Schedule B7

APPENDIX A5

The Derivation of HILs for PCBs and PBDEs

OPC50357 - B

<div style="border:1px solid black">

Contents
The Derivation of HILs
for PCBs and PBDEs

</div>

OPC50357 - B

1 PCBs

1.1 General

Polychlorinated biphenyls (PCBs) are a group of synthetic organic compounds comprising two benzene rings joined together, with between one and ten chlorine atoms attached. There are 209 possible PCB variants (congeners) though PCBs are typically found as a complex mixture in commercial products and in the environment (WHO 1993). Of the 209 possible congeners, 12 are able to assume the same flat shape as dioxins and can cause impacts via the same mechanism. Consequently, it is normal to consider the PCB contribution to dioxin toxicity by measuring those congeners specifically. Some or all of these 12 congeners are always going to be present in any PCB contamination. There is evidence that using the dioxin-like PCBs as the basis for assessing risk from PCBs is also protective for the risks from the non-dioxin-like PCBs, i.e. the non-dioxin-like PCBs are less toxic than the dioxin-like PCBs.

The following relates to the assessment of non-dioxin-like PCBs only. The assessment of dioxins and dioxin-like PCBs needs to be conducted on a site-specific basis where there is the potential for a PCB source (such as PCB oil contamination) to be present at a site.

Several comprehensive reviews of PCBs in the environment and their toxicity to humans are available and should be consulted for more detailed information not presented in this summary (ATSDR 2000; WHO 1993; WHO 2003; EPHC 2003). The following provides a summary of the key aspects of PCBs that are relevant to the derivation of a soil HIL.

PCBs are typically in the form of an oily liquid or solid and are colourless to light yellow. Some PCB congeners may also exist as a vapour in air. They are odourless and tasteless. PCBs do not burn easily and have good insulating properties. They are both chemically and thermally stable. PCBs are relatively insoluble in water with the solubility decreasing with increasing chlorine content (ATSDR 2000).

Commercial PCB mixtures are also known by their trade names, such as Aroclor (USA), Phenochlor (France), Clophen (Germany), Kanechlor (Japan), Fechlor (Italy) and Sovol (USSR). Information on the toxicity and behaviour of a number of commercial PCB mixtures, Aroclors, is available, with Aroclor 1254 most commonly used as an indicator for the assessment of PCB mixtures. WHO (2003) provides a review of the most common commercial Aroclor mixtures with respect to the composition and toxicity of congeners present, and the various mixtures of indicator congeners (that differ from that of Aroclor 1254) may need to be considered on a site-specific basis.

Due to the thermal and chemical stability of PCBs, they are widely used as coolants and lubricants in transformers, capacitors and other electrical equipment (ATSDR 2000). In Australia, PCBs were also used in the manufacture of plastics, adhesives, paints and varnishes and were found in consumer products such as pesticides, fluorescent lighting and carbonless copy paper. PCBs were used in Australia between the 1930s and 1970s, when the importation of PCBs was banned.

1.2 Previous HIL

The derivation of the previous HIL (HIL A = 10 mg/kg) for PCBs is presented by Di Marco & Buckett (1993) and NEPC (1999). In summary, the HIL was derived on the basis of the following:
- Background intakes from air, water and food were estimated to be 5.4 ng/kg/day for a child and 4.4 ng/kg/day for an adult, estimated to be approximately 5% of the adopted PTDI (derived PTDI of 0.0001 mg/kg/day for Aroclor 1016).

- Due to the lack of published data for PCBs, the lowest threshold value derived for Aroclors 1016 and 1248 were considered. A PTDI of 0.0001 mg/kg/day was derived for Aroclor 1016 based on a NOAEL of 0.0125 mg/kg/day, and a safety factor of 100.

- Intakes derived from ingestion (assuming 30% bioavailability), inhalation of dust (assuming 50% bioavailability) and dermal absorption (10% absorption) were considered in the derivation of the soil HIL of 10 mg/kg.

1.3   Significance of Exposure Pathways

1.3.1   Oral Bioavailability

Bioavailability of PCBs in soil appears to be important due to their high affinity for soil particles and organic matter. Bioavailability was considered in the derivation of the current HIL (Di Marco & Buckett 1993) with 30% assumed for oral intakes and 50% assumed for inhalation. The basis for this assumption is not available and no more detailed reviewed of PCB bioavailability (oral or inhalation) in soil is available.

Insufficient data is available to adequately define the bioavailability of PCBs in the range of contaminated sites that may need to be considered in Australia. On this basis, a default approach of assuming 100% oral bioavailability has been adopted in the derivation of an HIL. It is noted that a site-specific assessment of bioavailability can be undertaken where required.

