotient, or TEQ, concentration. The TEQ concentration is then compared to the toxicity value for 2,3,7,8-TCDD to determine whether dioxins and furans are present at levels that will cause unacceptable impacts to human health.

The TEF normalization process described above is based on the use of oral toxicity factors. EPA states that TEFs may be applied to other exposure routes, including inhalation, as an interim estimate (*Recommended Toxicity Equivalence Factors (TEFs) for Human Health Risk Assessments of 2,3,7,8-Tetrachlorodibenzo-p-dixoin and Dioxin-Like Compounds*, EPA 2010a).

The Risk Based Concentrations for total dioxins and furans, treated as 2,3,7,8-TCDD TEQ, are 3×10^{-8} $\mu g/m^3$ for carcinogenic effects, and 4×10^{-5} $\mu g/m^3$ for non-carcinogenic effects. These protective concentrations were obtained using the 1996 OEHHA Inhalation Risk Unit value of 38 per $\mu g/m^3$ for 2,3,7,8-TCDD, and the OEHHA RfC of 4×10^{-5} $\mu g/m^3$, respectively.

In formula form, the TEQ for PCDDs and PCDFs is calculated as:

$$TEQ_{PCDDs,PCDFs} = \sum_{i=1}^{7}\left(PCDD_i \cdot TEF_i\right) + \sum_{i=1}^{10}\left(PDCF_i \cdot TEF_i\right)$$

D.3 Polychlorinated Biphenyls (PCBs)

Polychlorinated biphenyls are comprised of a group of 209 congeners, 12 of which are considered dioxin-like in terms of their structural similarity and mechanism of toxicity. Most people are more familiar with the term "PCB Aroclors". Aroclors are specific mixtures of portions of the 209 PCB congeners (for example, Aroclor 1260, Aroclor 1254), and were created by Monsanto and used commercially to insulate and cool electrical equipment from the 1930s up to 1977, when Monsanto ceased production. The use of Aroclors was banned by EPA in 1979. However, because PCBs are extremely persistent and bioaccumulate through the food chain, the residual PCBs related to past Aroclor use still exist today, and have spread globally. As Aroclor mixtures deteriorate, their original mixture of PCB congeners changes over time. Therefore, there is a need to be able to evaluate mixtures of PCB congeners rather than Aroclors, although Aroclors are still evaluated in special cases. The term "Total PCBs" is used in different ways, depending on the situation: 1) for a sum of all 209 PCB congeners; 2) for a sum of Aroclors. Additionally and separately, a sum of normalized concentrations of the 12 dioxin-like PCB congeners can be evaluated using a Toxic Equivalency Factor (TEF) methodology.

D.3.1 Total PCBs

The Risk Based Concentration for total polychlorinated biphenyls is 0.01 $\mu g/m^3$, and should be compared to a straight summed concentration of all 209 PCB congeners in a mixture.

D.3.2 Dioxin-Like PCB Congeners

The 12 dioxin-like PCB congeners are evaluated by applying a TEF methodology, using the dioxin 2,3,7,8- -TCDD as the "index" chemical to which the TEQ for the 12 dioxin-like PCB congeners are compared. The 12 dioxin-like congeners are known to be carcinogenic, and typically are assumed to be of more concern than the remaining 197 PCB congeners. Each of the 12 dioxin-like PCB congeners has an assigned TEF (World Health Organization 2005, USEPA 2010a); please refer to Table D-2.

To evaluate the concentration of a PCB mixture which contains the dioxin-like congeners, each dioxin-like PCB congener is multiplied by its assigned TEF, and then the results for all 12 are summed to produce a Toxic Equivalency Quotient (TEQ) concentration, which is then compared to the toxicity value for 2,3,7,8-TCDD.

Just as with the evaluation of dioxins and furans, the Risk Based Concentrations for the sum of the 12 dioxin-like PCBs, treated as 2,3,7,8-TCDD TEQ, are 3×10^{-8} $\mu g/m^3$ for carcinogenic effects, and 4×10^{-5} $\mu g/m^3$ for non-carcinogenic effects. These protective concentrations were obtained using the 1996 OEHHA Inhalation Risk Unit value of 38 per $\mu g/m^3$ for 2,3,7,8-TCDD, and the OEHHA RfC of 4×10^{-5} $\mu g/m^3$, respectively.

In formula form, the TEQ for dioxin-like PCB congeners is calculated as:

$$\mathrm{TEQ_{pcb}} = \sum_{i=1}^{12}\left(\mathrm{PCB_i} \cdot \mathrm{TEF_i}\right)$$

D.4 Polycyclic Aromatic Hydrocarbons

Polycylic aromatic hydrocarbons (PAHs) are produced whenever fossil fuels or organic matter is combusted. PAHs can also exist as contaminants in uncombusted petroleum products. Several PAHs can increase the risk of developing cancers, and one PAH (benzo[a]pyrene) can also impair normal fetal development. Concentrations of individual PAHs should be normalized to a concentration of the PAH benzo(a)pyrene through the use of TEFs. Once this normalization is completed and the TEF results summed, the resulting TEQ concentration can be compared to the toxicity value for benzo(a)pyrene. The Risk Based Concentration chosen for total PAHs (minus naphthalene) was 0.0009 $\mu g/m^3$, which was calculated using the 1999 EPA Inhalation Unit Risk value of 1.0×10^{-4} per $\mu g/m^3$.

The list of 26 PAHs shown below should be used to generate a concentration for Total PAHs. Please note that current laboratory analytical methods are available for only a subset of the PAHs in Table D-3.

