



Project Summary

Development of Advisory Levels for Polychlorinated Biphenyls (PCBs) Cleanup

Polychlorinated biphenyls (PCBs), commercially known as Aroclors, consist of mixtures of chlorinated biphenyl compounds. Many sites contaminated by PCBs remain contaminated because of PCB persistence in the environment. Although commercial PCB production in the United States has been banned by the Toxic Substances Control Act, continued use in previously existing commercial equipment can result in spills which require cleanup. The Environmental Protection Agency (EPA) has become increasingly involved in the discovery, assessment, and cleanup of these sites.

The purpose of this study is to provide advisory levels for PCB cleanup, and to describe the technical and scientific rationale and methods used in developing these advisory levels for PCBs in contaminated soil. This required the development of exposure and risk assessment methodology related to hazardous waste and spill sites, and analyses of health effects data.

The currently available modeling techniques considered most appropriate are used to estimate exposures. PCBs advisory levels are presented as ranges of values to reflect the difference in soil-air partition coefficients depending on soil type, different types of commercial Aroclors, and variations in the soil ingestion rate.

This Project Summary was developed by EPA's Office of Health and Environmental Assessment, Washington, D.C., to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

The full report of this project summary was prepared in response to a request from the Office of Emergency and Remedial Response (OERR), that the Office of Health and Environmental Assessment (OHEA) develop advisory levels for polychlorinated biphenyls (PCBs) which can be used as guidelines for initiating removal action for sites contaminated with PCBs. Interested offices within EPA, including OERR, have advised OHEA that these advisory levels for PCBs cleanup should be developed based on considerations of public health protection from short-term and long-term exposures. The advisories presented include permissible levels of PCBs in soil corresponding to 10-day and lifetime acceptable intakes.

Exposure routes considered in developing these advisory levels include drinking water, ingestion of PCB-contaminated soil by children and adults, and inhalation of ambient air contaminated with PCBs. Other exposure routes, such as dermal exposure, food intake, and ingestion of fish which have bioaccumulated PCBs, are considered in relation to their importance and their relevance to this project. In view of the high bioaccumulation factor for PCBs, the consideration of bioaccumulation is important in setting PCB levels in surface water in which aquatic animals live. If one of these routes is a controlling factor in relation to the exposure route or human intake considered, the advisories need to be reevaluated.

Chemical Composition

Commercial-grade PCBs, consisting of mixtures of different composition, are sold under the trade name Aroclors. Impurities such as chlorinated dibenzo-

furans and chlorinated naphthalenes are known to exist in commercial PCBs. The sole producer of Aroclors in the United States for the period 1957 to 1972 was the Monsanto Chemical Company. Their products are characterized by four-digit numbers. The first numbers represent the type of molecule (12 = biphenyl-based; 54 = terphenyl-based; 25 or 44 = blends of PCBs and chlorinated terphenyls); and the last two digits refer to the percentage of chlorine by weight. PCB products are also manufactured in other countries, including Germany, France, Japan and the U.S.S.R.

Although one might expect some 140 to 150 separate congeners in an Aroclor, the actual analysis of Aroclor 1248, for example, identified less than 50 peaks using high-resolution gas chromatography. No compounds which can be formed by addition of chlorine rather than substitution were found in a detailed study of PCBs published in 1976. It is suspected that the conditions prevailing during industrial manufacturing of PCBs do not favor the formation of addition compounds, or that these latter compounds might have been destroyed in the step used to purify the Aroclor. The literature data show that even for the same type of Aroclor, the compositions of individual biphenyls vary slightly.

Major PCB components in foreign products bearing the names of Kanechlor and Phenoclor for Japanese and French products, respectively, have been identified. The number of the major components separated from Kanechlor 400 is five, and that from Phenoclor DP6 is seven.

Exposure Assessment

It is likely that not all of the PCBs ingested or inhaled by humans are absorbed. Proper calculations of absorption rate and hence exposure should be based on realistic pharmacokinetics-type models to determine intake. Lack of experimental data with which to estimate the parameters needed in the pharmacokinetics models has prevented their applications to the analysis for PCB absorptions through human exchange boundaries. Future work should consider these models. Although most animal studies (in rats and mice) on the extent of absorption in the gastrointestinal tract show absorption in excess of 90%, there are two experiments on monkeys reporting less than 88% absorption in one case and less than 13% and 40% absorption for a specific congener in another case, based on the analysis of feces and urine.

Vehicles used in administering PCBs were not specified. It is likely that the high adsorption characteristics of PCBs on soil could retard the absorption rate in the human intestinal tract. In the risk analysis performed in the present study, the absorption rate for humans after ingestion of PCB-contaminated soil is considered to be 30%.