1.3.2   Dermal absorption

US EPA (2004) recommends a dermal absorption value of 0.14 (14%) for PCB Aroclors 1254/1242 and other PCBs, based on a study by Wester et al. (1993). A range of dermal absorption values is presented by ATSDR (2000). Review of these studies suggests that, while the data is limited, the value recommended by US EPA (2004) is adequately representative.

1.3.3   Inhalation of Dust

PCBs are not considered sufficiently volatile to be of significance and inhalation exposures associated with particulates outdoors and indoors are expected to be of less significance than ingestion of soil. While likely to be negligible, potential inhalation exposures associated with dust have been considered in the HIL derived.

1.3.4   Plant Uptake

PCBs accumulate in terrestrial vegetation by the following possible mechanisms: uptake from soil through the roots; dry deposition on aerial parts (particle-bound or gaseous); and wet deposition on aerial parts (particle-bound or solute).Where PCBs are sorbed to soil and organic matter, the potential for plant uptake is reduced; however, it remains of potential significance (CCME 1999). The uptake of PCBs (in soil) into edible fruit and vegetable crops has been the subject of a number of studies with a range of bioaccumulation factors derived for different crops (ATSDR 2000), with adsorption onto root surfaces most significant compared with translocation within the root or upper portions of the plant (CCME 1999). On this basis, the potential for the uptake of PCBs into home-grown produce has been considered in the derivation of an HIL A. This has been undertaken on the basis of the equations presented in Appendix B, with the following parameters and plant uptake factors estimated:

Parameter	Value	Reference/Comment
Parameters		
K_{oc}	131 000 (cm^3/g)	RAIS (2010) for Aroclor 1254
log K_{ow}	6.79	RAIS (2010) for Aroclor 1254
Diffusivity in water	6.75×10^{-6} (cm^2/s)	RAIS (2010) for Aroclor 1221
Calculated Plant Uptake Factors (mg/kg produce fresh weight per mg/kg soil)		
Green vegetables	0.00026	calculated
Root vegetables	0.0038	calculated
Tuber vegetables	0.079	calculated
Tree fruit	0.00096	calculated

1.3.5 Intakes from Other Sources – Background

Background intakes (5.4 ng/kg/day for a child) were estimated by Di Marco & Buckett (1993) in the derivation of the previous HIL. Review of information available from FSANZ (2003) indicates that PCBs remain undetected in Australian and New Zealand food supplies, information consistent with that identified by Di Marco & Buckett (1993). Hence, intakes from food are considered negligible.

Intakes estimated by WHO (2003) are 0.3−3 ng/kg/day from air (including data derived from close-to-stack emissions from industrial/hazardous waste sources) and less than 0.2 ng/kg/day, from water. These values are similar to those noted above. Air concentrations reported by WHO (2003) from areas away from significant sources ranged from 0.002−0.95 ng/m^3 with PCBs in air noted to be slowly declining since the early 1980s. Based on these concentrations, intake of PCBs in air away from significant sources is approximately 0.3 ng/kg/day (the lower end of the range reported by WHO). Intakes estimated by RIVM (2001) are dominated by food (particularly where seafood dominates the diet), where the total intake is estimated to be 10 ng/kg/day. More recent review of intakes of PCBs from food by RIVM (2003) suggests that median lifelong intakes are estimated to be 5.6 ng/kg/day, similar to those estimated by Di Marco & Buckett (1993).

If the intakes estimated by WHO (2003) for air (away from significant sources) and water are considered relevant to current background intakes in Australia (where intakes from food are negligible), these comprise approximately 0.5 ng/kg/day, approximately 2.5% of the recommended oral TRV. These intakes are considered negligible.

1.4 Identification of Toxicity Reference Values

1.4.1 Classification

The International Agency for Research on Cancer (IARC 1987) has classified PCBs as Group 2A—probably carcinogenic to humans. This evaluation is based on limited evidence in humans (occupational studies) and sufficient evidence in experimental animals, where some PCBs (particularly those with greater than 50% chlorination) produced liver neoplasms in mice and rats after oral administration.

It is noted that US EPA has classified PCBs as Group B2—probable human carcinogen.

1.4.2 Review of Available Values/Information

PCBs have been associated with carcinogenic effects (in particular, hepatocarcinogenic effects have been seen in animals for PCBs with higher levels of chlorination) but the mode of action is of prime importance for determining the most appropriate dose−response approach to adopt for establishing an HIL. Review by WHO (2003) notes that the results of in vitro and in vivo genotoxicity studies on PCB mixtures are generally negative and suggest that PCB mixtures do not pose a direct genotoxic threat to humans. Although the mechanistic basis of the hepatocarcinogenicity of PCB mixtures in rodents is not clearly understood, it apparently is not due to genotoxicity. This is consistent with information provided by ATSDR (2000) and RIVM (2001).

