

The Epidemiology of PCBs

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I. Summary

Twenty four published and unpublished reports covering 21 epidemiologic studies of human exposure to PCBs were reviewed and evaluated. The studies showed that high occupational exposures to PCBs have resulted in chloracne and dermatitis. Alterations in liver and fat metabolism were found in most studies that examined these functions, but there was no clinical illness associated with these alterations or with level and duration of exposure to PCBs. Studies of mortality rates in exposed populations have shown no pattern of cancer deaths related to PCB exposure.

II. Introduction

This is a review and evaluation of the epidemiologic evidence concerning the health effects of exposure to PCBs, particularly at levels that do not cause acute toxic effects. A study is considered "epidemiologic evidence" if it measures, directly or indirectly, the differences in the risk of ill health among populations with different exposures to PCBs.

In the past several decades there have been many clinical studies of the effects of heavy exposures to PCBs (e.g. Von Wedel et al [1], Schwartz [2]). Such studies are extremely useful in identifying the kinds of effects that should be investigated. However, they do not address the question of the risk of incurring such effects, and are therefore not included in this review.

The studies reviewed here fall into three categories. First, there are studies of accidental heavy exposures and the resulting acute and chronic effects. In each case the study was prompted by an outbreak of illness or the occurrence of a death in an exposed population, after which the population was studied.

Second, there are studies of the relationship between exposure to PCBs and the resulting body burden of PCBs in serum or adipose tissue. Strictly speaking these are not epidemiologic studies since they do not deal with health effects. However, if a relationship between level of exposure and body burden cannot be verified, the interpretation of epidemiologic studies becomes difficult if not impossible.

The third category is studies that were done because the populations in question were known or suspected to be exposed to PCBs, rather than because some untoward health outcome had been observed first.

Many published reports combine some or all of these types of investigations. In the sections that follow, we consider first the studies of accidental overexposure, second the studies of PCB exposure versus body burden, and third the epidemiologic studies of exposed populations. In the latter section the discussion will be organized with respect to the health effects that were investigated. These are (a) dermatologic symptoms, (b) biochemical alterations, (c) other symptoms and illnesses, (d) carcinogenicity.

III. Accidental Heavy Exposures

Two epidemiologic studies of accidental exposure have been reported. The first, by Meigs et al [3] in 1954, described an outbreak of chloracne in a plant in which a process change had introduced an unspecified PCB compound into the work environment. Breathing zone levels of PCB were stated to be 0.1 mg/cum. Seven of 14 exposed workers developed chloracne, but liver function tests were normal in six of these, with some borderline abnormalities in the seventh. The chloracne disappeared after treatment, and the single borderline liver function abnormality improved, but did not disappear after 13 months. Improved process control prevented any recurrence.

Although the estimated PCB level must be accepted with reservation because of the state of the art at that time, it is clear that the chloracne resulted from the PCB exposure. Given the lack of controls and the small rate of abnormal liver function, it is unlikely that the PCB exposure had any connection with the liver function findings.

The second incident is the now famous Yusho incident in 1968 which has been documented in many reports (Kuratsune et al [4], Urabe et al [5]), in which some thousand Japanese became ill after eating cooking oil which had been contaminated with Kanechlor 400, a PCB compound of Japanese manufacture.

The most common acute symptoms observed were hyperpigmentation and acne-like lesions, discharge from the eyes, central nervous system symptoms, and vomiting and diarrhea. There was a

dose-response relationship between the amount of oil ingested and the proportion of persons reporting symptoms. Three years later about half the patients had improved, but still had symptoms. Six years later many patients still reported such symptoms as headache, stomach pain, numbness of the extremities, joint pain and respiratory symptoms [5].

Out of ten live births to women affected by Yusho, nine showed hyperpigmentation and most had increased eye discharges. These symptoms later disappeared. Although there have been reports of premature eruption of teeth (two children out of a series of 13) and unusually wide fontanelles and sagittal sutures (three out of 13) it is not at all clear that these findings represent any more than the normal variation to be expected, since no control observations were made (Funatsu et al [6]).

In general, laboratory tests of the Yusho victims showed elevated serum triglyceride levels, low serum cholesterol in serious cases, and elevated SGOT and SGPT levels in serious cases (Higuchi [7]).

As of the end of 1977, 51 deaths among Yusho patients had been identified [5]. The percentage of cancer deaths (35.4) exceeded that of the prefecture in which the deaths occurred (21.1). However, the figures do not appear to be very useful for several reasons. First, after the original incident, the criteria for diagnosis of Yusho had been changed, so that it is impossible to determine the denominator which produced this number. The completeness of ascertainment of the deaths is unknown. In addition, no adjustment for age appeared to have been made in the

above comparison. Finally, the average elapsed time from exposure to death was less than ten years, and cannot be calculated precisely because the dates of death are not provided. This may well be too short a period for cancers resulting from the exposure to show up.

Although the Yusho incident represented a massive ingestion of PCBs, recent reanalysis of the cooking oil and of the estimated intake by the patients shows that the exposure to polychlorinated dibenzofurans (PCDFs) and polychlorinated quater-phenyls (PCQs) was about equal to the exposure to PCBs, and current determinations of PCQs in blood and other tissues of Yusho patients have shown levels similar to that of PCBs [8]. It is therefore doubtful whether any generalization can be made from this incident to lower level environmental or occupational exposures to PCBs.

IV. Environmental Levels and Body Burdens

Two studies of the relationship between ingestion of PCBs and blood levels of PCBs have been reported (Michigan Dept. of Public Health [9] and Kreiss et al [10]). In each case the study was concerned with ingestion of fish known to contain relatively high levels of PCBs. In the first, an association was found between blood PCBs and exposure level as estimated by the amount of Lake Michigan sport fish consumed. In the second the relationship between blood PCBs and a complex of factors was examined in a population in an area with high levels of environmental contamination. Age, sex and fish consumption, in that order of importance, were associated with blood levels of PCBs. To the extent that fish consumption measures ingestion of PCBs, these studies confirm that blood PCBs are a function of ingestion of PCBs as well as of age and sex. Other associated variables were examined in [10] but will be discussed in the following section.

A number of studies of blood PCBs and exposure to atmospheric PCBs have been made, most of them in conjunction with studies of health effects. The portions of the studies relevant to this section are reviewed here.

There are three types of studies. The first compares groups which have had different exposure levels as estimated from process considerations or environmental measurements. For convenience such a study design will be called Type A. The second, which we will designate Type B, measures the change over time in a single group after PCBs have been removed from the environment (or after

the group has left the environment). The third, Type C, compares groups that have had different durations of exposure. Often the same report will contain more than one type of study. For example, an exposed group may be compared with an unexposed group (Type A) and within the exposed group long term exposed workers may be compared with short term workers (Type C).

The measure of body burden has in most cases been a single number representing, depending on the study, blood PCBs, plasma PCBs, serum PCBs (all of which are called "blood" PCBs in this review), or level of PCBs in adipose tissue. Analytic methods have varied over time and among investigators. More recently measures of body burden have sought to determine separately the levels of higher chlorinated biphenyls (5 or more chlorine atoms per molecule) and lower chlorinated biphenyls.

Table 1 lists the studies considered in this section, with the type of design and whether or not separate determinations of higher and lower chlorinated biphenyls were made. All of the studies except Baker et al are occupational.

All of the Type A studies agree in showing a higher body burden of PCBs in populations with higher environmental exposure, except for one anomaly in Baker et al. There, persons exposed to sludge containing PCBs had slightly lower blood levels than the controls, on the average. However, the sludge exposed persons and the controls were not matched for age, which Kreiss et al showed to be the most important factor associated with blood PCB level. It therefore appears unequivocal that higher exposure to PCBs means a higher body burden, all other things being equal.

The Type B studies appear at first glance to be more equivocal (Table 2). Two studies show a decrease when exposure ceased or decreased and two do not. However, the studies showing no decrease remeasured their study groups within a month or two after exposure changed. The ones showing a decrease remeasured after three months and one year.

The fact that Ouw et al found no decrease after two months while Kitamura et al found over a 50 percent decrease after three months gives rise to some uneasiness. However, in the former study exposure was decreased but still present, while in the latter study PCB use had ceased. Ouw et al also suggest that after exposures in their study plant had decreased, workers did not wear gloves as recommended, so that the blood PCB levels may have resulted from skin contact.

Table 3 shows the findings for the Type C studies other than Maroni et al and Smith et al that is, for those that compared duration of exposure with a single measurement of blood PCB level. The results are not consistent. The study of Baumgarner et al found very low levels (average 4 ppb) in exposed workers, which may have accounted for their failure to find a relationship with duration. On the other hand the exposed workers in Hasegawa et al had an average level of 370 ppb and still showed no relationship with duration.

The studies of Maroni et al and Smith et al suggest a possible explanation. Maroni et al made separate comparisons of high chlorinated PCBs and low chlorinated PCBs between workers with present and past exposures. They found differences in the

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11. GLOSSARY

Acute Exposure--Exposure to a chemical for a duration of 14 days or less, as specified in the Toxicological Profiles.

Bioconcentration Factor (BCF)--The quotient of the concentration of a chemical in aquatic organisms at a specific time or during a discrete time period of exposure divided by the concentration in the surrounding water at the same time or during the same time period.

Carcinogen--A chemical capable of inducing cancer.

Ceiling value (CL)--A concentration of a substance that should not be exceeded, even instantaneously.

Chronic Exposure--Exposure to a chemical for 365 days or more, as specified in the Toxicological Profiles.

Developmental Toxicity--The occurrence of adverse effects on the developing organism that may result from exposure to a chemical prior to conception (either parent), during prenatal development, or postnatally to the time of sexual maturation. Adverse developmental effects may be detected at any point in the life span of the organism.

Embryotoxicity and Fetotoxicity--Any toxic effect on the conceptus as a result of prenatal exposure to a chemical; the distinguishing feature between the two terms is the stage of development during which the insult occurred. The terms, as used here, include malformations and variations, altered growth, and in utero death.

Frank Effect Level (FEL)--That level of exposure which produces a statistically or biologically significant increase in frequency or severity of unmistakable adverse effects, such as irreversible functional impairment or mortality, in an exposed population when compared with its appropriate control.

EPA Health Advisory--An estimate of acceptable drinking water levels for a chemical substance based on health effects information. A health advisory is not a legally enforceable federal standard, but serves as technical guidance to assist federal, state, and local officials.

Immediately Dangerous to Life or Health (IDLH)--The maximum environmental concentration of a contaminant from which one could escape within 30 min without any escape-impairing symptoms or irreversible health effects.

Intermediate Exposure--Exposure to a chemical for a duration of 15-364 days, as specified in the Toxicological Profiles.

Immunologic Toxicity--The occurrence of adverse effects on the immune system that may result from exposure to environmental agents such as chemicals.

In vitro--Isolated from the living organism and artificially maintained, as in a test tube.

In vivo--Occurring within the living organism.

Key Study--An animal or human toxicological study that best illustrates the nature of the adverse effects produced and the doses associated with those effects.

Lethal Concentration(10) (LC10)--The lowest concentration of a chemical in air which has been reported to have caused death in humans or animals.

Lethal Concentration(50) (LC50)--A calculated concentration of a chemical in air to which exposure for a specific length of time is expected to cause death in 50% of a defined experimental animal population.

Lethal Dose(10) (LD10)--The lowest dose of a chemical introduced by a route other than inhalation that is expected to have caused death in humans or animals.

Lethal Dose(50) (LD50)--The dose of a chemical which has been calculated to cause death in 50% of a defined experimental animal population.

Lowest-Observed-Adverse-Effect Level (LOAEL)--The lowest dose of chemical in a study or group of studies which produces statistically or biologically significant increases in frequency or severity of adverse effects between the exposed population and its appropriate control.

Lowest-Observed-Effect Level (LOEL)--The lowest dose of chemical in a study or group of studies which produces statistically or biologically significant increases in frequency or severity of effects between the exposed population and its appropriate control.

Malformations--Permanent structural changes that may adversely affect survival, development, or function.

Minimal Risk Level--An estimate of daily human exposure to a chemical that is likely to be without an appreciable risk of deleterious effects (noncancerous) over a specified duration of exposure.

Mutagen--A substance that causes mutations. A mutation is a change in the genetic material in a body cell. Mutations can lead to birth defects, miscarriages, or cancer.

Neurotoxicity--The occurrence of adverse effects on the nervous system following exposure to a chemical.

No-Observed-Adverse-Effect Level (NOAEL)--That dose of chemical at which there are no statistically or biologically significant increases in frequency or severity of adverse effects seen between the exposed population and its appropriate control. Effects may be produced at this dose, but they are not considered to be adverse.

No-Observed-Effect Level (NOEL)--That dose of chemical at which there are no statistically or biologically significant increases in frequency or severity of effects seen between the exposed population and its appropriate control.

Permissible Exposure Limit (PEL)--An allowable exposure level in workplace air averaged over an 8-h shift.

q_1^* --The upper-bound estimate of the low-dose slope of the dose-response curve as determined by the multistage procedure. The q_1^* can be used to calculate an estimate of carcinogenic potency, the incremental excess cancer risk per unit of exposure (usually $\mu\text{g/L}$ for water, mg/kg/day for food, and $\mu\text{g/m}^3$ for air).

Reference Dose (RfD)--An estimate (with uncertainty spanning perhaps an order of magnitude) of the daily exposure of the human population to a potential hazard that is likely to be without risk of deleterious effects during a lifetime. The RfD is operationally derived from the NOAEL (from animal and human studies) by a consistent application of uncertainty factors that reflect various types of data used to estimate RfDs and an additional modifying factor, which is based on a professional judgment of the entire database on the chemical. The RfDs are not applicable to nonthreshold effects such as cancer.