Absorption from dermal exposure has been reported to be as significant as from other routes of exposure, but little information is available for the quantitative evaluation of dermal absorption rates. Five percent dermal absorption is assumed for soil contaminants in contact with human skin.

Inhalation studies using PCB aerosols show that the absorption of PCBs from inhalation exposure readily occurs. In the present analysis, an absorption factor of 50% is assumed for absorption of PCB vapors after inhalation into human lungs.

The circumstances under which human exposure occurs are divided into three classes depending on population distribution: (1) Exposure occurs onsite. This can be further subdivided into: (a) sites that are readily accessible to children, and, hence, the soil from which will be subject to ingestion, dermal contact, and inhalation, and (b) sites for which there is no possibility of soil ingestion, and, hence, exposure is only through inhalation; (2) sites which no population is assumed to enter within a radius of 0.1 km from the site; and (3) sites which no population is assumed to enter within a radius of 1 km from the site.

The soil ingestion rates used for Class (1)(a) evaluations are 3 and 0.6 g/day. The former is a value based on data from a study of an adult person with pica, while the latter represents a long-term average value for soil ingestion. If sites are not accessible to populations at distances of 0.1 km or 1 km from the site, as in Classes (2) and (3) above, it is assumed that no ingestion of contaminated soil occurs and the exposure route is that of inhalation.

Emission Evaluation

The emission rate of volatilized PCBs can be considerably reduced by covering the contaminated soil by low-porosity uncontaminated soil or clay material. The reduction in the emission rate will result in a decrease in ambient air concentrations of PCBs by the action of blowing winds. When PCB-contaminated material is directly exposed to the atmosphere, the PCB levels in soil required to maintain

the same level of exposure will be less than those expected when the PCB-contaminated material is covered with low-permeability material of appropriate thickness. The cover would also serve as a deterrent to soil ingestion and direct dermal contact.

The depletion of PCBs from soil caused by volatilization is accounted for in the exposure analysis by solving a partial differential equation simulating PCB vapor diffusion through the soil air-phase pores, and the distribution of PCBs between air and soil phases. Boundary conditions assume that the air-phase resistance is relatively small compared to the diffusional resistance in the soil air-phase pores. The available experimental data reasonably follow the time-emission rate relationship predicted from the models based on this assumption. Since the depletion rate varies over time, it is averaged over the exposure period. Depletion averaged over a period of time should lead to a lesser inhalation exposure than that based on the model, assuming that depletion does not occur.

The worst-case emissions would occur when the contaminated soil is initially exposed to the atmosphere and the soil is contaminated up to the conditions exhibiting saturation vapor pressure. A constant emission rate can be assumed if the vapor-phase concentration maintains a constant value at the surface of soil contamination for time-varying emission rates. Calculations corresponding to Classes (1), (2), and (3) for exposure possibilities with surface contamination are repeated at an assumed 25-cm thickness of a soil cover initially free from PCB contamination. Among many factors affecting the emission rate (including vapor pressure, soil-air partition coefficient, Henry's Law constant, etc.), the value of the soil-air partition coefficient shows the most wide-ranging variation, because of the variation of the experimental soil-water partition coefficient available in the literature for soil textures ranging from 40 to 1,000 cm³/g.

PCB Levels in Soil

The method for determining the permissible PCB levels in soil, which combines the routes of soil ingestion, inhalation, and dermal exposure, has been computerized to avoid the necessity for hand calculations.

The results of these computer calculations are summarized in Tables 1 and 2, which have been prepared using different combinations of the following variables:

Table 1. Permissible PCB Soil Contamination Levels (Uncovered Surface Contamination)

Location and Route of Human Exposure	Permissible Levels ($\mu\text{g PCB/g soil}$) Corresponding to					
	Noncancer Short-Term* Acceptable Intake ($\mu\text{g/day}$) ^b		Cancer Risk Specific Doses ($\mu\text{g/day}$)			
	100 for Child	700 for Adult	0.00175 (10^{-7} Risk)	0.0175 (10^{-6} Risk)	0.175 (10^{-5} Risk)	1.75 (10^{-4} Risk)
<i>On the contaminated site</i>						
-Soil ingestion ^c , inhalation ^a	25-100 ^d	510-730	0.008-0.01	.08-0.1	0.8-2	8-17
-Soil ingestion ^d , inhalation ^a	42-420	2100-3000	0.01-0.06	0.1-0.6	1-6	35-61
-Inhalation only ^a	47-vs ^g	vs	0.01-0.2	0.1-2.0	1-20	77-470
0.1 km from contaminated site -Inhalation only ^a	vs	vs	2.0-220	90-2.2x10 ⁴	7.7x10 ³ -vs	8.7x10 ⁵ -vs
1 km from contaminated site -Inhalation only ^a	vs ^g	vs	220-1.3x10 ³	2.2x10 ⁴ -1.3x10 ⁵	vs	vs

*Short-term \approx 10-day intake.