On the basis of the available information, it is considered appropriate that a threshold dose−response approach be adopted for PCBs. The following are available from Level 1 Australian and International sources:

Source	Value	Basis/Comments
Australian		
ADWG	No evaluation available	
OCS (2012)	No evaluation	

Source	Value	Basis/Comments
	available	
International		
WHO (2003)	TDI = 0.00002 mg/kg/day	Derived on the basis of a LOAEL of 0.005 mg/kg/day for Aroclor 1254 associated with immunological effects in a 23-month study in monkeys, and an uncertainty factor of 300. WHO considers this TDI relevant to mixtures of PCBs.
WHO (2011)	No evaluation available	
RIVM (2001)	TDI = 0.00001 mg/kg/day TC = 0.0005 mg/m^3	TDI based on a LOAEL of 0.005 mg/kg/day for Aroclor 1254 associated with immunological effects in a 23-month study in monkeys, and an uncertainty factor of 270 (approx. 300). An additional factor of 2 has been applied that relates the TDI derived from Aroclor 1254 to that relevant to PCB mixtures, where the seven indicator PCBs are present in Aroclor 1254 between 40 and 50%. Hence the assessment of mixtures has been undertaking by assuming 50% of the TDI for Aroclor 1254. TC is based on a LOAEC (adjusted) of 0.3 mg/m^3 for Aroclor 1254 associated with marginal effects in experimental animals, and an uncertainty factor of 300. The additional 50% factor noted above is also applied to the Aroclor TC.
ATSDR (2000)	Oral MRL = 0.00002 mg/kg/day	Chronic oral MRL based on the same study as considered by RIVM and WHO (2003), with no additional adjustment for PCB mixtures. No inhalation MRL has been derived.
US EPA (IRIS 2012)	RfD = 0.00002 mg/kg/day	US EPA RfD (last reviewed in 1994) derived on the same basis as that presented by ATSDR and WHO (2003). US EPA also presents a non-threshold oral slope factor for PCBs which is not considered relevant in this assessment.

All the currently available oral threshold values for PCBs, based on Aroclor 1254, are derived from the same study with the only difference being the application of an additional factor by RIVM (2001) to address PCB mixtures. WHO (2003) considers that the available TDI for Aroclor 1254 is adequate to address PCB mixtures with no further adjustment. Hence the value derived by WHO (2003), also adopted by ATSDR and US EPA, is recommended for use in the derivation of a soil HIL.

Few inhalation-specific studies are available, with RIVM deriving an inhalation-specific value based on limited data. No dermal or inhalation-specific studies or data are available. As the data is limited and does not suggest the toxicity of PCBs is significantly different via inhalation, the oral TDI is recommended for the assessment of all pathways of exposure.

1.4.3   Recommendation

On the basis of the discussion above, the following toxicity reference values (TRVs) have been adopted for PCBs in the derivation of HILs

1.5   Calculated HILs

On the basis of the above, the following HILs have been derived for PCBs (refer to Appendix B for equations used to calculate the HILs and Appendix C for calculations):

HIL Scenario	HIL (mg/kg)	Percentage Contribution from Exposure Pathways			
		Ingestion of	Ingestion of	Dermal	Inhalation

		Soil/Dust	Home-grown Produce	Absorption of Soil/Dust	(dust)
Residential A	1	19	46	35	<1
Residential B	1	12	--	88	<1
Recreational C	1	21	--	79	<1
Commercial D	7	9	--	91	<1

-- Pathway not included in derivation of HIL

1.6   References

ATSDR 2000, *Toxicological Profile for Polychlorinated Biphenyls*, Agency for Toxic Substances and Disease Registry, November 2000.

CCME 1999, *Polychlorinated Biphenyls (total), Canadian Soil Quality Guidelines for the Protection of Environmental and Human Health,* Canadian Council of Ministers of the Environment, 1999.

Di Marco, P & Buckett, K 1993, 'Derivation of a Health Investigation Level for PCBs', presented in the proceedings of the *Second National Workshop on the Health Risk Assessment and Management of Contaminated Sites, Contaminated Sites Monograph Series, No. 2,* 1993.

EPHC 2003, *Polychlorinated Biphenyls Management Plan*, Revised edition, April 2003, Scheduled Waste Management Group, available from http://www.environment.gov.au/settlements/publications/chemicals/scheduled-waste/pcbmanagement/index.html#download.

IARC 1987, *Summaries & Evaluations, Polychlorinated Biphenyls*, Supplement 7: (1987), p. 322, International Agency for Research on Cancer.

NEPC 1999, *Schedule B (7a), Guideline on Health-Based Investigation Levels, National Environment Protection (Assessment of Site Contamination) Measure*, National Environment Protection Council, Australia.

RIVM 2001, *Re-evaluation of human-toxicological Maximum Permissible Risk levels*, National Institute of Public Health and the Environment, Bilthoven, Netherlands, available from: http://www.rivm.nl/bibliotheek/rapporten/711701025.html.