Reportable Quantity (RQ)--The quantity of a hazardous substance that is considered reportable under CERCLA. Reportable quantities are: (1) 1 lb or greater or (2) for selected substances, an amount established by regulation either under CERCLA or under Sect. 311 of the Clean Water Act. Quantities are measured over a 24-h period.

Reproductive Toxicity--The occurrence of adverse effects on the reproductive system that may result from exposure to a chemical. The toxicity may be directed to the reproductive organs and/or the related endocrine system. The manifestation of such toxicity may be noted as alterations in sexual behavior, fertility, pregnancy outcomes, or modifications in other functions that are dependent on the integrity of this system.

Short-Term Exposure Limit (STEL)--The maximum concentration to which workers can be exposed for up to 15 min continually. No more than four excursions are allowed per day, and there must be at least 60 min between exposure periods. The daily TLV-TWA may not be exceeded.

Target Organ Toxicity--This term covers a broad range of adverse effects on target organs or physiological systems (e.g., renal, cardiovascular) extending from those arising through a single limited exposure to those assumed over a lifetime of exposure to a chemical.

Teratogen--A chemical that causes structural defects that affect the development of an organism.

Threshold Limit Value (TLV)--A concentration of a substance to which most workers can be exposed without adverse effect. The TLV may be expressed as a TWA, as a STEL, or as a CL.

Time-weighted Average (TWA)--An allowable exposure concentration averaged over a normal 8-h workday or 40-h workweek.

Uncertainty Factor (UF)--A factor used in operationally deriving the RfD from experimental data. UFs are intended to account for (1) the variation in sensitivity among the members of the human population, (2) the uncertainty in extrapolating animal data to the case of humans, (3) the uncertainty in extrapolating from data obtained in a study that is of less than lifetime exposure, and (4) the uncertainty in using LOAEL data rather than NOAEL data. Usually each of these factors is set equal to 10.

APPENDIXES

APPENDIX A: PEER REVIEW

A peer review panel was assembled for PCBs. The panel consisted of the following members: Dr. Rolf Hartung, Chairman, Toxicology Program, University of Michigan; Dr. James Olson, Associate Professor of Pharmacology and Therapeutics, SUNY Buffalo; Dr. Shane Que Hee, Associate Professor of Environmental Health, University of Cincinnati Medical Center. These experts collectively have knowledge of PCB's physical and chemical properties, toxicokinetics, key health end points, mechanisms of action, human and animal exposure, and quantification of risk to humans. All reviewers were selected in conformity with the conditions for peer review specified in the Superfund Amendments and Reauthorization Act of 1986, Section 110.

A joint panel of scientists from ATSDR and EPA has reviewed the peer reviewers' comments and determined which comments will be included in the profile. A listing of the peer reviewers' comments not incorporated into the profile, with a brief explanation of the rationale for their exclusion, exists as part of the administrative record for this compound. A list of databases reviewed and a list of unpublished documents cited are also included in this record.

APPENDIX B: FEDERAL REGISTER ANNOUNCEMENT

**DEPARTMENT OF HEALTH AND HUMAN SERVICES
AGENCY FOR TOXIC SUBSTANCES AND DISEASE REGISTRY
ENVIRONMENTAL PROTECTION AGENCY
(ATSDR-2; FRL-3269-7)**

NOTICE OF AVAILABILITY OF TOXICOLOGICAL PROFILES

AGENCIES: Department of Health and Human Services (DHHS): Agency for Toxic Substances and Disease Registry (ATSDR); and Environmental Protection Agency (EPA).

ACTION: Notice.

SUMMARY: The Superfund Amendments and Reauthorization Act (SARA) (Public Law 99-499) amends the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA or Superfund) (42 U.S.C. 9601 et seq.) by establishing certain requirements for the Agency for Toxic Substances and Disease Registry (ATSDR) of DHHS and EPA with regard to hazardous substances which are most commonly found at facilities on the CERCLA National Priorities List (NPL). Among these statutory requirements is a mandate for the Administrator of ATSDR to prepare toxicological profiles for each substance previously included on the first priority list of 100 chemicals. The list identified the first 100 chemicals which both Agencies determined posed the most significant potential threat to human health. This list was published in the Federal Register on April 17th, 1987 (52 FR 12866) as required by SARA section 110.

This notice announces the expected availability dates of the first 25 draft toxicological profiles for review and comment.

AVAILABILITY: The following draft toxicological profiles are expected to be publicly available by the date indicated:

Date/Profile	CAS #
October 17, 1987:	
Benzo(a)anthracene	56-55-3
Benzo(a)pyrene	50-32-8
Beryllium	7440-41-7
Chloroform	67-66-3
Chromium	7440-47-3
Chrysene	218-01-9
Dibenzo(a,h)anthracene	53-70-3
Heptachlor/Heptachlor epoxide	76-44-8 / 1024-57-3
Nickel	7440-02-0
N-Nitrosodiphenylamine	86-30-6
October 29, 1987:	
Aldrin/dieldrin	309-00-2 / 60-57-1
Arsenic	7440-38-2
Benzo(b)fluoranthene	205-99-2
PCBs - Aroclor 1260, 1254, 1248,	11096-82-5, 11097-69-1, 12672-29-6
1242, 1232, 1221,	53469-21-9, 11141-16-5, 11104-28-2
1016	12674-11-2
2,3,7,8- Tetrachlorodibenzo-p-dioxin	1746-01-6
November 5, 1987	
Benzene	71-43-2
Bis(2-ethylhexyl)phthalate	117-81-7
Cadmium	7440-43-9
1,4-Dichlorobenzene	106-46-7
Methylene chloride	75-09-2
November 30, 1987	
Cyanide	57-12-5
Lead	7439-92-1
Tetrachloroethylene	127-18-4
Trichloroethylene	79-01-6
Vinyl chloride	75-01-4

A full 90-day public comment period will be provided for each profile, starting from the actual release date. The close of the comment period for each draft profile will be indicated on the front of each profile.

Requests for draft toxicological profiles should be sent to:

Ms. Georgi Jones
Director, Office of External Affairs
Agency for Toxic Substances and Disease Registry
Chamblee 28 South
1600 Clifton Rd.
Atlanta, GA 30333

Specify the profiles you wish to review. One copy of each profile requested will be forwarded, free of charge, as they become available. In the case of undue delays, requestors will be notified.

Five copies of all comments should be sent to Ms. Jones at the above address by the end of the comment period. All written comments and the draft profiles will be available for public inspection at the Agency for Toxic Substances and Disease Registry (ATSDR), Building 28 South, Room 1103, 4770 Buford Highway, NE, Chamblee, GA, from 8am to 4:30pm, Monday through Friday, except legal holidays. Written comments and other data submitted in response to this notice and the draft toxicological profiles should bear the docket control number ATSDR-2.

SUPPLEMENTARY INFORMATION:

I. BACKGROUND

On October 17, 1986, the President signed the Superfund Amendments and Reauthorization Act of 1986 (Public Law 99-499), which extends and amends the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA or Superfund, 42 U.S.C. 9601 et seq.).

Section 110 of SARA amends section 104(i) of CERCLA by establishing requirements for the preparation of: (1) lists of hazardous substances in order of priority, (2) toxicological profiles of those substances, and (3) a research program to fill data gaps associated with the substances.

In compliance with section 104(i)(2)(A) of CERCLA, ATSDR and EPA published on April 17, 1987 (52 FR 12866) the first priority list of 100 hazardous substances. This priority list of 100 was further broken down into four groups of 25 chemicals. The first group of 25 was to be the subject of the second phase of the requirements, i.e., the development of the first set of toxicological profiles. Section 104(i)(3) of CERCLA spells out the content of these profiles and the timetable by which they must be developed. Profiles on at least 25 substances on the first priority list were to be completed within one year of the enactment of SARA (by October 17, 1987). The remaining seventy-five are to be completed at a rate of at least twenty-five per year with the total 100 completed within four years after the enactment of the SARA amendments. Revision and republication is mandated as necessary but no less often than once every three years.

Each profile is required to include an examination, summary and interpretation of available toxicological information and epidemiologic evaluations. This information and data are to be used to ascertain the levels of significant human exposure for the substance and the associated health effects. The profiles must also include a determination of whether adequate information on the health effects of each substance is available or in the process of development. The Agencies' intention is that this information be used to identify the key toxicological testing needs that when filled will improve our ability to define significant human exposure levels.

The toxicological profiles are to be provided to the States and made available to the public. The profiles are to be prepared in accordance with the guidelines developed by ATSDR and EPA. These guidelines were published along with the priority list of 100 in the April 17, 1987 Federal Register Notice (52 FR 12870).

This current notice announces the projected availability dates of the first 25 draft toxicological profiles. The documents have undergone extensive internal review and have been subject to scientific and technical peer review by outside experts. We are now announcing their availability and encouraging public participation and comment on the further development of these profiles. Although the profiles will not be completed by the October 17, 1987 deadline, we believe that the extra time given to peer review and public review and comment is important to the development of quality profiles of scientific merit.

Although we are reasonably confident that the key studies for each of the 25 substances were considered during the profile development process, this *Federal Register* notice solicits any significant studies, including unpublished data, which may aid the revision of these draft profiles.

II. LEVELS OF SIGNIFICANT HUMAN EXPOSURE

The setting of specific levels of significant human exposure has presented a unique set of problems. The significance of a specific level of a hazardous substance depends on the context in which that level is evaluated. For example, a low level that may be insignificant with respect to causing acute, immediately debilitating symptoms may be highly significant with respect to causing gradual, chronic effects over a longer term. Since these profiles are intended for use by a diverse group of people who have different situations in which to interpret the significance of specific levels, it was considered appropriate at this time to describe the range of exposures over which effects may occur (where data are available), and to allow the user to make determinations as to which type of effect is significant in any particular instance. A format for graphically displaying the levels of significant human exposure has been developed and is used in the profiles to present the ranges over which effects may be observed.

We encourage public comment and recommendations on this specific issue.

III. SOLICITATION OF PUBLIC COMMENT

We are soliciting public comment on all phases of the development of the toxicological profiles. A previous *Federal Register* notice, published on April 17, 1987 (52 FR 12866) solicited comment on the first priority list of hazardous substances. We are currently reviewing those comments and are evaluating the impact that those comments may have on the priority list and the methods used in its development.

As the first 25 toxicological profiles become available in draft form, we are eager to provide them to the States, industry, public health professionals, scientists and the general public. We welcome comment and feedback on the content of the profiles; the format and scope of the documents; the process used in the development of the levels of significant human exposure and the overall process used in the development of the profiles.

There are specific items that we would like to draw to the attention of the reader and would strongly encourage as candidates for close attention during the comment period.

A. PUBLIC HEALTH STATEMENT

The draft profiles include a public health statement which is intended to provide the lay public with a concise statement of the general health risks associated with the chemical of concern. The summary as originally planned should be able to stand alone. If removed from the rest of the document, it should still be capable of conveying

to the public the substantive health concerns associated with the substance. We are also considering the development of more abbreviated versions of the public health statements and are evaluating a number of different formats. This notice specifically invites comments on the existing public health effects statements in the draft profiles and solicits recommendations for alternative approaches.

B. DATA/STUDIES USED IN THE DEVELOPMENT OF THE PROFILES

In general, and for each chemical-specific profile, have the appropriate studies been used in the development of these documents? Our concern here is that we capture the critical, or "key", studies but not miss other data that may be important in the valid evaluation of the toxicological profile chemicals.

C. FORMAT AND CONTENT OF THE PROFILES

The draft profiles represent our best effort to provide the information required by Section 104 (1)(3) of CERCLA in the most useful format for the various identified users of the profiles, given the constraints of the tight timeframe. Every effort has been made to define sections clearly and to format the documents in such a way that they can be used as resource documents by many different audiences. We specifically request comment on the format and content of the initial set of profiles, including how the format might be modified for subsequent sets of profiles.

D. LEVELS OF SIGNIFICANT HUMAN EXPOSURE

What is the most useful way of presenting this type of information? For this first generation of profiles we have selected a graphic presentation that reflects a "range" of values that covers both upper and lower bounds of effect levels. Is this more useful than a single number? Are there other ways of presenting this type of information that would be more useful to the eventual user?

E. IDENTIFICATION OF SIGNIFICANT DATA GAPS

The process used to develop the draft profiles has resulted in the identification of the full range of health effects data gaps associated with each chemical. However, depending on individual circumstances some subset of the identified data gaps may be essential in determining levels of significant exposure, while other data gaps may be less immediate. ATSDR, EPA, and the National Toxicology Program (NTP) have been exploring ways to identify the critical data elements that are needed to establish significant human exposure levels. This notice specifically requests comment and suggestions for approaching this phase of the toxicological profile process.

not detected (Jensen and Sundstrom 1974). As both of these compounds are found in commercial PCB mixtures and in the environment, the presence of the 2,2',4,4',5,5'-hexa-CB congener in adipose tissue appears to be related to resistance to metabolism (EPA 1987a). That this congener is not metabolized or is minimally metabolized is also indicated by the finding that the blood concentration of this congener decreased only 10% over 300 to 500 days (Chen et al. 1982) and by the results of in vitro metabolism studies with human liver microsomes (Schnellman et al. 1983, 1984).

There were lower concentrations of PCBs with unsubstituted 3,4-positions on at least one of the phenyl rings than PCBs with substitutions in the 2,4- or 3,4- positions on both rings in the blood and adipose tissue from capacitor-manufacturing facility workers (Wolff et al. 1982a).

4.2.3.2 Animal

The metabolism of PCBs has been investigated in numerous studies with animals and reviewed by EPA (1987a) and Drill et al. (1981). A variety of substrates have been tested, and the PCBs were usually administered by the oral or parenteral routes. General findings of these studies reported by EPA (1987a) are presented below.