^bBased on average weights of 10 and 70 kg for a child and an adult, respectively.

^cChildren ages 1-5, with pica (consuming 3 g soil/day).

^dChildren ages 1-5, without pica (consuming 0.6 g soil/day).

^eInhalation rates are assumed to be 20 m³/day for the short-term and longer-term noncancer exposures; all other (more chronic) exposures assumed to be 10 m³/day as a result of 182 days' exposure per year.

^fRanges result in each case because (1) four PCBs (1242, 1248, 1254, 1260) are considered, each with a different vapor pressure, and (2) high and low values for soil-air partition coefficient are used in the calculations.

^gvs denotes no theoretical upper-bound limit. Practical reasons require no free-flowing PCB liquids for the limit.

- (1) Surface contamination representing a situation where the contaminated soil surface has been left uncovered after removal action.
- (2) 25-cm (10-inch) clean cover applied, representing a situation in which clean soil material is used on top of the contaminated soil surface.
- (3) Two different soil ingestion rates (3 and 0.6 g/day) for Class (1) (a), corresponding to sites accessible to children.
- (4) Different acceptable intake (AI) levels (short-term AI, and AIs at different cancer risk levels).
- (5) Four Aroclors (Aroclor 1242, 1248, 1254, and 1260).
- (6) Two selected values of the soil-air partition coefficient, representing the high and low values.
- (7) Exposures for 10 days after cleanup or spill of contaminants for short-term advisories.

Table 1 shows the range of values for permissible PCB concentrations in soil when the soil is contaminated up to the surface in contact with the atmosphere and is left uncovered. Table 2 represents the case where the contaminated soil left at the site, or after remediation, is covered with a 25-cm (10-inch) clean soil layer. The ranges in both tables result from the use of four Aroclors and the use of high and low values for the soil-air partition coefficient. Other factors reflected in the ranges are differences in vapor pressures and Henry's Law constants for each Aroclor.

Results

The symbol "vs" in Tables 1 and 2 indicates that no upper-bound limit for PCB concentrations in soil can be derived from the exposure evaluation, because the PCB concentration in soil is above the

vapor saturation concentration. There are two reasons for such a result. First, the emission rate cannot exceed the upper-bound value which can be expected when the air-phase concentration of PCBs at the contaminated soil surface is maintained at the vapor saturation point. The concentration at the vapor saturation point corresponds to the vapor pressure concentration. Second, when the cover is applied, not only is the emission rate retarded, but also the concentration of PCBs in soil being ingested is controlled by the amount of PCBs adsorbed on soil in equilibrium with the air phase being emitted. Therefore, the concentration of PCBs in the initially clean soil material cannot exceed the concentration in equilibrium with saturated vapor.

In actuality, the "no upper limit," or the level above vapor saturation, designated by vs, should be interpreted with great care. The assumptions used in the ex-

Table 2. Permissible PCB Soil Contamination Levels (25-cm-Thick Clean Cover)

Location and Route of Human Exposure	Permissible Levels ($\mu\text{g PCB/g soil}$) Corresponding to					
	Noncancer Short-Term ^a Acceptable Intake ($\mu\text{g/day}$) ^b		Cancer Risk Specific Doses ($\mu\text{g/day}$)			
	100 for Child	700 for Adult	0.00175 (10^{-7} Risk)	0.0175 (10^{-6} Risk)	0.175 (10^{-5} Risk)	1.75 (10^{-4} Risk)
<i>On the contaminated site</i>						
-Soil ingestion ^c , inhalation ^e	110-200 ^f	800-1400	0.01-0.2	0.1-2.0	1-17	22-vs
-Soil ingestion ^d , inhalation ^e	450-vs ^g	3100-vs	0.02-0.6	0.2-6.0	1.0-48	93-vs
-Inhalation only ^e	vs	vs	0.02-1.0	0.2-vs	2.0-vs	770-vs
0.1 km from contaminated site -Inhalation only ^e	vs	vs	1-vs	620-vs	vs	vs
1 km from contaminated site -Inhalation only ^e	vs	vs	vs	vs	vs	vs