RIVM 2003, *Indicator PCBs in foodstuffs: occurrence and dietary intake in The Netherlands at the end of the 20th century*, National Institute of Public Health and the Environment, RIVM Report: 639102025/2003, Bilthoven, Netherlands.

RAIS (2010), *Risk Assessment Information System*, website and database maintained by the Oak Ridge Operations Office, available from: http://rais.ornl.gov/.

US EPA (IRIS 2012), data and information available from the *Integrated Risk Information System*, an online database, available from http://www.epa.gov/iris/.

US EPA 2004, *Risk Assessment Guidance for Superfund, Volume I: Human Health Evaluation Manual (Part E, Supplemental Guidance for Dermal Risk Assessment), Final*, EPA/540/R/99/005, OSWER 9285.7-02EP, July 2004.

Wester, RC, Maibach, HI, Sedik, L, Melendres, J, & Wade, M 1993, 'Percutaneous Absorption of PCBs from Soil: In-vivo Rhesus Monkey, In-vitro Human Skin, and Binding to Powered Human Stratum Corneum', *J. Toxicol. Environ. Health,* vol. 39, pp. 375–382.

WHO 1993, *Environmental Health Criteria No 140 – Polychlorinated Biphenyls and Terphenyls*, World Health Organization, Geneva.

WHO 2003, *Concise International Chemical Assessment Document 55, Polychlorinated Biphenyls*: Human Health Aspects, World Health Organization, Geneva.

2 Polybrominated Diphenyl Ethers (Br1 to Br9)

2.1 General

Polybrominated diphenyl ethers (PBDE) are a group of compounds manufactured for their flame retardant properties. They consist of two phenyl groups bound to a single oxygen atom with the hydrogen atoms on the phenyl groups substituted with between one and ten bromine atoms. The group consists of 209 congeners, which differ in the number and location of substituted bromine atoms. The internationally accepted numbering system for PBDE congeners is the acronym 'BDE' followed by a number from 1 to 209 (NICNAS 2007).

Several comprehensive reviews of PBDEs in the environment and their toxicity to humans are available and should be consulted for more detailed information not presented in this summary (ATSDR 2004; NICNAS 2007; UNEP 2009). The following provides a summary of the key aspects of these compounds that are relevant to the derivation of a soil HIL.

The literature to date indicates that the toxicity and environmental fate of PBDEs with a lower number of substituted bromine atoms (penta-BDE to hexa-BDE) is different from higher brominated BDEs (deca-BDE to BDE-209). Lower brominated BDEs have been demonstrated to be more toxic in animal studies, have a higher bioavailability and are more readily transported in the environment. As a result, ATSDR has recommended separating deca-BDE from lower brominated BDEs (ATSDR 2004). For the purpose of this assessment, lower brominated BDEs are considered to be BDEs containing between one and nine substituted bromines and it is these lower brominated BDEs for which HILs have been derived.

It is noted that the toxicity of higher BDEs is less certain, hence if significant levels of PBDE that include higher BDEs are present, a site-specific assessment should be conducted.

Further studies regarding the toxicity and environmental fate of lower brominated BDEs may result in this grouping being revised to a smaller proportion of significant congeners in future reviews.

PBDE are manufactured compounds, which have been widely used in industrial and consumer applications. A review of the compounds conducted by scientific and regulatory bodies has culminated in tetra- and penta-BDEs (components of technical penta-BDE) and hexa- and hepta-BDEs (components in technical octa-BDE) being listed as a Persistent Organic Pollutants (POPs) under the Stockholm Convention in May 2009 (UNEP 2009). All production and use of these compounds has subsequently been banned, with the exception of recycling activities (UNEP 2009). PBDEs are not manufactured in Australia but were historically imported and used until 2005 (NICNAS 2007). Importation of products pre-treated with PBDEs is expected to decrease following the recent ban. Technical penta-BDE was mainly used in polyurethane foams (such as in furnishings) whereas technical octa-BDE and deca-BDE were mainly used in hard plastics (such as for electrical equipment) (NICNAS 2007). The articles treated with PBDEs usually have long lives and, as such, articles containing PBDEs are still expected to be in use (NICNAS 2007). Deca-BDE was declared a priority existing chemical in Australia and is currently being assessed as to its environment and human health risks (NICNAS 2007).

2.2 Previous HIL

No previous HIL is available for lower BDEs (NEPC 1999).

2.3   Significance of Exposure Pathways

2.3.1   Oral Bioavailability

Insufficient data is available to adequately define the bioavailability of lower BDEs, hence a default approach of assuming 100% oral bioavailability has been adopted in the derivation of an HIL. It is noted that a site-specific assessment of bioavailability can be undertaken where required.

2.3.2   Dermal absorption

Insufficient data is available on the dermal absorption of lower BDEs from soil. Hence the default values of 0.1 (10%) suggested by US EPA (2004) for semi-volatile organic compounds has been adopted in the derivation of HILs.