Phenolic products are the major PCB metabolites although sulfur-containing metabolites (e.g., methylsulfones), trans-dihydrodiols, polyhydroxylated PCBs, and methyl ether derivatives have also been identified. Although the effects of chlorine substitution patterns on sites of oxidation have not been studied systematically, EPA (1987a) suggests the following:

1. Hydroxylation is favored at the para position in the least chlorinated phenyl ring unless this site is sterically hindered (i.e., 3,5-dichloro substitution).
2. In the lower chlorinated biphenyls the para position of both biphenyl rings and carbon atoms that are para to the chloro substituent are all readily hydroxylated (Sparling et al. 1980).
3. The availability of two vicinal unsubstituted carbon atoms (particularly C5 and C4 in the biphenyl nucleus) also facilitates oxidative metabolism of the PCB substrate but is not a necessary requirement for metabolism.
4. As the rate of chlorination increases on both phenyl rings the rate of metabolism decreases.
5. The metabolism of specific PCB isomers by different species can result in considerable variations in metabolite distribution.

The occurrence of *trans*-dihydrodiol metabolites suggests that metabolism of PCBs proceeds through formation of arene oxide intermediates (EPA 1987a). Arene oxides are potential electrophiles that have been implicated in cellular necrosis, mutagenicity, and carcinogenicity. The toxicological significance of PCB metabolism is unknown, but most studies suggest that the parent hydrocarbon initiates most of the common toxic responses by initial binding to the cytosolic receptor protein (EPA 1987a). The role of metabolism in the genotoxicity of PCBs has not been delineated.

PCB metabolites are usually more polar than the parent compounds and conjugated with glucuronides or sulfates prior to elimination. Rats and mice that were exposed to di-, tetra-, or penta- CBs by intraperitoneal injection or diet eliminated metabolites of glutathione conjugates and other sulfur-containing compounds (Kurachi 1983, Kurachi and Mio 1983b).

4.2.4 Excretion

4.2.4.1 Inhalation

Data concerning the excretion of PCBs in humans and animals following inhalation exposure were not available.

4.2.4.2 Oral

The excretion of PCBs is to a large extent dependent on the metabolism of PCBs to more polar compounds (EPA 1987a). At equilibrium, the elimination of PCBs from all tissues will be dependent on the structure-dependent metabolism rates of the individual PCB congeners. For example, biological half-lives in the rat range from 1.15 days for 2,2'-dichlorobiphenyl to approximately 460 days for 2,2',4,4',5,5'-hexachlorobiphenyl (Tanabe et al. 1981, Wyss et al. 1986). Metabolites of the more highly chlorinated congeners are eliminated primarily via the feces (Goto et al. 1974).

Human. Chen et al. (1982) report on the determination of PCBs in the blood of humans in Taiwan after they consumed rice-bran oil contaminated with Kanechlor 500 and PCDFs. Blood samples from 17 patients were examined, with 2 to 3 samples taken from each patient 2 to 17 months apart. The results indicated that the tetra- and some penta-isomers tend to be eliminated more rapidly than other penta-, hexa-, and hepta-isomers. Half-lives for the 2,4,5,2',4'- and 2,3,4,3',4'-penta-isomers in blood were determined to be 9.8 and 8.7 months, respectively. The data also indicated that two adjacent unsubstituted carbon atoms at the meta-para positions facilitated metabolism and subsequent elimination from the blood.

Animal. Hashimoto et al. (1976) examined the excretion of [¹⁴C] PCB compounds given to rats by gavage at a total dose of 6.35 to 7.85 mg/kg over a period of 5 to 50 days. The PCBs studied were predominantly tetra- and hexa-chlorinated isomers. The results indicated that 1.9 to 4.9% of the dose of tetra-PCBs was excreted in the urine, with higher amounts excreted in rats treated for longer periods. In rats treated with hexa-PCBs, only 0.3% of the dose was excreted in the urine. About 47 to 68% of the dose of both tetra- and hexa-isomers was excreted in the feces.

Mizutani et al. (1977) studied the elimination of tetra-CB isomers in mice fed diets containing a single isomer at 10 ppm for 20 days. Biological half-lives for the individual isomers were 0.9, 9.2, 3.4, 0.9, and 2.1 days for 2,3,2',3'-; 2,4,2',4'-; 2,5,2',5'-; 3,4,3',4'-; and 3,5,3',5'-, respectively. The authors were not able to relate the difference in rates of elimination to chlorine substitution patterns.

In a study of the influence of molecular structure on the excretion of 14 PCB congeners in mice, Gage and Holm (1976) found that the 4,4'-; 3,3',4',6'-; 2,3,2',4',6'-; and 2,3,4,2',4',5'- isomers were eliminated most rapidly. These compounds had at least one pair of ortho-meta vicinal carbon atoms unsubstituted, a configuration thought to be important for rapid metabolism and excretion. The most slowly eliminated compounds were 2,4,5,2',4',5'- and 2,3,4,2',4',5'-hexa- isomers.

Felt et al. (1977) examined the elimination of [^{14}C]-2,5,4'-tri-CB in rhesus monkeys. The monkeys were fed 550 mg of the compound in fruit daily for 84 days. On the basis of total excreted and recovered radioactivity, the half-life of 2,5,4'-tri-CB was found to be 4.5 to 4.8 days.

Bleavins et al. (1984) examined the excretion of PCBs in female European ferrets given a single dose of 0.05 mg [^{14}C]-labeled Aroclor 1254 in food. The results showed that urinary excretion accounted for $\leq 1/10$ of the quantity of PCB that was eliminated in the feces. Excretion of PCBs was highest during the first week following dosing, when 22.1 and 1.8% of the absorbed dose was excreted in the feces and urine, respectively.

4.2.4.3 Dermal

Data concerning the excretion of PCBs by humans or animals following dermal exposure were not located.

4.2.4.4 Parenteral Routes

Human. No data were located in the available literature.

Animal Studies. Injection studies indicate that PCBs can be excreted unmetabolized into the gastrointestinal tract. Yoshimura and Yamamoto (1975) recovered unmodified tetra-CB from the duodenal contents of rats injected intravenously with tetra-CB. Daily excretion for 4 days ranged from 0.5 to 0.8% of the total dose per day. Goto et al. (1974) found that 4.7 to 23.2% of injected PCBs were excreted unchanged into the gastrointestinal tract by 10 days postdosing, with the excretion of a penta- isomer greater than the excretion of di-, tri-, or tetra- isomers.

4.3 TOXICITY

Evaluation of the toxicity of Aroclors and other commercial PCB mixtures is complicated by numerous factors, including isomer and congener composition, differences in species susceptibility, quantitatively inconsistent data, and varying degree of contamination with toxic contaminants such as chlorinated dibenzofurans. Because of these factors and a lack or paucity of data for some of the Aroclors (most of the studies were conducted with the higher chlorinated

Aroclors), it is assumed that effects resulting from exposure to a specific Aroclor are representative of effects which may be produced by the other Aroclors. In the following sections, data delineating the threshold region of the most toxic Aroclor for specific end points are presented. Although the relative contribution of the inhalation and dermal routes in occupational exposures is unknown, health effects data for exposed workers are discussed in the inhalation subsections.

4.3.1 Lethality and Decreased Longevity

4.3.1.1 Inhalation

Human. Pertinent data were not located in the available literature.

Animal. Inhalation LC50s of Aroclor were not located in the available literature. Roznaova (1943) reported that all four rats exposed to Solvol (a European PCB mixture) at concentrations of 10 g/m³ for 3 h became comatose and died, while 11 similar exposures at 0.5 g/m³ resulted in only one death. Liver and renal damage was noted along with congestion in the heart and spleen. Insufficient detail was available to determine how the atmosphere was generated or what methods were used to verify the concentration. Treatment-related mortality was not observed in groups of 9 to 10 rats, 6 to 10 mice, 3 to 4 rabbits, 4 to 6 guinea pigs or 1 cat that were exposed 7 h/day, 5 days/week to vapor concentrations of 8.6 mg/m³ (0.83 ppm) Aroclor 1242 for 24 days, 5.4 mg/m³ (0.41 ppm) Aroclor 1254 for 121 days, 6.83 mg/m³ (0.66 ppm) Aroclor 1242 for 120 days, 1.5 mg/m³ (0.11 ppm) Aroclor 1254 for 213 days, or 1.9 mg/m³ (0.18 ppm) Aroclor 1242 for 214 days (Treon et al. 1956). It was necessary to heat the Aroclors to 55 to 138°C to attain the above concentrations, and 8.6 mg/m³ Aroclor 1242 was "approaching saturation" concentration. These concentrations may be low as the technique used to estimate them was invalidated. Possible contamination by PCDF was not reported.

4.3.1.2 Oral

Human. Pertinent data were not located in the available literature.

Animal. Acute oral LD50 values for the PCBs covered by this profile (Aroclors 1254, 1221, 1260, 1232, 1242, and 1248) are presented in Table 4.1. No values for Aroclor 1016 were found in the available literature. The lowest oral LD50 in rats was 1.01 g/kg for Aroclor 1254 as reported by Garthoff et al. (1981). In mink, the lowest LD50 was between 0.75 and 1.0 g/kg for Aroclor 1221 as reported by Aulerich and Ringer (1977). As seen from the data of Grant and Phillips (1974) and Linder et al. (1974), immature rats appear to be more sensitive than adult rats. The full range of LD50 values for all PCBs is greater, with the lowest value of 0.5 g/kg for hexachlorobiphenyl in guinea pigs (McConnell and McKinney 1978) and the highest value of 11.3 g/kg reported for Aroclor 1262 in the rat (Fishbein et al. 1974).

In mice maintained on diets that provided 1000 ppm Aroclor 1254 for 14 days, 3/5 died of unspecified causes by day 15 (Sanders et al. 1974). All mice treated at 4000 ppm died within 7 days after the onset of

Table 4.1. Acute oral LD₅₀s of Aroclors

Aroclor	Species/strain	Sex/age	LD ₅₀ (g/kg)	References
1254	Rat/Wistar	M/30 days	1.3	Grant and Phillips 1974
		F/30 days	1.4	
		M/60 days	1.4	
		F/60 days	1.4	
		M/120 days	2.0	
		F/120 days	2.5	
	Rat/Sherman	M/weanling	1.295	Linder et al. 1974
		NR ^a /adult	4-10	
	Rat/Osborne-Mendel	M/adult	1.01 (single dose)	Garthoff et al. 1981
			1.53 (5 doses over 2½ weeks)	
			1.99 (5 doses, 1 day/week)	
	Mink/pastel	NR/NR	4	Aulerich and Ringer 1977
1221	Rat/NR	NR/NR	3.98	Fishbein 1974
	Rat/Sherman	F/NR	4.0	Nelson et al. 1972
	Mink/pastel	NR/NR	>0.75 to <1.0	Aulerich and Ringer 1977
	1260	Rat/Sherman	NR/adult	4-10
M/weanling			1.315	
1232	Rat/NR	NR/NR	4.47	Fishbein 1974
1242	Rat/Sprague-Dawley	M/adult	4.25	Bruckner et al. 1973
	Rat/NR	NR/NR	8.65	Fishbein 1974
	Mink/pastel	NR/NR	>3	Aulerich and Ringer 1977
1248	Rat/NR	NR/NR	11	Fishbein 1974

^aNR = not reported.

treatment. No deaths occurred in five mice that were similarly treated with 250 ppm.

For intermediate-exposure durations, the LC50 for Aroclor 1254 fed to mink in the diet for 28 days ranged from 79 to 84 ppm and 47 to 58 ppm after a 7-day withdrawal period (Hornshaw et al. 1986). In mink fed Aroclor 1254 for 9 months, the LC50 was 6.65 ppm (Ringer et al. 1981). Death generally was due to nonspecific hemorrhagic lesions.

Groups of 24 male rats that were fed diets containing 0, 25, 50, or 100 ppm Aroclor 1254 for 104 to 105 weeks experienced dose-related decreased survival (92, 83, 58, and 46%, respectively) (NCI 1978). The cause of death was not specified but may have been related to development of nodular hyperplasia in the liver. There was no effect on survival of female rats similarly treated. There was no attempt to identify or quantitate impurities.

4.3.1.3 Dermal

Human. Pertinent data were not located in the available literature.

Animal. Median lethal doses for single application of Aroclors to the skin of rabbits ranged from >1269 mg/kg for Aroclors 1242 and 1248 in 50% corn oil to <3169 mg/kg for undiluted Aroclor 1221 as reported by Nelson et al. (1972) and summarized by Fishbein (1974) (Table 4.2).

4.3.2 Systemic/Target Organ Toxicity

4.3.2.1 Liver

Inhalation, human. Epidemiological studies and clinical surveys indicate that occupational exposure to Aroclors can produce alterations in liver enzymes (e.g., SGOT, GGTP) that are inconsistent and not clearly associated with clinically detectable liver disease (Ouw et al. 1976; Alvares et al. 1977; Fischbein et al. 1979, 1985; Baker et al. 1980; Smith et al. 1981a,b,c; Brown and Jones 1981; Fischbein 1985; Emmett 1985; Lawton et al. 1985; Drill et al. 1981; Kriess 1985). Asymptomatic hepatomegaly was reported in one study (Maroni et al. 1981a). The subjects of these studies were primarily involved in electrical equipment (e.g., capacitors, transformers) manufacturing and repair, and many had measurable and often high serum levels of PCBs.