^aShort-term \cong 10-day intake.^bBased on average weights of 10 and 70 kg for a child and an adult, respectively.^cChildren ages 1-5, with pica (consuming 3 g soil/day).^dChildren ages 1-5, without pica (consuming 0.6 g soil/day).^eInhalation rates are assumed to be 20 m³/day for the short-term and longer-term noncancer exposures, all other (more chronic) exposures assumed to be 10 m³/day as a result of 182 days' exposure per year.^fRanges result in each case because (1) four PCBs (1242, 1248, 1254, 1260) are considered, each with a different vapor pressure, and (2) high and low values for soil-air partition coefficient are used in the calculations.^gvs denotes no theoretical upper-bound limit. Practical reasons require no free-flowing PCB liquids for the limit.

posure evaluation are critical. They include but are not limited to: (1) no soaking of clean cover by liquid PCBs for the thickness of 25 cm; (2) no disturbance of cover material by construction activities or children digging the ground; (3) no exposure to initial spills when 25 cm of clean cover (Table 2) is assumed; (4) no population enters the area within the respective radius of distances from the site; and (5) the cover material is at least equivalent to soil material.

From a practical point of view, the first assumption is tantamount to requiring the presence of no free liquids in the soil, which may otherwise result in the phenomenon of "wicking." Since the ranges shown in Tables 1 and 2 are dependent upon the type of Aroclors and the values of the soil-air partition coefficient, site-specific or Aroclor-specific information should be used to establish an appropriate level of PCBs for that particular condition. Computer outputs

for the selected Aroclors under the ranges and conditions of common environmental concern can be used to find the permissible concentrations in soil suitable to particular situations.

Table 1, for example, can be interpreted as follows:

(1) When the site is amenable to access by children with possibilities of ingesting the contaminated soil exposed to the atmosphere, and when exposure occurring to the children by inhalation and dermal contact is accounted for, the permissible PCB levels in soil should range from 25 to 100 $\mu\text{g/g}$ and 42 to 420 $\mu\text{g/g}$ for prevention of noncancer effects from 10-day exposure for a child with an average weight of 10 kg ingesting soil at the rates of 3 and 0.6 g/day, respectively. For cancer effects, permissible levels in soil for a lifetime exposure to PCBs resulting from ingestion of and dermal contact with contaminated soil and inhalation of contaminated air should range

from 0.08 to 0.1 $\mu\text{g/g}$ and 0.1 to 0.6 $\mu\text{g/g}$, corresponding to an upper-bound risk estimate of 10^{-6} at assumed soil ingestion rates of 3 and 0.6 g/day, respectively. The specific level will depend on the types of Aroclor present, the likely ingestion rate, and the extent of soil-air partitioning. For sites in which there is no possibility of soil ingestion, PCB levels in soil, based on the inhalation route only, should range from 47 $\mu\text{g/g}$ to no limit value for a 10-day exposure for a child with an average weight of 10 kg, and correspond to no limit value for an adult with an average weight of 70 kg. The permissible levels of PCBs in soil, based on the inhalation pathway only, range from 0.1 to 2 $\mu\text{g/g}$, corresponding to a lifetime AI at a risk factor of 10^{-6} . Again, the level will be dictated by the types of Aroclor present and the specific characteristics of the site involved.

(2) If there is no possibility of a population entering the contaminated site within

a radius of 0.1 km from the site, the PCB levels in soil can remain at no limit value and 90 to 2.2×10^4 $\mu\text{g/g}$, without exceeding 10-day AI and lifetime AI at 10^{-6} risk, respectively.

Similar interpretations can be made for the results applicable to sites without affected population up to 1 km from the site, and to the carcinogenic risks listed at 10^{-4} , 10^{-5} and 10^{-7} .

Conclusion

The short-term AI levels (100 $\mu\text{g/g}$ day for a child and 700 $\mu\text{g/g}$ day for an adult) used to develop 10-day advisories based on noncancer effects are derived from animal studies, which collectively indicate

that the experimental threshold for adverse effects of Aroclor 1254 is at or near a dose of 1.0 $\mu\text{g/kg}$ body weight. Using this dose as a No Observed Adverse Effect Level and a safety factor of 100, the 10-day AI levels for noncancer effects described above (100 and 700 $\mu\text{g/day}$) were computed. The permissible concentrations of PCBs in soil are calculated from multimedia exposure assessments by requiring that the total PCBs intake rate from pertinent exposure pathways do not exceed these AIs. Advisory levels for 1-day and lifetime noncancer effects cannot be derived at this time because of the insufficiency of available data. However, in view of the experimental duration, the 10-day advisories may well be used for the 1-day advisories.

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The complete report, entitled "Development of Advisory Levels for Polychlorinated Biphenyls (PCBs) Cleanup," (Order No. PB 86-232 774/AS; Cost: \$22.95, subject to change) will be available only from:

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