It is noted that EU (2004) estimated a dermal absorption value of 1% as a maximum for deca-BDE, based on assumptions associated with the lipophillic nature of the compound and analogies to PCB. However, it is also noted in this review that dermal absorption may also be associated with accumulation in the stratum corneum, which may behave as a storage site, resulting in a low systemic release over time.

2.3.3   Inhalation of Dust

Lower BDEs are not considered sufficiently volatile to be of significance and inhalation exposures associated with dust particulates outdoors and indoors are expected to be of less significance than ingestion of soil. While likely to be negligible, potential inhalation exposures associated with dust have been considered in the HIL derived.

2.3.4   Plant Uptake

Limited data is available on the potential for lower BDEs to be taken up by plants from soil into edible fruit and vegetable crops. ATSDR notes that PBDEs will be strongly adsorbed to soil, hence PBDEs present in soil-pore water will bind to soil organic matter. Because PBDEs adsorb strongly to soil, they will have very low mobility, and leaching of PBDEs from soil to groundwater will be insignificant.

Review of plant uptake of deca-PBDE (BDE-209) into plants from soil by Huang et al. (2010) suggests that deca-BDE is taken up and translocated within the plants assessed (ryegrass, alfalfa, pumpkin, squash, maize and radish). Nineteen lower brominated (di- to nona-) PBDEs were detected in the soil and plant samples and five hydroxylated congeners were detected in the plant samples, indicating debromination and hydroxylation of BDE-209 in the soil−plant system. Evidence of a relatively higher proportion of penta- through to di-BDE congeners in plant tissues than in the soil indicates that there is further debromination of PBDEs within plants or lower brominated PBDEs are more readily taken up by plants.

On the basis of the available information, the potential for the uptake of lower BDEs into home-grown produce has been considered in the derivation of an HIL A. This has been undertaken on the basis of the equations presented in Appendix B with the following parameters and plant uptake factors estimated:

Parameter	Value	Reference/Comment
Parameters		
K_{oc}	1 698 000 (cm^3/g)	Refer to note below*
log K_{ow}	6.84	RAIS (2010) for penta-BDE (BDE-99)
Diffusivity in water	5.32x10^{-6} (cm^2/s)	Estimated as per Guan et al. (2009)
Calculated Plant Uptake Factors (mg/kg produce fresh weight per mg/kg soil)		
Green vegetables	0.00026	calculated
Root vegetables	0.0038	calculated
Tuber vegetables	0.079	calculated

Parameter	Value	Reference/Comment
Tree fruit	0.00096	calculated

* The estimation of potential plant uptake of BDE is sensitive to the value of K_{oc} adopted. The data would normally be derived from RAIS (2010) for consistency; however, the data provided is only for penta-BDE with data from no other lower BDEs presented for comparison. Data presented in ATSDR (2001) suggests log K_{oc} ranges from 2.89–5.1 for penta-BDE and from 5.92–6.22 for octa-BDE. Review by Guan et al. (2009) provides log K_{oc} values for the lower BDEs (BDE-28 to BDE-208) that range from 5.73–6.49. Due to the range of values provided for the lower BDEs, the average of values presented by Guan et al. (2009), log K_{oc} = 6.23, has been adopted.

2.3.5 Intakes from Other Sources – Background

Background intakes were evaluated by NICNAS (2007) on the basis of PBDE levels in blood rather than as an intake. The presence of PBDEs in blood lipids indicates exposure by the general population; however, the data does not determine the major source of exposure. Data available from FSANZ (2007) suggests that dietary sources are likely to be low, therefore house dust may be the major source, but there is little correlation between exposure levels and house construction/contents. FSANZ notes a review by USA where dietary exposures did not explain the current body burden and exposures to hose dust were estimated to account for 82% of the total intake. Based on information presented in the available reviews, the following can be noted with respect to background intakes of PBDEs:

- A range of dietary intakes has been determined by FSANZ (2007) for all age groups. Estimated 95th percentile dietary intakes from FSANZ (2007) for a child aged 2–5 years ranged from 7 ng/kg/day (lower-bound) to 389 ng/kg/day (upper-bound). These intakes are consistent with data reported from other countries, including Canada and USA, and corresponded with a margin of exposure (MoE) of 300 or greater where a threshold of 0.1 mg/kg/day was considered. The MoE was greater for all other age groups considered in the study.

- PBDE in dust reported in indoor air in Australian buildings (Toms et al. 2006) ranged from 0.5–179 pg/m^3 for homes and 15–487 pg/m^3 for offices. Dust concentrations ranged from 87 ng/g–3070 ng/g. PBCEs were detected in 9 out of 10 surface wipe samples. No estimation of intake associated with measured levels in air and dust was presented. The study size was limited and showed dust levels similar to or lower than those conducted overseas in Canada and USA.