Monitoring data were reported only in some of the studies and do not adequately characterize exposure levels because of limitations and dissimilarities in sampling methods, durations, and locations, changes in workplace ventilation and Aroclor formulations during the exposure period, wide ranges in concentrations within and between studies without indications of average levels, emphasis on correlating effects with serum PCB concentrations rather than air concentrations of PCBs, and unknown contribution of dermal exposure to total exposure. It appears, however, that air concentrations of Aroclors were often <1 mg/m³. In one study that reported comprehensive monitoring data, capacitor-manufacturing plant workers were exposed primarily to Aroclors 1242 and 1254 at 8-h average time-weighted concentrations that ranged from 0.07 to 11.0 mg/m³ (Fischbein et al. 1979). Approximately 40% (131) of the workers in this study were employed for ≥20 years. There was a

Table 4.2. Acute dermal LD₅₀ values of Aroclors in rabbits

Aroclor	Vehicle	LD ₅₀ (mg/kg)
1221	Undiluted	>2000 <3469
1232	Undiluted	>1260 <2000
1242	Undiluted	>794 <1269
1248	Undiluted	>794 <1269
1260	50% corn oil	>1260 <2000

Source: Fishbein 1974.

correlation between SGOT and serum PCB levels. Alvares et al. (1977) found that the mean antipyrine half-life was significantly lower in five workers exposed to Aroclor 1016 (10.8 h) than in controls (15.6 h).

Inhalation, animal. Reversible degenerative lesions of the liver were observed in rats, mice, rabbits, cats, and guinea pigs exposed to 1.5 mg/m³ (0.11 ppm) Aroclor 1254 vapor 7 h/day, 5 days/week for a 213-day period (Treon et al. 1956). Exposure to Aroclor 1242 for 7 h/day, 5 days/week at 1.9 mg/m³ (0.18 ppm) for 214 days or 8.6 mg/m³ (0.83 ppm) for 24 days did not produce histological effects in the liver or other viscera. It was necessary to heat the Aroclors to attain the concentrations used in this study.

Oral, human. Serum PCB levels were positively associated with increased GGTP levels and blood pressure in Triana, Alabama, residents that were exposed to contaminated fish (Kreiss et al. 1981). The significance of these effects is uncertain as the fish also contained high concentrations of DDT. Hepatic function indices were not affected in residents of Bloomington, Indiana, that had PCBs in their serum (Baker et al. 1980).

Oral, animal. Carter (1985) exposed groups of 12 male Charles River rats to 0, 4, 8, or 16 ppm of Aroclor 1254 in the diet for 4 days and found that relative liver weights were increased at ≥ 8 ppm.

Litterst et al. (1972) exposed groups of six male Osborne-Mendel rats to Aroclors 1260, 1254, 1248, or 1242 in the diet at concentrations of 0, 0.5, 5.0, or 500 ppm for 4 weeks. Increased microsomal nitroreductase and demethylase activities occurred at ≥ 0.5 ppm, increased pentobarbital hydroxylation and relative liver weight occurred at ≥ 50 ppm, and increased liver triglycerides occurred at 500 ppm.

Dietary exposure to 5 or 25 ppm Aroclor 1242 for 2, 4, or 6 months produced increased hepatic microsomal hydroxylase activity and histochemically discernible lipid content of hepatocytes in groups of six male Sprague-Dawley rats (Bruckner et al. 1974). Increased relative liver weight was observed at 25 ppm at 4 and 6 months and at 5 ppm at 4 months.

Frank histological effects in the liver (e.g., fatty degeneration) occurred in rats exposed to ≥ 20 ppm Aroclor 1254 or 1260 for 28 days (Chu et al. 1977), rats exposed to ≥ 20 ppm Aroclor 1254 or 1260 for 8 months (Kimbrough et al. 1972), and mice exposed to 37.5 ppm but not 3.75 ppm Aroclor 1254 for 6 months (Koller 1977).

In a study in which 4 male and 18 female rhesus monkeys were fed diets containing Aroclor 1248, Barsotti et al. (1976) conducted autopsies on one female monkey that died after being fed 2.5 ppm of Aroclor 1248 for 173 days and on one female monkey that died after being fed 5.0 ppm of Aroclor 1248 for 310 days. Hepatic effects in both monkeys included focal areas of necrosis, enlarged hepatocytes, and lipid droplets. Although only one animal per dose was examined, these effects must be regarded as treatment-related because of the characteristic nature of the hepatic response. Also, similar effects on the liver were observed in an earlier study by Allen (1975) in which the animals received Aroclor 1248 in the diet at levels of 100 and 300 ppm for 2 or 3 months.

Chronic dietary studies were conducted with rats exposed to 25 to 100 ppm Aroclor 1254 for 2 years (NCI 1978, Morgan et al. 1981, Ward 1985), 100 ppm Aroclor 1260 for 16 months followed by 50 ppm for 8 months, and then no treatment for 5 months (Norback and Weltman 1985) or 100 ppm Aroclor 1260 for 21 months (Kimbrough et al. 1975). Treatment-related nonproliferative liver lesions or nonproliferative liver lesions that did not progress to neoplasms after 1 year were not described in these studies.

The effects of chlorination and chemical composition of PCBs with regard to the dose effects relation of liver toxicity after subchronic exposure are indicated by the data of Biocca et al. (1981). In this study, hepatotoxic effects were observed in mice after 5 weeks of maintenance on diets containing 0.3 ppm of 3,4,5-symmetrical hexachlorobiphenyl, while similar effects were observed only after 30 ppm of 2,4,5-symmetrical hexachlorobiphenyl and 100 ppm of 2,4,6-symmetrical hexachlorobiphenyl, and no effects were noted after 300 ppm of 2,3,6-symmetrical hexachlorobiphenyl. Similar dependence of liver toxicity on the chemical composition of the PCB mixture would be anticipated following chronic exposure in mice and other species.

None of the above studies reported possible contamination of the Aroclor with PCDF.

Dermal. Aroclor 1260 in isopropanol vehicle was applied to the shaved backs of groups of four female New Zealand rabbits daily 5 days/week at a dose of 118 mg/day for 38 days (Vos and Beems 1971) or 120 mg/day for 28 days (Vos and Notenboom-Ram 1972). Histological alterations were produced in the livers, including centrilobular degeneration and liver cell atrophy, focal hyalin degeneration of the cytoplasm of the hepatocyte, enlarged nuclei, and loss of glycogen. Aroclor 1260 used in these experiments was reported to be free of PCDF contamination.

General discussion. The liver is the organ most often implicated in the toxicity of Aroclors in animals. Hepatotoxicity is suggested in occupationally exposed humans (EPA 1987a, Drill et al. 1981). Hepatic effects have been observed in numerous studies with exposed rats, mice, guinea pigs, rabbits, dogs, and monkeys, but rats have been tested most extensively. The effects appear to be reversible at low doses, are similar among species, and include enzyme induction, liver enlargement, fat deposition, and necrosis. Enzyme induction is the most sensitive indicator of hepatic effects, but few studies were designed to define minimum effective doses of Aroclors. The liver enlargement is associated with hepatocyte enlargement and an increase in smooth endoplasmic reticulum and/or increased enzymatic activity. Proliferative lesions in the liver have been attributed to Aroclor treatment (Sect. 4.3.6 on carcinogenicity in this section). The hepatic effects of Aroclors in animals appear to be typical of chlorinated hydrocarbons.

Histologically documented liver damage is a consistent finding among PCB-exposed animals. That hepatic alterations have been inconsistently observed in humans may be related to the fact that many of the studies (particularly the earlier ones) did not account for confounding variables, such as alcohol consumption, exposure to additional chemicals, or previous medical histories, or may be an

artifact of the relative insensitivity of the standard biochemical tests of liver damage (e.g., SGOT) as compared with biopsy evaluation (Letz 1983, Drill et al. 1981). Drill et al. (1981) concluded that SGOT and/or GGPT appear to be the most sensitive indicators of PCB exposure in humans, and that changes in liver enzymes may occur at levels below those at which chloracne occur. Abnormal liver function and some hepatomegaly have been documented in Yusho and Yu Cheng patients, but PCDFs, polychlorinated quaterphenyls, and perhaps other contaminants (e.g., chlorinated diphenyl ethers) are significant etiologic factors (Fischbein 1985).

Aroclors are commonly used to induce hepatic enzymes in animal studies with other chemicals. Exposures in these studies are not representative of realistic human exposures, as large doses are usually given by intraperitoneal injection or gavage to obtain maximal enzyme induction. Induction of enzymes by PCBs occurs in both the cytochrome P-450 and P-448 systems, has been observed in humans, and is not restricted to the liver (Letz 1983). Implications of enzyme induction for human health include the occurrence of disease secondary to the increased metabolism of endogenous or exogenous substances, and the interference with medical therapy due to increased metabolism of administered drugs (Letz 1983).

Safe et al. (1985) reviewed data concerning the mechanism of PCB induction of liver microsomal enzymes. The activity of individual PCBs depends on their structure. The most active congeners are those substituted at both para and at two or more meta positions and include 3,4,4',5-tetra-, 3,3',4,4'-tetra-, 3,3',4,4',5-penta-, and 3,3',4,4',5,5'-hexachlorobiphenyl. The coplanar PCBs induce rat liver microsomal aryl hydrocarbon hydroxylase and cytochromes P-450a, P-450c, and P-450d, thus resembling 3-methylcholanthrene and 2,3,7,8-TCDD in their mode of microsomal enzyme induction. Mono-ortho- and di-orthochloro analogs of coplanar PCBs exhibit a mixed type of enzyme induction similar to Aroclor 1254. These PCBs induce aryl hydrocarbon hydroxylase, dimethylaminoantipyrine, *N*-demethylase, and cytochromes P-450a through P-450e. Results of quantitative structure-activity relationships showed a correlation between aryl hydrocarbon hydroxylase induction activity and binding affinity for the 2,3,7,8-TCDD cytosolic receptor protein, with the order of activity as follows: coplanar PCBs > 3,4,4',5-tetrachlorobiphenyl = mono-ortho coplanar PCBs > diortho coplanar PCBs. Support for the receptor-mediated mechanism of action was found when the coplanar and mono-ortho coplanar PCBs were administered to C57BL/6J and DBA/2J mice. C57BL/6J mice contain much higher concentrations of the Ah receptor than do DBA/2J mice. The PCBs induced aryl hydrocarbon hydroxylase in the responsive C57BL/6J mice but not in the unresponsive DBA/2J mice.

4.3.2.2 Cutaneous tissues

Inhalation, human. Effects such as chloracne, skin rashes, and burning eyes and skin have been associated with occupational exposure to Aroclors (Meigs et al. 1954; Ouw et al. 1976; Fischbein et al. 1979; 1982, 1985; Baker et al. 1980; Smith et al. 1981a,b,c; NIOSH 1977a; EPA 1987a; Drill et al. 1981; Kimbrough 1987a). Monitoring data do not adequately characterize exposure levels for the reasons indicated in

Sect. 4.3.2.1 on liver effects in humans after inhalation exposure. Also, correlations between chloracne and duration of exposure or blood concentrations of Aroclors are poor or nonexistent. Drill et al. (1981) concluded that individuals with blood levels of ≥ 200 ppb of PCBs have an increased risk of chloracne and that chloracne may occur more frequently in workers exposed to PCBs that have been heated and to PCBs that have $\geq 54\%$ chlorination. The conclusions of Drill et al. (1981), however, are based on Kanechlor as well as Aroclor toxicity data. As chloracne is reported frequently among workers who were exposed to Kanechlors, the higher chloracnegenic potential of Kanechlors and heated Aroclors may be related to higher levels of PCDFs and polychlorinated quaterphenyl contaminants (Drill et al. 1981).

In one study, 34 workers who were exposed to Aroclor 1242 at concentration between 0.32 and 2.22 mg/m³ for 5 to 23 years in an electrical plant complained of burning of the eyes, face, and skin; five had eczematous rashes on the hands and legs (Ouw et al. 1976). Aroclor 1242 was reported to be free of impurities.

Inhalation, animal. Pertinent data were not located in the available literature.

Oral, human. Pertinent data were not located in the available literature.

Oral, animal. Cutaneous effects occurred in rhesus monkeys fed diets that contained Aroclors for subchronic durations (Allen and Norback 1973, Allen et al. 1974a, Allen 1975, Barsotti and Allen 1975, Barsotti et al. 1976, Thomas and Hinsdill 1978, Becker et al. 1979, Allen et al. 1979, McNulty et al. 1980). These include facial (particularly periorbital) edema, purulent discharge from the eyes, chloracne, and alopecia. The effects appear to be reversible and have been produced by diet exposures as low as 2.5 ppm Aroclor 1248 for 1 to 6 months (Barsotti and Allen 1975) and 3 ppm Aroclor 1242 for 6 months (Becker et al. 1979). NOAELs were not identified in the available studies.

In the Barsotti and Allen (1975) study, rhesus monkeys were fed diets containing 2.5 or 5.0 ppm Aroclor 1248 for 1 year. The animals exposed to 2.5 ppm (all females) developed periorbital edema, alopecia, erythema, and acneform lesions of the face and neck within 1 to 2 months. The males treated at 5.0 ppm had only moderate periorbital edema and erythema.

Thomas and Hinsdill (1978) fed 0, 2.5, and 5.0 ppm Aroclor 1248 to adult female rhesus monkeys. All eight monkeys in each Aroclor-treated group developed alopecia, chloracne, and facial edema after 6 months of treatment.

In the Becker et al. (1979) study, six young (7 to 8 months old) monkeys were fed diets containing 0, 3, 10, 30, or 100 ppm Aroclor 1242 (two were fed 10 ppm). Facial changes (palpebral swelling and erythema but no loss of hair) were evident by the end of the second month at ≥ 10 ppm and in the sixth month at 3 ppm; mortality was 4/6 by day 245, including the monkey fed 3 ppm.