Because benzo(a)pyrene has both cancer and non-cancer effects, the concentration of benzo(a)pyrene as an individual PAH should also be compared separately against the non-cancer RBC for benzo(a)pyrene, which is an RfC value of 0.002 $\mu g/m^3$ (EPA 2017). Because the RfC is based on developmental effects, this value for benzo(a)pyrene should be compared to 24-hour-based concentrations as well as annual averaged concentrations of this PAH.

Naphthalene is both a representative volatile PAH and was the single most emitted PAH in Oregon circa 2005. Thus, at that time, naphthalene was evaluated separately from the other PAHs, and a concentration of 0.03 $\mu g/m^3$ was chosen as its Ambient Benchmark Concentration. The benchmark was calculated using the 2004 California Office of Environmental Health Hazard Assessment (OEHHA) Unit Risk Estimate of 3.4×10^{-5} per $\mu g/m^3$.

D.5 References

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Table D-1: Toxicity Equivalency Factors for Dioxin/Furan Congeners

Congener	Toxicity Equivalency Factor[1]
PCDDs	
2,3,7,8-TetraCDD	1
1,2,3,7,8-PentaCDD	1
1,2,3,4,7,8-HexaCDD	0.1
1,2,3,6,7,8-HexaCDD	0.1
1,2,3,7,8,9-HexaCDD	0.1
1,2,3,4,6,7,8-HeptaCDD	0.01
1,2,3,4,6,7,8,9-OctaCDD	0.0003
PCDFs	
2,3,7,8-TetraCDF	0.1
1,2,3,7,8-PentaCDF	0.03
2,3,4,7,8-PentaCDF	0.3
1,2,3,4,7,8-HexaCDF	0.1
1,2,3,6,7,8-HexaCDF	0.1
2,3,4,6,7,8-HexaCDF	0.1
1,2,3,7,8,9-HexaCDF	0.1
1,2,3,4,6,7,8-HeptaCDF	0.01
1,2,3,4,7,8,9-HeptaCDF	0.01
1,2,3,4,6,7,8,9-OctaCDF	0.0003

Note
1 = from Van den Berg et al. (2006); adopted for use by the World Health Organization and by USEPA (2010).

Table D-2: Dioxin-Like PCB Congeners and Related TEFs

Congener	TEF[1]
3,3',4,4'-Tetrachlorinated biphenyl (PCB 77)	0.0001
3,4,4',5-TetraCB (PCB 81)	0.0003
3,3',4,4',5-PentaCB (PCB 126)	0.1
3,3',4,4',5,5'-HexaCB (PCB 169)	0.03
2,3,3',4,4'-PentaCB (PCB 105)	0.00003
2,3,4,4',5-PentaCB (PCB 114)	0.00003
2,3',4,4',5-PentaCB (PCB 118)	0.00003
2',3,4,4',5-PentaCB (PCB 123)	0.00003
2,3,3',4,4',5-HexaCB (PCB 156)	0.00003
2,3,3',4,4',5'-HexaCB (PCB 157)	0.00003
2,3',4,4',5,5'-HexaCB (PCB 167)	0.00003
2,3,3',4,4',5,5'-HeptaCB (PCB 189)	0.00003

1 = from Van den Berg et al. (2006); adopted for use by the World Health Organization and by USEPA (2010).

Table D-3. Recommended Revised List of PAHs and Related TEFs (Reduction from 2005 list of 32 PAHs to proposed 26)

#	PAH	EPA Required (1) [a]	EPA Requested (14) [b]	From MN list (11) [c]	TEF [c,d]
1	5-Methylchrysene			⊙	1 [d]
2	6-Nitrochrysene			⊙	10 [d]
3	Acenaphthene		⊙		NA
4	Acenaphthylene		⊙		NA
5	Anthanthrene			⊙	0.4
6	Anthracene		⊙		0
7	Benz(a)anthracene		⊙		0.2
8	Benzo(a)pyrene	⊙			1
9	Benzo(b)fluoranthene		⊙		0.8
10	Benzo(c)fluorene			⊙	20
11	Benzo(e)pyrene		⊙		NA
12	Benzo(g,h,i)perylene			⊙	0.009
13	Benzo(j)fluoranthene			⊙	0.3
14	Benzo(k)fluoranthene		⊙		0.03
15	Chrysene		⊙		0.1
16	Cyclopenta[c,d]pyrene			⊙	0.4
17	Dibenz(a,h)anthracene		⊙		10
18	Dibenzo(a,e)pyrene			⊙	0.4
19	Dibenzo(a,h)pyrene			⊙	0.9
20	Dibenzo(a,i)pyrene			⊙	0.6
21	Dibenzo(a,l)pyrene			⊙	30
22	Fluoranthene		⊙		0.08
23	Fluorene		⊙		NA
24	Indeno(1,2,3-c,d)pyrene		⊙		0.07
25	Phenanthrene		⊙		0
26	Pyrene		⊙		0

Notes:

[a] Naphthalene is also required but already has its own risk-based concentration.

[b] Per EPA National Air Toxics Trend Sites (NATTS) Technical Assistance Document (TAD) 2009, Revision 2, Table 1.1-1. Note that the most-current version of NATTS, published in 2016, requests the same list of PAHs as those presented in the 2009 NATTs.

[c] PAHs on Minnesota Department of Health 2014 list of 19 priority cPAHs that are not already required or requested by EPA.

[d] Values were obtained from an External Review Draft version of EPA's2010 *Development of a relative potency factor (RPF) approach for polycyclic aromatic hydrocarbon (PAH) mixtures*. Although this document is not supposed to be cited or quoted, the Air Toxics Science Advisory Committee considers this information to be the best and most current science available on this topic. A portion of the TEFs represent the average range of Potency Equivalency Factors provided in this document.

NA – not listed in either EPA 2010b nor by MnDOH, but is a NATTS-requested PAH.