- Upper-bound total intakes of PBDEs from all sources (ambient and indoor air, dietary and dust) in Canada (Health Canada 2006) have been estimated to be approximately 0.95 µg/kg/day for children aged 0.5–4 years. Higher intakes (2.6 µg/kg/day) are noted for breastfed infants. Recent review of total intakes from food, dust and air of PBDEs in USA (Schecter et al. 2008) range from 1.2 ng/kg/day for adults to 307 ng/kg/day for infants.

- Based on the Australian data noted above, intakes by young children may range from 0.007–0.5 µg/kg/day. The higher value is half that estimated by Health Canada (2006), both of which exceed the recommended oral TRV.

- On the basis of the above, total intakes (and those reported from Australia) vary and may comprise a significant proportion of the recommended threshold value. Hence, consideration of 80% of the recommended TRV as background intakes is considered appropriate.

2.4 Identification of Toxicity Reference Values

2.4.1 Classification

The International Agency for Research on Cancer (IARC 1999) has classified technical deca-BDE as Group 3—not classifiable. No classification is available for other BDEs.

It is noted that US EPA has a classification for deca-BDE where it is classified as Group C—possible human carcinogen. US EPA has classified technical penta-BDE and technical octa-BDE as Group D—not classifiable.

2.4.2   Review of Available Values/Information

Review of PBDEs, in particular, penta-BDE and octa-BDE by NICNAS (2007), indicated there is insufficient information on the carcinogenic potential of these PBDEs, and that the overall conclusion relating to penta-BDE is that it is not genotoxic. Further review of octa-BDE, PBDE mixtures and penta-BDE (JECFA 2006) suggests that PBDE mixtures and individual congeners are not genotoxic. On the basis of the available information, it is considered appropriate that a threshold dose−response approach be adopted for PBDEs.

The following are available for the lower BDEs from Level 1 Australian and International sources:

Source	Value	Basis/Comments
Australian		
ADWG (NHMRC 2004)	No evaluation available	
OCS (2012)	No evaluation available	
NICNAS (2007)	No ADI/TDI established	Based on review of PBDEs and available studies, the highest toxicity was associated with penta-BDE associated with neurodevelopmental effects in pups and dams where the LOAELs were 0.8 mg/kg/day in pups and 0.06 mg/kg/day in dams.
FSANZ (2007)	No ADI/TDI established	Review of dietary intakes considered a margin of exposure (MoE) approach where a threshold value of 0.1 mg/kg/day was considered, based on a review by JECFA.
International		
JECFA (2006)	No ADI/TDI established	Due to the complexity of PBDEs and the lack of adequate data, a provisional maximum tolerable daily intake or provisional tolerable weekly intake has not been derived for PBDEs. Limited data suggests that, for more toxic PBDE congeners, adverse effects would be unlikely to occur in rodents at doses less than approximately 0.1 mg/kg/day.
WHO (2011)	No evaluation available	
Health Canada (2006)	No ADI/TDI established	A threshold value of 0.8 mg/kg/day was identified for penta-BDE, based on neurobehavioural effects in neonatal mice, considered the critical effects and appropriate for undertaking a MoE approach to the assessment of risk.
ATSDR (2004)	No chronic duration MRLs derived	No chronic duration MRLs have been derived for lower brominated BDEs, due to insufficient data. An intermediate duration oral MRL of 0.007 mg/kg/day has been derived on the basis of a LOAEL of 2 mg/kg/day associated with liver effects in rats exposed to penta-BDE. An intermediate duration inhalation MRL of 0.006 mg/m^3 has been derived based on a NOAEL of 1.1 mg/m^3 for thyroid effects in rats exposed to commercial octa-BDE mixture.
US EPA	RfD = 0.0001	RfD established (in 2008) for BDE-99 (penta-BDE) on the

Source	Value	Basis/Comments
(IRIS 2012)	mg/kg/day for penta-BDE (BDE-99) RfD = 0.0002 mg/kg/day for hexa-BDE (BDE-153) RfD = 0.0001 mg/kg/day for tetra-BDE (BDE-47) RfD = 0.003 mg/kg/day for octa-BDE	basis of a benchmark dose approach and a $BMDL_{ISD}$ of 0.29 mg/kg/day associated with neurobehavioral effects in mice, and an uncertainty factor of 3000. Hexa-BDE RfD established (in 2008) for BDE-153 on the basis of a NOAEL of 0.45 mg/kg/day associated with neurobehavioral effects in mice, and an uncertainty factor of 3000. Tetra-BDE RfD established (in 2008) for BDE-47 on the basis of a benchmark dose approach and a $BMDL_{ISD}$ of 0.35 mg/kg/day associated with neurobehavioral effects in mice, and an uncertainty factor of 3000. Octa-BDE RfD (established in 1986) for octa-BDE based on a NOAEL of 2.51 mg/kg/day associated with liver effects in rats, and an uncertainty factor of 1000. Note the US EPA (2008) review established an RfD = 0.007 mg/kg/day for deca-BDE (BDE-209), based on a NOAEL of 2.22 mg/kg/day associated with neurobehavioral effects in mice, and application of a 300-fold uncertainty factor. While not part of the lower-BDEs evaluated for the derivation of the soil HIL, this evaluation indicates that deca-BDE is less toxic than the lower BDEs.