Rats exposed to Aroclor 1254 in the diet developed alopecia, facial edema, and exophthalmos after 104 weeks of 50 ppm and 72 weeks of 50 ppm (NCI 1978); these effects did not occur after 104 weeks of 25 ppm.

In a single-dose study, thickening and erythema of the pinna of the ear occurred in mice exposed to 200 ppm of Aroclor 1254 in the diet for 23 weeks (Bell 1983).

All of the above studies did not report possible impurities.

Dermal, human. Pertinent data were not located in the available literature.

Dermal, animal. Daily application of 118 mg Aroclor 1260 (free of PCDF) in isopropanol vehicle to the shaved backs of four female New Zealand rabbits 5 days/week for 38 days produced thickening of the skin and acneform lesions resulting from hyperplasia and hyperkeratosis of the epidermal and follicular epithelium (Vos and Beems 1971). These results were verified in another similarly designed study (Vos and Notenboom-Ram 1972).

General discussion. Relatively small groups of animals were tested in most of the studies, but the cutaneous effects are well characterized. The cutaneous effects in occupationally exposed humans are generally consistent with the animal data, but effect levels cannot be ascertained and the contribution of direct skin exposure or contaminants cannot be evaluated with the information reported in the papers.

4.3.2.3 Immunological effects

Inhalation, human. Significant alterations in various globulin fractions have not been observed in Aroclor-exposed workers (Ouw et al. 1976; Smith et al. 1981a,b,c).

Inhalation, animal. Pertinent data were not located in the available literature.

4.3.2.4 Oral

Human. Pertinent data were not located in the available literature.

Animal. Female guinea pigs maintained on diets that contained 50 ppm of Aroclor 1260 for 6 weeks had significantly lowered tetanus autotoxin titers, circulating leukocytes and lymphocytes, and thymus atrophy (Vos and van Genderen 1973). Exposure to 10 ppm Aroclor 1260 in the diet for 8 weeks produced splenic atrophy in guinea pigs (Vos and de Roij 1972). NOAELs were not identified in these studies. The Aroclor 1260 used in these studies was reported to be free from PCDF impurities.

Thomas and Hinsdill (1978) exposed groups of 5 to 8 female rhesus monkeys to 0, 2.5, or 5.0 ppm Aroclor 1248 in the diet for 11 months. Significantly lower antibody response to sheep red blood cells occurred at 5.0 ppm. There was no treatment-related effect on antibody response to tetanus toxoid.

Barsotti et al. (1976) also found evidence of an immunological effect in rhesus monkeys fed 2.5 or 5.0 ppm Aroclor 1248 in the diet for 7 months prior to mating and during pregnancy. Monkeys developed shigellosis during and after treatment, indicating an increased susceptibility to infection.

Thomas and Hinsdill (1978) also fed Aroclor 1248 to mice at 100 or 1000 ppm in the diet for 3 to 5 weeks. The mice had enhanced sensitivity to *Salmonella typhimurium* and endotoxin, indicating lowered resistance to infection.

Dermal, human. Pertinent data were not located in the available literature.

Dermal, animal. Dermal application of 120 mg/day Aroclor 1260 (free of PCDF impurities) in isopropanol 5 days/week for 4 weeks produced moderate thymic atrophy in rabbits (Vos and Notenboom-Ram 1972). Similar application of 118 mg/day Aroclor 1260 for 38 days produced histological atrophy of the thymus cortex and a reduction in the number of germinal centers in the spleen and lymph nodes in rabbits (Vos and Beems 1971).

General discussion. The Thomas and Hinsdill (1978) study suggests that the threshold for immunosuppression in monkeys is in the diet concentration range of 2.5 to 5.0 ppm. Treatment of rodents with oral or dermal doses of Aroclors, non-Aroclor PCBs, and/or individual PCB congeners that have a different composition than those covered by this profile has also produced effects on the immune system. This is illustrated in the study by Biocca et al. (1981) in which a decrease in thymus weight was observed in mice exposed to 3,4,5-symmetrical hexachlorobiphenyl for 5 weeks in the diet at 10 ppm, compared with similar effects produced at levels of 300 ppm for 2,4,5- or 2,4,6-symmetrical hexachlorobiphenyl or at 167 ppm Aroclor 1242 in the diet of mice in a 6-week study (Loose et al. 1978a,b). These effects include immunosuppression as measured by increased mortality to *Salmonella typhosa* endotoxin and *Plasmodium berghei* in mice given 167 ppm Aroclor 1016 or 1242 in the diet for 6 weeks (Loose et al. 1978a,b), and increased mortality caused by *S. typhimurium* endotoxin in mice that were given 100 or 1000 ppm Aroclor 1248 in the diet for 5 weeks (Thomas and Hinsdill 1978). PCBs also caused splenic, thymic, and lymph node atrophy in rats (Allen et al. 1975, Allen and Abrahamsom 1973, Parkinson et al. 1983).

Although PCBs appear to be immunosuppressive in animals, the effect of PCBs on immune system function in humans has not been adequately evaluated. Based on animal splenic and lymphoid system histological alterations, Drill et al. (1981) speculated that significant immunosuppression in humans may occur only at high dosages secondary to malnutrition (i.e., via general toxic responses such as decreased food intake, decreased body weight, or decreased body weight gain).

Immunotoxicity of PCBs appears to be dependent upon expression of the aromatic hydrocarbon receptor and on the ability of PCBs to bind to the receptor (EPA 1987a). The receptor binding affinity of PCBs is dependent on the molecular conformation that is determined by the chlorine substitution pattern.

4.3.2.5 Thyroid

Inhalation. Pertinent data were not located in the available literature.

Oral, human. Pertinent data were not located in the available literature.

Oral, animal. Rats exposed to Aroclor 1254 for 4 to 12 weeks experienced thyroid alterations that included enlargement, reduced follicular size, follicular cell hyperplasia, and accumulation of colloid droplets and large, abnormally shaped lysosomes in the follicular cells (Collins et al. 1977; Collins and Capen 1980b,c; Kasza et al. 1978). The thyroid alterations resulted in reduced serum thyroxine levels and appear to be reversible after cessation of exposure. None of these studies reported the purity of the Aroclor 1254 sample used.

Collins and Capen (1980b) exposed groups of six male Osborne-Mendel rats to 0, 5, 50, or 500 ppm Aroclor 1254 in the diet for 4 weeks. Histological and ultrastructural effects consistent with those described above occurred at ≥ 5 ppm, and reduced serum thyroxine occurred at ≥ 50 ppm. A NOAEL for thyroid alterations cannot be discerned from the available studies.

Dermal. Pertinent data were not located in the available literature.

General discussion. Although effects of Aroclor exposure on the thyroid have been investigated in only a few studies, this gland is an unequivocal target of Aroclor in rats. The lowering of serum thyroxine by Aroclors appears to be the combined result of a direct effect on thyroid follicular cells with an interference in hormone secretion plus an enhanced peripheral metabolism of thyroxine (Collins et al. 1977).

Ultrastructural lesions in thyroid follicular cells and reductions in serum levels of thyroid hormones (thyroxine and triiodothyronine) occurred in neonatal and weanling rats whose dams were fed diets containing 50 or 500 ppm Aroclor 1254 throughout gestation and lactation (Collins and Capen 1980a). These authors also reported that other studies have found that decreased reproductive performance and interference in growth and development occurred in man and animals that were rendered hypothyroid and that PCBs enhance the peripheral metabolism and excretion of thyroxine-glucuronide in the bile. These findings and the thyroid effects in Aroclor-exposed adult rats summarized previously suggested to Collins and Capen (1980a) that some of the well-documented PCB-related disturbances in reproduction, growth, and development may be related to alterations in thyroid structure and function in the dam, fetus, or neonate.

4.3.2.6 Stomach

Effects on the stomach have been studied only in animals exposed orally. Oral administration of Aroclor 1248 (Allen and Norback 1973; Allen et al. 1974a,b; Allen 1975; Barsotti and Allen 1975) and Aroclor 1242 (Becker et al. 1979) to monkeys produced gastritis, which progressed to hypertrophy and hyperplasia of the gastric mucosa. Related

effects include mucous-filled cysts that penetrate the muscularis mucosa. These effects were initiated by exposures as low and/or short as a single gavage dose of 1.5 g/kg of Aroclor 1248 (Allen et al. 1974a), 25 ppm of Aroclor 1248 in the diet for up to 1 year (Barsotti and Allen 1975), and 3 ppm of Aroclor 1242 for 71 days (Becker et al. 1979).

The Aroclor-induced gastric lesions occurred only along the greater curvature of the stomach (not in the cardiac or pyloric regions, which are more usual regions for gastric effects), did not occur in other sections of the gastrointestinal tract, and have not been observed in species other than monkeys (Becker et al. 1979, Drill et al. 1981). These gastric effects may therefore be species specific. Aroclor 1254-induced metaplasia and adenocarcinoma in the glandular stomach of F344 rats have been reported (Morgan et al. 1981) (Section 4.3.6 on carcinogenicity in this section). These studies did not report the purity of the Aroclor sample used.

4.3.2.7 Porphyria

Inhalation, human. Exposure-related urinary porphyrins, porphyrin-related disease, or cases of porphyria cutaneous tarda have not been reported in clinical studies of Aroclor-exposed workers (Alvares and Kappas 1979; Fischbein et al. 1979; Smith et al. 1981a,b,c).

Inhalation, animal. Pertinent data were not located in the available literature.

Oral, human. Pertinent data were not located in the available literature.

Oral, animal. Groups of six male Sprague-Dawley rats were treated with 0, 5, or 25 ppm of Aroclor 1242 (purity not reported) in the diet for 2, 4, or 6 months (Bruckner et al. 1974). Urinary coproporphyrin levels were increased in rats treated at both concentrations.

Dermal, human. Pertinent data were not located in the available literature.

Dermal, animal. Fecal coproporphyrin was elevated in female New Zealand rabbits that received a 120-mg application of Aroclor 1260 to shaved backs 5 days/week for 4 weeks (Vos and Notenboom-Ram 1972). Fecal coproporphyrin and protoporphyrin were increased in rabbits similarly treated with 118 mg/day Aroclor 1260 5 days/week for 36 days (Vos and Beems 1971). The Aroclor 1260 used in these studies was free of PCDF.

General discussion. Goldstein et al. (1974) found that onset of porphyria was delayed in rats fed a higher concentration (100 ppm) of Aroclor 1254, occurring after 2 or 7 months of treatment, and that there was an increase in delta-aminolevulinic (ALA) synthetase activity. Other results of this study suggest that PCBs may affect uroporphyrin formation or utilization, rather than induction of ALA synthetase (the increase in ALA synthetase activity was probably secondary to the porphyria) (Drill et al. 1981). Induction of ALA synthetase (a rate-limiting enzyme in heme synthesis) is the mechanism of porphyrogenic action of many other chemicals (Drill et al. 1981, Hill 1985).

Although porphyria has not been reported in Aroclor-exposed humans, Drill et al. (1981) observed that occurrence of increased ALA synthetase activity in treated animals raises the possibility that PCBs can cause an attack of porphyria in patients suffering from acute, intermittent porphyria. Chronic hepatic porphyria and porphyria cutanea tarda are associated with exposure to other polyhalogenated compounds, including polybrominated biphenyls and 2,3,7,8-TCDD (Hill 1985).

4.3.2.8 Kidney

The only study that reported effects on the kidneys was Vos and Beems (1971). In this study, Aroclor 1260 in isopropanol vehicle was applied to the shaved backs of New Zealand rabbits for 5 days/week at a dose of 118 mg/day for 38 days. Hydropic degeneration of the convoluted tubules, destruction of tubular epithelial cells, tubular dilation, and proteinaceous casts were observed. No mention of kidney effects was made in the study by Vos and Notenboom-Ram (1972), in which Aroclor 1260 was applied to the shaved backs of rabbits at 120 mg/day, 5 days/week for 28 days.

4.3.3 Developmental Toxicity

4.3.3.1 Inhalation

Human. Fifty-one infants born to women employed at two capacitor-manufacturing facilities with a history of high exposure to Aroclors 1254, 1242, and/or 1016 had mean birth weights and mean gestational ages that were lower than infants born to women who had worked in low-exposure areas (Taylor et al. 1984). The differences were small (153 g and 6.6 days), and the birth weight difference appears to have resulted from the shortened gestation rather than from a retardation of intrauterine growth. High-exposure workers were exposed to Aroclor during the manufacturing process for at least 1 year prior to the birth of the infant.

Animal. Pertinent data were not located in the available literature.

4.3.3.2 Oral

Human. Birth weight, length, head circumference, gestational age, and neonatal behavior were evaluated in 313 newborn infants (Fein 1984, Fein et al. 1984, Jacobson et al. 1984a). Of these infants, 242 were born to mothers who had consumed moderate to large quantities of Lake Michigan fish sometime during their lives, and 71 were born to mothers who did not consume Lake Michigan fish. Mean ($\pm$ standard deviation) fish consumption and duration of consumption were 6.7 ± 5.8 kg/year and 15.9 ± 9.1 kg/year, respectively; consumption during pregnancy was 4.1 ± 4.4 kg/year. Maternal serum PCB concentrations averaged 5.5 ± 3.7 ng/mL, which reportedly is comparable to those for other midwestern area samples, and umbilical cord serum PCB levels averaged 2.5 ± 1.9 ng/L. Both maternal consumption of fish and levels of PCBs in cord serum were positively correlated with lower birth weight, smaller head circumference, and shorter gestation (Fein et al. 1984). Infants of mothers who had consumed contaminated fish were, on the average, 190 g

lighter, had head circumferences 0.6 cm less, and were born 4.9 days earlier than infants of mothers who consumed contaminated fish. Similar values were determined when infants with cord serum levels ≥ 3 ng/mL were compared with infants whose cord levels were < 3 ng/mL (the analytical quantification limit) (160 g lighter, 0.6 cm less in head circumference, 8.8 days less in gestational age). Head circumference was significantly smaller in both analyses even after birth weight and gestational age were statistically controlled. Contaminated fish consumption was also positively correlated with impaired autonomic maturity, increased numbers of abnormal reflexes, and decreased range of state (Jacobson et al. 1984b). Range of state is a neurological category that includes peak of excitement, rapidity of build-up, irritability, and lability of state.