Limited quantitative data is available for the characterisation of chronic exposures to lower BDEs. The more recent evaluations by US EPA (IRIS 2012) for individual congeners BDE-99, BDE-153 and BDE-47 have considered threshold values (BMDLs or NOAELs) that are consistent with those identified in reviews by NICNAS (2007), JECFA (2006) and Health Canada (2006), that are associated with the more sensitive end point of neurobehavioral/developmental effects. These end points are more sensitive than those considered by ATSDR in the derivation of intermediate duration MRLs and considered in older reviews by US EPA for penta-BDE and octa-BDE. The uncertainty factor applied by US EPA to the individual congeners considered, 3000, includes an additional 10-fold factor to address database deficiencies.

There is no evaluation of a chronic threshold value that would be applicable to all lower BDEs as a group, hence application of the US EPA values requires an assumption that the congeners studied are an appropriate indicator for total lower BDEs. This is likely to be conservative but no more detailed evaluations are available. The individual congener studies by US EPA are noted by NICNAS (2007) to be those within commercial penta-BDE that are of most importance in biomonitoring and environmental sampling.

The lower RfD of 0.0001 mg/kg/day derived by US EPA for BDE-99 and BDE-47, similar to that derived for BDE-153, is recommended for use in the derivation of a soil HIL for lower BDEs. As noted in most other reviews, the available database is poor and limited with respect to identification of a threshold associated with chronic exposures to the group of congeners. Hence, the use of this threshold TRV requires further review and update in the future when further studies are undertaken.

No dermal or inhalation-specific chronic studies or data are available. For the presence of lower BDEs in soil, it is considered appropriate to consider use of the available threshold value for all pathways of exposures.

2.4.3   Recommendation

On the basis of the discussion above, the following toxicity reference values (TRVs) have been adopted for lower BDEs in the derivation of HILs:

Recommendation for Lower BDEs

Oral TRV (TRV_O) = 0.0001 mg/kg/day (US EPA (IRIS 2012)) for BDE-99 and BDE-47) for all pathways of exposure

Dermal absorption factor (DAF) = 0.1 (or 10%) (US EPA 2004)

Intakes allowable from soil (as % of TRV) = 20%

Background intakes from other sources (as % of TRV):

BI_O = 80% for oral and dermal intakes

BIi = 80% for inhalation

Uptake in home-grown produce considered in derivation of HIL A.

2.5   Calculated HILs

On the basis of the above, the following HILs have been derived for lower BDEs (refer to Appendix B for equations used to calculate the HILs and Appendix C for calculations):

HIL Scenario	HIL (mg/kg)	Percentage Contribution from Exposure Pathways			
		Ingestion of Soil/Dust	Ingestion of Home-grown Produce	Dermal Absorption of Soil/Dust	Inhalation (dust)
Residential A	1	39	8	53	<1
Residential B	2	16	--	84	<1
Recreational C	2	27	--	73	<1
Commercial D	10	12	--	88	<1

-- Pathway not included in derivation of HIL

2.6   References

ATSDR 2004, Toxicological Profile for Polybrominated Biphenyls and Polybrominated Diphenyl Ethers, Agency for Toxic Substances and Disease Registry, September 2004.

EU 2003, European Union Risk Assessment Report: Diphenyl Ether, Octobromo Derivative, CAS No: 32536-52-0, EINECS No: 251-087-9, European Union, Brussels.

FSANZ 2007, Polybrominated Diphenyl Ethers (PBDE) in Food in Australia, Study of Concentrations in Foods in Australia including Dietary Exposure Assessment and Risk Characterisation, Food Standards Australia and New Zealand, 2007.

Guan, Y, Sojinu, OSS, Li, S & Yeng, EY 2009, 'Fate of polybrominated diphenyl ethers in the environment the Pearl River Estuary, South China', Environmental Pollution, vol. 157 (2009), pp. 2166–2172.

Health Canada 2006, Polybrominated Diphenyl Ethers (PBDEs), State of the Science Report for a Screening Health Assessment, Health Canada.

Huang, H, Zhang, S, Christie, P, Wang, A & Xie, M 2010, 'Behaviour of Decabromodiphenyl Ether (BDE-209) in the Soil−Plant System: Uptake, Translocation, and Metabolism in Plants and Dissipation in Soil', Environ. Sci. Technol., vol. 44 (2), pp. 663–667.

IARC 1999, Summaries & Evaluations, Decabromodiphenyl oxide, vol. 71 (1999), pp.1365, International Agency for Research on Cancer.

JECFA 2006, Safety Evaluation of Certain Contaminants in Food – Polybrominated Diphenyl Ethers, prepared by the Sixty Fourth Meeting of the Joint FAO/WHO Expert Committee on Food Additives (JECFA), World Health Organization, Geneva.

NEPC 1999, Schedule B (7a), Guideline on Health-Based Investigation Levels, National Environment Protection (Assessment of Site Contamination) Measure, National Environment Protection Council, Australia.

NICNAS 2007, Interim Public Health Risk Assessment of Certain PBDE Congeners, National Industrial Chemicals Notification and Assessment Scheme, Commonwealth of Australia, Sydney, Australia.

RAIS (2010), Risk Assessment Information System, website and database maintained by the Oak Ridge Operations Office, and available from: http://rais.ornl.gov/.

Schecter, A, Harris, TR, Brummitt, S, Shah, N & Paepke, O 2008, 'PBDE and HBCD Brominated Flame Retardants in the USA, Update 2008: Levels in Human Milk and Blood, Food, and Environmental Samples', Epidemiology, vol. 19, Issue 6, pp. S76.

Toms, L, Muelle,r J, Bartkow, M & Symons, R 2006, Assessment of concentrations of polybrominated diphenyl ether flame retardants in indoor environments in Australia, Australian Government Department of the Environment and Heritage, Canberra, Australia.

UNEP 2009, Advanced Report of the Conference of the Parties of the Stockholm Convention on Persistent Organic Pollutants on the Work of its Fourth Meeting, Geneva, 4–8 May 2009, United Nations, Geneva.

US EPA (IRIS 2012), data and information available from the Integrated Risk Information System, an online database, available from http://www.epa.gov/iris/.

US EPA, 2004, Risk Assessment Guidance for Superfund, Volume I: Human Health Evaluation Manual (Part E, Supplemental Guidance for Dermal Risk Assessment), Final, EPA/540/R-99/005, OSWER 9285.7-02EP, July 2004.

3 Shortened forms

ADI	acceptable daily intake
ADWG	Australian Drinking Water Guidelines
AI	adequate intake
ANZECC	Australia and New Zealand Environment and Conservation Council
APVMA	Australian Pesticides and Veterinary Medicines Authority
ATDS	Australian Total Diet Survey
ATSDR	Agency for Toxic Substances and Disease Registry
BA	bioavailability
BI	background intake
BMD	benchmark dose
BMDL	Benchmark dose lower confidence limit
CCME	Canadian Council of Ministers of the Environment
CICAD	Concise International Chemicals Assessment Document
CNS	central nervous system
DAF	dermal absorption factor
DW	dry weight
EA	Environment Agency (England and Wales)
EHC	Environmental Health Criteria
EPA	Environment Protection Authority
FSANZ	Food Standards Australia and New Zealand
GAF	gastrointestinal absorption factor
HCB	hexachlorobenzene
HEC	human equivalent concentration
HED	human equivalent dose
HIARC	Hazard Identification Assessment Review Committee
HIL	health investigation level
HSDB	Hazardous Substances Data Bank
HSL	health screening level
IARC	International Agency for Research on Cancer
IEUBK	Integrated exposure uptake biokinetic model

IRIS	Integrated Risk Information System
JECFA	Joint FAO/WHO Expert Committee on Food Additives
JMPR	WHO/FAO Joint Meeting on Pesticide Residues
LOAEL	lowest observed adverse effect level
LOEL	lowest observed effect level
MF	modifying factor
MoA	mode (or mechanism) of action
MoE	margin of exposure
MRL	maximum residue limit
MRL	minimal risk level
NDI	negligible daily intake
NEPC	National Environment Protection Council
NEPM	National Environment Protection Measure
NHMRC	National Health and Medical Research Council
NOAEL	no observable adverse effect level
NOEL	no observable effect level
NSW DECC	New South Wales Department of Environment and Climate Change
OCS	Office of Chemical Safety
PBDE	polybrominated diphenyl ether
POP	persistent organic pollutant
PTDI	provisional tolerable daily intake
PTMI	provisional tolerable monthly intake
PTWI	provisional tolerable weekly intake
RAIS	Risk Assessment Information System
RDI	recommended daily intake
REL	reference exposure level
RfC	reference concentration
RfD	reference dose
RME	reasonable maximum exposure
SF	slope factor
TC	tolerable concentration

TD	tumorigenic dose
TDI	tolerable daily intake
TRV	toxicity reference value
UF	uncertainty factor
UL	upper limit
UR	unit risk
US EPA	United States Environmental Protection Agency
WHO	World Health Organization
WHO DWG	World Health Organization Drinking Water Guidelines