Rogan et al. (1986) examined birth weight, head circumference, and the results of behavioral tests in 930 children. At birth, samples of placenta, maternal and cord serum, and milk were collected and analyzed for PCBs. There was no correlation between birth weight or head circumference with PCB levels. Levels of PCBs in milk fat at birth of 3.5 to > 4 ppm, but not < 3.49 ppm, were significantly correlated with less muscle tone, decreased activity, and abnormal reflexes. The levels of PCBs to which these infants were exposed were probably as high as those encountered in the general population.

Jacobson et al. (1985) studied the effect of intrauterine exposure or exposure through breast milk to PCBs on visual recognition memory and preference for novelty in 123 infants. Measures of exposure included reports by the mothers of contaminated fish consumption, and analysis of cord serum levels and breast milk levels of PCBs. Reports of fish consumption and cord serum levels were predictors of poor visual recognition memory, while breast milk levels were not. There was a dose-related decrease in fixation to novelty: cord serum levels of 0.2 to 1.1 ng/mL were associated with mean scores of 61%, 1.2 to 2.2 ng/mL with mean scores of 60%, 2.3 to 3.5 ng/mL with scores of 57%, and 3.6 to 7.9 ng/mL with scores of 50%.

Animal. Rabbits were exposed to 0, 1.0, or 10.0 mg/kg/day and 12.5, 25.0, or 50 mg/kg/day Aroclor 1254 (purity not reported) by gavage on days 1 to 28 of pregnancy in separate experiments (Villeneuve et al. 1971). Abortions, stillbirths, and maternal deaths occurred at ≥ 12.5 mg/kg/day, but there were no treatment-related teratogenic effects at any dose level. It was noted that unpublished data from the same laboratory showed that administration of Aroclor 1221 at doses ≤ 25 mg/kg/day was not fetotoxic to rabbits (Villeneuve et al. 1971).

Doses of 0, 6.25, 12.5, 25, 50, or 100 mg/kg/day of Aroclor 1254 were administered by gavage on days 6 to 15 of gestation to rats (Villeneuve et al. 1971). Average pup weights were reduced at 100 mg/kg/day, although total litter weight (average weight times number of fetuses) did not differ from controls. There were no skeletal or visceral abnormalities or effects on conception, resorptions, litter size or number, or average litter weight in any of the treated groups. In other rat studies with Aroclor 1254 (purity not reported), reduced average fetal weight per litter (Spencer 1982) and reduced pup survival

and body weight at weaning (Linder et al. 1974) resulted from 100 mg/kg/day gavage exposure on days 6 or 7 to 15 of gestation.

Collins and Capen (1980a) fed diets containing 0, 50, or 500 ppm Aroclor 1254 (purity not reported) to groups of 15 female Osborne-Mendel rats throughout pregnancy and lactation. There was a statistically significant ($P < 0.001$) reduced litter size in the 500-ppm groups compared with controls. Statistically significant decreases in pup body weight were observed at 50 and 500 ppm in 21-day-old pups, but not at 7 or 14 days or at parturition. Ultrastructural lesions in thyroid follicular cells and reduction in serum levels of thyroid hormone (thyroxine and triiodothyronine) occurred in the neonatal and weanling rats at 50 and 500 ppm. Although pups are not usually examined for effects on the thyroid in developmental studies, the observation of thyroid effects in the neonates can be considered a fetotoxic effect because the thyroid is a target organ of Aroclor 1254 toxicity. Assuming that a rat consumes a daily amount of food equal to 5% of its body weight (EPA 1986a), the 50- and 500-ppm levels are equivalent to doses of 2.5 and 25 mg/kg/day, respectively; therefore, 2.5 mg/kg/day is the LOAEL for fetotoxicity in rats.

Haake et al. (1987) reported that treatment of pregnant C57BL/6 mice with Aroclor 1254 by gavage at 244 mg/kg on day 9 of gestation did not result in any fetuses with cleft palate.

Groups of eight female monkeys were maintained on diets containing 0, 0.25, or 1.0 ppm of Aroclor 1016 (free of PCDF) in the diet for approximately 7 months prior to mating and during pregnancy (Barsotti and Van Miller 1984). Mean birth weight in the 1.0-ppm group was significantly ($P < 0.01$) less than controls, but head circumference and crown-to-rump length were unaffected. All females conceived, carried their infants to term, and delivered viable offspring. More pronounced fetotoxic effects (early abortions or resorption, stillbirths, and/or reduced birth weight), lengthened menstrual cycles, and lowered serum progesterone levels occurred in monkeys exposed to 2.5 or 5.0 ppm Aroclor 1248 (purity not reported) in similarly designed studies (Allen and Barsotti 1976; Allen et al. 1979, 1980).

4.3.3.3 Dermal

Pertinent data were not located in the available literature.

4.3.3.4 General discussion

Comprehensive teratological examinations have not been conducted; however, the above studies and others (EPA 1987a) indicate that Aroclors were not teratogenic in rats and nonhuman primates when tested via the oral route during the critical periods of organogenesis at doses that produce fetotoxicity and/or maternal toxicity. Although fetotoxicity of Aroclors is documented in several species of animals, the possibility that contaminants (e.g., PCDFs) may be responsible for the effects should be recognized.

Reports of reduced birth weight and gestational age in infants of mothers with occupational and environmental exposure to Aroclors (Taylor et al. 1984, Fein 1984, Fein et al. 1984) are inconclusive but consistent with the animal developmental effects data. Although serum

levels of PCBs were correlated with these effects, the effects may not be specific to PCB contamination because the fish were also contaminated with other pollutants. The birth weight decreases are of the same order of magnitude as that reported by the Surgeon General for smoking during pregnancy (Fein 1984). Infants born to mothers who were exposed to Kaneclor PCBs during the Yusho incident had signs of toxicity and delayed development (e.g., abnormal skin pigmentation, ocular discharge, small size), but no developmental abnormalities (EPA 1987a, Miller 1985). These effects did not persist. As discussed earlier in this profile, the Yusho incident was a unique event in which effects may not be related to PCBs.

Higher concentrations of PCBs in breast milk than in cord serum have led some investigators to assume that postnatal lactation exposure poses a greater threat to infants than intrauterine exposure. Jacobson et al. (1985) indicated that this assumption may be inappropriate because, relative to body weight, even low prenatal exposure can be substantial. Also, fetuses may be particularly sensitive to toxic insult because of factors such as lack of protective barriers (i.e., blood-brain) and metabolizing capacities that are found postnatally. That intrauterine exposure may be more harmful than postnatal exposure is also suggested by the results of the Jacobson et al. (1985) study, which indicated that behavioral effects were correlated more with prenatal exposure (cord serum PCBs) than with exposure via breast milk.

4.3.4 Reproductive Toxicity

Data for reproductive effects in animals were available only for oral exposure.

Groups of 12 female and 4 male mink were maintained on diets that provided 0, 1, 5, or 15 ppm Aroclor 1254 (purity not reported) for 4 months and were mated (Aulerich and Ringer 1977). Dose-related impaired reproduction (reduced number of females whelped and reduced kit/female ratio) occurred at ≥ 5 ppm, with total inhibition of reproduction at 15 ppm. These effects were also produced at 2 ppm Aroclor 1254 in a similarly designed single-dose level study; however, these effects did not appear to result from adverse effects on spermatogenesis (Aulerich and Ringer 1977). Complete reproductive failure occurred in mink exposed to ≥ 5 ppm Aroclor 1242, and Aroclor 1016 reduced but did not completely eliminate mink reproduction at 20 ppm (Bleavins et al. 1980). The rat appears less sensitive, with fetal mortality and maternal toxicity reported after daily consumption for 9 weeks of Aroclor 1254 at a level of 6.4 mg/kg/day (Baker et al. 1977). The purity of the Aroclors was not reported.

Rats were exposed to 0, 1, 5, 20, 100, or 500 ppm of Aroclor 1254 (purity not reported) in the diet in 1- and 2-generation reproduction studies (Linder et al. 1974). Reduced litter sizes occurred in the F1b and F2 generations at ≥ 20 ppm.

In longer-term studies (Allen et al. 1979b, 1980; Barsotti et al. 1976), monkeys were exposed to Aroclor 1248 in the diet at levels of 2.5 and 5.0 ppm for 18 months. Maternal toxicity that included lengthened menstrual cycles was observed. At the high-dose level, there was nearly complete inhibition of reproduction, while at the low-dose

there were early abortions and fetal resorptions, although some live births did occur. Although this indicates that the monkey was very sensitive to the reproductive toxicity of Aroclor 1248, it should be noted that chemical analyses indicated that the PCBs were contaminated with approximately 1.7 ppm of PCDFs, which may have contributed to the observed toxicity.

Reproductive effects resulting from higher oral doses of Aroclor prior to and during gestation include prolonged estrous cycle and decreased sexual receptivity in rats (Brezner et al. 1984), reduced conception rate in mice (Welsch 1985), and reduced litter size in rats (Linder et al. 1974). Lactation exposure produced decreased reproductive capacity in male rats (Sager 1983) and premature vaginal opening and delayed first estrus in female rats (Brezner et al. 1984).

4.3.5 Genotoxicity

4.3.5.1 Human

No data were located in the available literature.

4.3.5.2 Nonhuman

Results of mutagenicity assays with PCBs in in vitro systems are summarized in Table 4.3. Results of studies using PCB mixtures other than Aroclors are included to provide additional information. PCBs gave generally negative results in *Salmonella typhimurium*, with and without metabolic activation. The only positive responses were obtained by Wyndham et al. (1976), who observed increases in reversion frequency in *Salmonella typhimurium* strain TA1538 exposed to 4-chlorobiphenyl and, to a lesser extent, Aroclor 1221 only in the presence of metabolic activation. Negative results were obtained with the more highly chlorinated Aroclor 1254 and 2,2',5,5'-tetrachlorobiphenyl. These data suggested that the less chlorinated PCBs may be metabolized to mutagenic compounds to a greater extent than the more chlorinated PCBs (EPA 1985a). Harbison (1986) discounted the positive results of the Wyndham et al. (1976) study because of the inability of one of the authors to reproduce those findings and because of negative results in all of the other bacterial test systems.

PCBs gave generally negative results in in vivo assays with rats and mice (Table 4.4). Weakly positive results (chromosomal aberrations) were obtained in ring dove (*Streptopelia risoria*) embryos from doves fed Aroclor 1254 at 10 ppm in the diet.

4.3.6 Carcinogenicity

4.3.6.1 Inhalation

Human. Bahn et al. (1976, 1977) reported an increased incidence of malignant melanomas in employees of a northeastern U.S. petrochemical plant where Aroclor 1254 was used for 9 years in the 1950s. Two of 31 heavily exposed workers developed malignant melanomas. This incidence was significantly above the expected rate. Quantitative exposure data were not reported.

Table 4.3. Genotoxicity of PCBs in vitro

End point	Species (test system)	Result with activation/without activation	References
Gene mutation	<i>Salmonella typhimurium</i>	-/-	Schoeny et al. 1979, Schoeny 1982, Heddle and Bruce 1977, Wyndham et al. 1976
	Chinese hamster V79 cells	-/-	Hattula 1985
Chromosomal aberrations	Human lymphocytes	-	Hoopingarner et al. 1972

Table 4.4. Genotoxicity of PCBs in vivo

End point	Species (test system)	Result	References
Chromosomal aberration	<i>Drosophila melanogaster</i>	—	Nilsson and Ramel 1974
	Ring dove (<i>Streptopelia risoria</i>)	+	Peakall et al. 1972
	Chicken	—	Blazak and Marcun 1975
	Mouse	—	Watanabe and Sugahara 1981
	Rat	—	Green et al. 1975a, Garthoff et al. 1977, Dikshith et al. 1975
Dominant lethal	Mouse	—	Green et al. 1975b, Keplinger et al. 1971, Calandra 1976

Brown and Jones (1981) conducted a cohort mortality study of 2567 workers in two capacitor factories where PCBs were used. All-cause mortality and cancer mortality were lower than expected. Excess mortality was observed for rectal cancer and liver cancer, but neither was statistically significant. Monitoring data were not reported.

Gustavsson et al. (1986) performed a cohort study of 142 male Swedish capacitor-manufacturing workers who had been exposed to PCBs for an average of 6.5 years between 1965 and 1978. Airborne PCB levels measured in 1973 were 0.1 mg/m³. It is not clear if this level represents an average for 1965-1978. Skin contamination had occurred in some of the workers. Seven cancers had occurred in these workers, which was in agreement with national statistics. One person had two rare tumors, a slow-growing mesenchymal tumor and a malignant lymphoma. The authors concluded that this study did not indicate any excess mortality or cancer incidence among PCB workers, but that such effects could not be ruled out because of the small cohort and relatively short follow-up period.

Davidorf and Knupp (1979) found no relationship between possible PCB exposure and increased annual occurrence of ocular melanoma in Ohio during 1967-1977.

Animal. No data were located in the available literature.

4.3.6.2 Oral

Human. Urabe et al. (1979) reported that by 1979, 31 Yusho patients had died, 11 from malignant neoplasms. These data were insufficient to determine if there was an increase in cancer among the exposed population.

Statistically significant excess risk of liver cancer has been reported in Yusho patients that were studied for a follow-up period of over 16 years (Amano et al. 1984, Kuratsune 1986). Because the excess of liver cancer was found in only one prefecture, the findings are considered tentative. Simultaneously with exposure to PCBs, the patients were also known to be exposed to PCDFs and polychlorinated quinones, which may have contributed to the excess risk of liver cancer. Further analysis of these studies is in progress. Although the findings are suggestive of a relation between oral exposure to PCBs and excess risk of liver cancer, the Carcinogen Assessment Group considers the present data inadequate (EPA 1987a).

Animal. Kimbrough et al. (1975) fed groups of 200 female weanling Sherman rats diets containing 0 or 100 ppm Aroclor 1260 (purity not reported). Aroclor treatment was discontinued 6 weeks before the rats were killed at 23 months of age. Mean final body weights and body weight gain were significantly ($P < 0.001$) reduced in the treated group, but food consumption in the two groups was comparable. Actual PCB intake in the treated rats was 11.6 mg/kg/day during the first week of exposure, 6.1 mg/kg/day at 3 months, and 4.3 mg/kg/day at 20 months. Almost all treated rats (170/184) exhibited a few to multiple tan nodules on the surface of the liver and more on sectioning. Only one control animal had gross abnormalities of the liver. Hepatocellular carcinomas were found in 1/173 (0.58%) controls and 26/184 (14%) treated rats. Neoplastic

nodules were found in the livers of 0/173 controls and 144/184 treated rats. The total incidence of neoplastic liver lesions was 1/173 (<1%) in controls and 170/184 (92%) in treated rats.

In a shorter preliminary study, Kimbrough et al. (1972) exposed groups of 10 male and female Sherman rats to 0, 100, 500, or 1000 ppm Aroclor 1254 (purity not reported) or 1260 in the diet for <1 year. No neoplastic nodules or hepatocellular carcinomas were found.

Norback and Weltman (1985) fed a group of Sprague-Dawley rats (70 per sex) a diet containing Aroclor 1260 (purity not reported) at a concentration of 100 ppm for 16 months, and 50 ppm for an additional 8 months, followed by a control diet for 5 months. A control group consisted of 63 rats per sex. In the treated rats examined after 18 months, 95% of the 47 females and 15% of the 46 males had hepatocellular neoplasms. This indicated a gender-related effect. Among treated females, 43/47 had trabecular carcinomas and/or adenocarcinomas, and another 2 females had neoplastic nodules only. Two of 46 treated males had trabecular carcinomas, and another 5 had neoplastic nodules. Incidences of hepatocellular neoplasms in control rats were 0/32 males and 1/49 females, the one female having a single neoplastic nodule. The progression of hepatocellular lesions was as follows: centrolobular cell hypertrophy at 1 month, foci of cell alteration at 3 months and areas at 6 months; neoplastic nodules at 12 months, trabecular carcinoma at 15 months, and adenocarcinoma at 24 months. The authors noted that while the tumors met morphologic criteria for malignancy, they were relatively unaggressive as they did not metastasize to distant organs or invade blood vessels. Mortality was not affected, probably because of the late appearance and slow growth of the tumors. Both treated and control rats developed cholangioma, cystic cholangioma, and adenofibrosis, but the incidence was greater in the treated group.

EPA (1987a) used the Norback and Weltman (1985) study as the basis for a carcinogenic risk assessment of PCBs using combined incidences of neoplastic nodules and hepatocellular carcinomas. Because this study demonstrated the progression of hepatocellular lesions through neoplastic nodules to carcinomas, it provides justification for using the combined incidences for quantitative risk assessment.

NCI (1978) exposed groups of 24 Fischer 344 rats per sex per dose to 0, 25, 50, or 100 ppm Aroclor 1254 in the diet for 104 to 105 weeks. Mean body weights of mid- and high-dose males and low-dose females were below those of controls from week 10 onward. There was a significant dose-related reduction in survival among treated males. There was a significant dose-related trend in combined incidences of lymphomas and leukemias in males, but incidences in each dose group were not significantly different from matched controls. NCI (1978) concluded that these tumors could not clearly be related to administration of Aroclor 1254. Hepatocellular adenomas and carcinomas were found in treated groups but not controls (males: mid-dose 1/24, high-dose 3/24; females: mid-dose 1/24, high-dose 2/24). Nonneoplastic hyperplastic nodules also occurred at a high incidence in treated animals but not controls. The tumor incidences were not significant, but the hyperplastic nodules appeared to be treatment related. Adenocarcinomas were found in the stomach, jejunum, or cecum of two treated males and two treated females.

and a carcinoma was found in one treated male. Although their incidence was not statistically significant, the low historical incidences of these lesions suggest that they might have been treatment related. NCI (1978) concluded that the high incidence of hepatocellular proliferative lesions in male and female rats was related to treatment, but that Aroclor 1254 was not carcinogenic in this bioassay. There was no attempt to identify or quantitate impurities.

Morgan et al. (1981) reexamined the NCI (1978) data with respect to gastric adenocarcinomas. Stomachs from rats used in that study were available for further sectioning and examination. Incidences of focal stomach lesions, mostly metaplasia, were 6, 10, 17, and 35% in rats receiving 0, 25, 50, and 100 ppm, respectively. Adenocarcinomas were found in six treated rats. When compared with incidences of stomach adenocarcinomas in historical controls (1/3548), the incidence 6/144 was significant at $P < 0.001$. The authors commented that adenocarcinoma and intestinal metaplasia appeared to be related and might have the same initiating mechanism. They concluded that Aroclor 1254 led to induction of intestinal metaplasia and probably to induction of adenocarcinoma in the glandular stomachs of F344 rats.

Ward (1985) also reexamined data from the NCI (1978) bioassay. He noted that hepatocellular adenomas, carcinomas, and eosinophilic and vacuolated hepatocellular foci usually occurred only in treated rats. It appeared that eosinophilic hepatocellular foci and tumors arose de novo rather than from naturally occurring basophilic foci. He suggested that Aroclor 1254 induced or initiated these unique lesions rather than promoted the growth of naturally occurring lesions. Ward (1985) also discussed the intestinal metaplasia and adenocarcinomas in treated rats. He noted that the metaplastic lesions were similar to those seen in monkeys, but differed in being focal and singular, while monkey lesions were diffuse. The appearance of the few metaplastic lesions in the stomachs of controls was different from those in treated rats, which resembled precancerous lesions induced by gastric carcinogens. Ward (1985) concluded that the effects of PCBs on the glandular stomach of rats should be studied further.

Kimura and Baba (1973) fed diets containing 38.5 to 616 ppm Kanechlor 400 to groups of 10 rats per sex for 159 to 538 days. Treated animals experienced significantly decreased body weight gain and other signs of toxicity. EPA (1985a) concluded that this study was too short and the doses too high to be useful for assessing carcinogenic potential of this PCB mixture.

Ito et al. (1974) exposed groups of 10 male Wistar rats to 100 to 1000 ppm of Kanechlor 300, 400, or 500 in the diet for up to 1 year. Nodular hyperplasia, which was considered preneoplastic, was observed in a few of the treated rats. No significant tumorigenic effects were noted. EPA (1985a) judged this study to be inadequate because of its short duration and the small numbers of animals used.

Kimbrough and Linder (1974) fed groups of 50 male Balb/cJ mice diets containing 0 or 300 ppm Aroclor 1254 (purity not reported) for 11 months or for 6 months followed by a 5-month recovery period. Treated mice had enlarged livers and adenofibrosis, a possible premalignant lesion (EPA 1987a). Incidences of hepatomas were: 0/34 and 0/24 in two

control groups, 9/22 in the 11-month exposure group, and 1/24 in the 5-month exposure group. This study provided evidence of the potential hepatocarcinogenicity of PCBs in mice.

Ito et al. (1974) observed hepatocellular carcinomas (5/12 mice) and liver nodules (7/12) in dd mice fed 500 ppm of Kanechlors 500 for 32 weeks. This study provides supporting evidence for the hepatocarcinogenicity of PCB mixtures.

Because PCB mixtures are often contaminated with PCDFs, it is possible that the carcinogenic response of some PCB mixtures is due to or augmented by these contaminants. Schaeffer et al. (1984) fed male Wistar rats diets containing 100 ppm Clophen A 30 (30% chlorines by weight) or Clophen A 60 (60% chlorines by weight) for 800 days. These PCB mixtures were reported to be free of furans. Hepatocellular carcinomas developed in 61% of the rats fed Clophen A 60. Only 3% of the Clophen A 30 treated rats developed hepatocellular carcinomas, while 89% had preneoplastic lesions. This study demonstrates that PCB mixtures free from contamination with furans elicit a carcinogenic response.

4.3.6.3 Dermal

Human. Human exposures to PCBs via both the dermal and inhalation routes are discussed under the inhalation data.

Animal. DiGiovanni et al. (1977) reported that Aroclor 1254 (purity not reported) showed weak initiator activity when applied to the skin of CD-1 mice. Berry et al. (1978) reported that Aroclor 1254 was not a skin tumor promoter in female CD-1 mice that had been initiated with DMBA, nor did it produce tumors when tested without DMBA initiation at a level of 1 mg administered twice weekly.

4.3.6.4 General discussion

The study by Kimbrough et al. (1975) demonstrated the hepatocarcinogenicity of Aroclor 1260 in female Sherman rats. A preliminary experiment using smaller groups of animals of the same sex and strain exposed for <1 year did not result in neoplastic nodules or hepatocellular carcinomas (Kimbrough et al. 1972). These results suggest that hepatocellular carcinomas caused by PCBs can be detected only in long-term experiments at doses low enough to prevent interfering toxicity. In addition, because the large long-term experiment only produced a 14% incidence of carcinomas, relatively large numbers of animals must be used to detect a significant increase in tumor incidence. Similarly, the NCI (1978) rat study with group sizes of 24 rats per sex was considered not sensitive enough to identify as significant an increase in tumor incidence of this magnitude (14%). The NCI (1978) study found hepatocellular carcinomas in 2/24 (8%) male rats fed 100 ppm Aroclor 1254. If incidences are expressed as the number of animals with tumor per number of animals at risk, as is more commonly done, the incidence is 2/20 or 10%. The 8 to 10% incidence is not detected as statistically significant with group sizes of 24 rats, nor would a 14% incidence, as was observed in the Kimbrough et al. (1975) study, be detected as statistically significant. EPA (1985a) concluded that the results of the NCI (1978) study did not by themselves demonstrate the carcinogenicity of Aroclor 1254, but they were

consistent with the positive results of the Kimbrough et al. (1975) study and supported them. EPA (1985a) stated that the carcinogenicity of Aroclor 1260 "appears to have been demonstrated" and the carcinogenicity of Aroclor 1254 was "suggested."

EPA (1985a) discussed the difficulties in using data from assays with commercial PCB mixtures for quantitative risk assessment. The composition of these mixtures is highly variable. Different lots of the same Aroclor, while having the same average chlorine content, can differ substantially in content of individual isomers. The metabolic and pharmacokinetic behavior of the pure isomers varies greatly with the degree and position of chlorine substituents. Analysis of an Aroclor 1254 lot indicated a predominance of pentachloro biphenyl isomers, which are relatively rapidly metabolized and excreted. An Aroclor 1260 lot was primarily hexa- and heptachloro isomers, which would be retained in adipose and skin storage depots for long periods. These storage depots might be considered effective removal of carcinogens from the target organs or, conversely, a carcinogen pool capable of mobilization and adding to target organ exposure. Different Aroclors administered at the same dosage could result in completely different tissue-specific exposure levels for the various pure isomers and metabolites. A potency estimate based only on administered dosage is therefore inappropriate. EPA (1985a) concluded that the potency of any commercial PCB mixture is probably higher than any estimate that would be derived by using dietary levels of exposure as a basis for calculation.

EPA (1985a) selected the Kimbrough et al. (1975) study as the basis for the carcinogenicity risk assessment for PCBs. More recently, the Norback and Weltman (1985) study was used for quantitative risk assessment in EPA (1987a), which supersedes the aforementioned assessment. The Norback and Weltman (1985) study was preferred because the strain of rats used (Sprague-Dawley) has a low incidence of spontaneous liver neoplasia, the duration of the study was for the life span of the rats, and there was a sequential progression of liver lesions to hepatocellular carcinomas.

The available epidemiological data do not indicate a consistent tumorigenic effect among people exposed to PCBs.

4.4 INTERACTIONS WITH OTHER CHEMICALS

Many of the interactive effects of PCBs with other chemicals are related to the capacity of PCBs for enzyme induction. Therefore, the effects of PCBs on toxicity of other compounds depend on the role of oxidative metabolism in the toxicity of those compounds. Reported effects of PCB pretreatment include increased metabolism and excretion of pentobarbital and decreased pentobarbital sleeping times (Chu et al. 1977, Villeneuve et al. 1972), increased mutagenicity of B(a)P (Hugton et al. 1979), and increased hepatotoxicity of halothane and vinylidene fluoride (Sipes et al. 1978, Conolly et al. 1979).

Increased dietary ascorbic acid may protect against some of the toxic effects of PCBs, such as altered enzyme activity and liver histopathology, perhaps by inhibiting lipid peroxidation (Chakraborty et al. 1978, Kato et al. 1981). The exact mechanism is not known.

PCBs have had mixed effects on tumor development. Aroclor 1254 pretreatment protected mice from lung tumors but increased the number of mice with liver tumors 18 months after administration of *N*-nitrosodimethylamine (Anderson et al. 1983). Makiura et al. (1974) reported that Kanechlor 500 inhibited hepatocarcinogenicity of 3'-methyl-4-dimethylaminoazobenzene, *N*-2-fluorenylacetamide, and *N*-nitrosodiethylamine when administered orally to rats. Nagasaki et al. (1975) found that Kanechlor 400 and 500 enhanced the hepatocarcinogenicity of α -BHC in mice. PCBs promoted the development of enzyme-altered foci or hyperplastic nodules following treatment with nitrosamines (Oesterle and Deml 1983, Pereira et al. 1982) or *N*-2-fluorenylacetamide (Tatematsu et al. 1979).

Birnbaum et al. (1985) found that 2,3,3',4,4',5-hexachlorobiphenyl, but not 2,2',4,4',5,5'-hexachlorobiphenyl, when coadministered with 2,3,7,8-TCDD to mice during gestation resulted in a dose-related enhancement of the TCDD-induced hydronephrosis in mouse fetuses, but 2,3,3',4,4',5-hexachlorobiphenyl alone caused hydronephrosis in the mouse fetuses. 2,2',4,4',5,5'-Hexachlorobiphenyl did not induce hydronephrosis.

Haake et al. (1987) found that Aroclor 1254 antagonized the teratogenicity of 2,3,7,8-TCDD in mice. In this study, treatment of pregnant mice by gavage with Aroclor 1254 at 244 mg/kg on day 9 of gestation followed by 2,3,7,8-TCDD at 20 μ g/kg on day 10 resulted in an 8.2% incidence of cleft palate. Treatment with 2,3,7,8-TCDD alone resulted in a 62% incidence of cleft palate. Aroclor 1254 alone was not teratogenic.

Bannister et al. (1987) found that Aroclor 1254 partially antagonized the 2,3,7,8-TCDD-induced microsomal enzyme induction and immunotoxicity in mice.

5. MANUFACTURE, IMPORT, USE, AND DISPOSAL

5.1 OVERVIEW

PCBs are no longer produced or used in the United States; however, many of the transformers and capacitors which were produced with PCBs, and contain PCBs, are still in service. Therefore, these products constitute a potential source of exposure to the environment and to humans. Disposal of PCB materials is controlled by federal regulations.

5.2 PRODUCTION

PCBs have been commercially produced in the United States since 1929. Annual U.S. production of PCBs peaked in 1970 when 85 million pounds were produced. It was estimated that approximately 1000 million pounds of PCBs had been sold in North America since 1970. Manufacture of PCBs (Aroclors) in the United States was terminated in October 1977 because these products accumulated and persisted in the environment and because of their toxic effects. Monsanto, the sole U.S. manufacturer at that time, had been producing Aroclors 1016, 1221, 1242, and 1254. In 1974, Monsanto produced just over 40 million pounds of the Aroclor mixtures. Production had been approximately 40 million pounds annually since 1971. Monsanto produced PCB Aroclor products at a facility in Sauget, Illinois, but production was stopped in October 1977. Of the total PCBs sold in the United States since 1970, over 98% were Aroclor 1260, 1254, 1248, 1242, 1232, 1221, and 1016 and less than 2% were Aroclor 1268 and Aroclor 1262. Therefore, 98% of PCBs sold in the United States since 1970 have been covered in this document (IARC 1978, Hatton 1979, Durfee 1976, EPA 1976).

The Aroclors were prepared industrially by the chlorination of biphenyl with anhydrous chlorine in the presence of a catalyst such as iron filings or ferric chloride. The degree of chlorination, which determined which Aroclor was produced, was controlled by the anhydrous chlorine contact time in the reactor (EPA 1976).

5.3 IMPORT

Imports of PCBs through principal U.S. custom districts in recent years have been reported as follows (USITC, 1978, 1979, 1980, 1982):

Year	Import volume (lb)
1981	11,000
1979	357,147
1978	483,074
1977	280,867

No data were located to indicate that PCBs have been imported after 1981.

Section 6(e)(3)(A) of TSCA (Pub. L. 94-469, 90 stat. 2003, 15U.S.C.2601 et seq) prohibits all manufacture and importation of PCBs as of January 1, 1979. As of January 2, 1979, EPA announced that companies that had filed petitions for exemptions from the PCB manufacturing/importation ban could continue the manufacturing or importation activity until EPA has acted on the application petition. (EPA 1979).

5.4 USES

A thorough review of PCB use in the United States can be found in EPA (1976). By 1974, all U.S. use of PCBs was in closed systems for the production of capacitors and transformers. As of 1976, 70% of Monsanto's domestic sales of Aroclors was used in capacitor production and 30% in transformer production. Aroclors are no longer used in the production of capacitors and transformers; however, many of the devices manufactured with Aroclors are still in service today. The life expectancy of transformers containing PCBs is >30 years, and the life expectancy of capacitors can range from 10 to >20 years, depending upon electrical application. PCBs were used in capacitors and transformers because of their excellent dielectric properties and fire resistance. Production of a large capacitor involved filling the capacitor with the Aroclor oil (typically over 2 to 3 lb of PCB) through a small hole and then sealing. Transformers were similarly filled, but may contain many times the amount of PCBs, depending on size. As of 1976, only 5% of the transformers produced in the United States were filled with PCBs, but 95% of the capacitors used PCBs (Durfee 1976). As of 1981, an estimated 131,200 PCB transformers were still in service in the United States, representing approximately 1% of all operational transformers (Orris et al. 1986).

5.5 DISPOSAL

On April 18, 1978, regulations became effective in the United States concerning the storage and disposal of PCBs. These regulations specified incineration as the only acceptable method of PCB disposal unless, by reason of the inability to dispose of the waste or contaminated material in this manner, clearance is obtained from the EPA to dispose of the materials in another way. In March 1983, the EPA issued a procedural amendment to the PCB rule to enable new disposal technologies to receive approval on a nationwide basis. At present, EPA's PCB disposal rules typically require that various types of PCBs and PCB materials be disposed of in chemical-waste landfills or destroyed in high-temperature incinerators or high-efficiency boilers. The disposal rules are published in the July 1984 Code of Federal Regulations, 40CFR, Part 761 (Kokoszka and Flood 1985, Hatton 1979).

6. ENVIRONMENTAL FATE

6.1 OVERVIEW

At present, the major source of PCB exposure in the general environment appears to be environmental cycling of PCBs previously introduced into the environment. This cycling process involves volatilization from ground surfaces into the atmosphere with subsequent removal from the atmosphere via wet/dry deposition and then revolatilization. The environmental persistence of PCBs generally increases with an increase in the degree of chlorination of the congener. The Aroclors with a high degree of chlorination (1248, 1254, and 1260) are resistant to biodegradation and appear to be degraded very slowly in the environment. The chemical composition of the original commercial Aroclor mixtures which were released to the environment has changed over time since the individual congeners degrade and partition at different rates. Reviews of the environmental fate processes of PCBs are available (EPA 1987a, Leifer et al. 1983, Callahan et al. 1979).

6.2 RELEASES TO THE ENVIRONMENT

Since the Aroclors are no longer produced or used in the production of new products in the United States, industrial effluent discharges from production sources no longer occur. Current sources of PCB release to the environment include releases from landfills containing transformers, capacitors, and other PCB wastes, waste incineration of PCB materials, spills, and improper (or illegal) disposal to open areas (Weant and McCormick 1984, Murphy et al. 1985). In addition, explosions or overheating of transformers containing PCBs may release significant amounts of these materials into the local environment.

PCB emissions from landfills and incinerator stacks have been monitored (Murphy et al. 1985). This monitoring has indicated that the amount of PCBs released from these sources may not be significant when compared to estimated quantities of PCBs in the atmosphere.

Atmospheric fallout and washout have been identified as nonpoint sources of PCB exposure to the environment (Kleinert 1976, Weant and McCormick 1984, Swackhamer and Armstrong 1986, Larsson 1985). Although additional research is required for a definitive answer, evidence suggests that the current major source of PCB release to the environment is an environmental cycling process (Swackhamer and Armstrong 1986, Larsson 1985, Murphy et al. 1985). This cycling process involves volatilization of PCBs from bodies of water or from soil surfaces into the atmosphere. Once in the atmosphere, the PCBs are returned to earth via washout/fallout where the cycle is subsequently repeated with revolatilization. Since the volatilization and degradation rates of PCBs vary among the congeners present, this cycling process causes an

alteration of the PCB ratio in water and air relative to the original source.

6.3 ENVIRONMENTAL FATE

6.3.1 Transport and Partitioning

In water, adsorption to sediments or other organic matter is a major fate process for the PCBs (EPA 1987a, Callahan et al. 1979). Experimental and monitoring data have shown that PCB concentrations are higher in sediment and suspended matter than in the associated water column. Based on their water solubilities and octanol-water partition coefficients, the lower chlorinated components of the Aroclors will sorb less strongly than the higher chlorinated isomers. Although adsorption can immobilize PCBs for relatively long periods of time in the aquatic environment, resolution into the water column has been shown to occur on an environmental level (Swackhamer and Armstrong 1986, Baker et al. 1985). The substantial quantities of PCBs contained in aquatic sediments can therefore act as an environmental sink for environmental redistribution of PCBs.

Volatilization is also an important environmental fate process for the PCBs that exist in natural water in the dissolved state. The values of the estimated Henry's law constants for the Aroclors (although they occur as a mixture in natural water) (see Table 3.2) are indicative of significant volatilization from environmental waters (Lyman et al. 1982). A study conducted on Lake Michigan has indicated that volatilization may be the major removal mechanism of PCBs from lakes (Swackhamer and Armstrong 1986). Strong PCB adsorption to sediment, however, significantly decreases the rate of volatilization, with the higher chlorinated Aroclors having longer volatilization half-lives than the lower chlorinated Aroclors (EPA 1985a). However, eventual resolution of PCBs from sediment into the water column can then result in volatilization.

The low water solubility, high octanol-water partition coefficients of the PCBs and demonstrated strong adsorption of PCBs to soils and sediment (EPA 1987a, Callahan et al. 1979, Sklarew and Girvin 1987) indicate that significant leaching should not occur in soil under most conditions. The tendency of the lower chlorinated PCBs to leach will be greater than the highly chlorinated PCBs. In the presence of organic solvents, PCBs can leach significantly in soil (Griffin and Chou 1981).

Organics having vapor pressures $>10^{-4}$ mm Hg should exist almost entirely in the vapor phase in the atmosphere, while organics having vapor pressures $<10^{-8}$ mm Hg should exist almost entirely in the particulate phase (Eisenreich et al. 1981). The vapor pressures of the Aroclors (see Table 3.2) indicate that they should therefore exist primarily in the vapor phase in the atmosphere. Monitoring data have shown that between 87 and 100% of the PCBs in air are operationally in the vapor phase (Eisenreich et al. 1981). The tendency of PCBs to adsorb to particulates will increase as the degree of chlorination increases.

PCBs in the atmosphere are physically removed by wet and dry deposition (Eisenreich et al. 1981). Dry deposition occurs only for the PCBs associated in the particulate phase. The PCB concentration of rain

anywhere in the world may typically range between 1 and 250 ng/L (Eisenreich et al. 1981), which is an indication of the importance of wet deposition.

6.3.2 Transformation and Degradation

The ability of PCBs to be degraded or transformed in the environment is dependent upon the degree of chlorination of the biphenyl molecule (EPA 1987a, Leifer et al. 1983, Callahan et al. 1979). In general, the persistence of PCB congeners increases as the degree of chlorination increases.

In the atmosphere, the vapor phase reaction of PCBs with hydroxyl radicals (which are photochemically formed by sunlight) may be the dominant transformation process. The estimated half-lives for this reaction in a typical atmosphere with various PCB isomers are as follows (EPA 1987c): monochlorobiphenyl, 12.9 days; dichlorobiphenyl, 27.8 days; trichlorobiphenyl, 1.43 months; tetrachlorobiphenyl, 3.1 months; pentachlorobiphenyl, 4.75 months; hexachlorobiphenyl, 10.3 months; and heptachlorobiphenyl, 1.31 years.

In the aquatic environment, transformation processes such as hydrolysis and oxidation do not significantly degrade PCBs (Mabey et al. 1981; Callahan et al. 1979). Photolysis appears to be the only viable chemical degradation process in water; however, sufficient experimental data are not available to determine its relative rate or importance in the environment (Leifer et al. 1983).

Reviews of the biodegradability of PCBs are available (EPA 1987a, Leifer et al. 1983). In general, the results show that mono-, di-, and trichlorinated biphenyls (Aroclors 1221 and 1232) biodegrade relatively rapidly, tetrachlorinated biphenyls (Aroclors 1016 and 1242) biodegrade slowly, and higher chlorinated biphenyls (Aroclors 1248, 1254, and 1260) are resistant to biodegradation. In addition to the degree of chlorination, chlorine positions on the biphenyl ring appear to be important in determining the biodegradation rate. For example, PCBs containing all of the chlorines on one ring are degraded faster than PCBs containing the chlorines distributed between both rings, and PCBs containing chlorines in the ortho positions are more resistant (Leifer et al. 1983). A study of subsurface aquatic sediments has shown that PCBs containing chlorines in the para positions are preferentially biodegraded as compared to other ring positions (Brown et al. 1987). This study of subsurface sediments, primarily from spill sites, has also shown that the higher chlorinated congeners are biotransformed by a reductive dechlorination to lower chlorinated PCBs which are biodegradable by aerobic processes. This is important since PCBs in soil systems or in aquatic sediments have not been shown to degrade by processes other than biodegradation. Therefore, biodegradation is probably the ultimate degradation process in soils and in sediments.

A summary of experimentally determined bioconcentration factors of various Aroclors (1016, 1248, 1254, and 1260) in aquatic species (fish, shrimp, oyster) has found Aroclor bioconcentration factors ranging from 26,000 to 660,000 (Leifer et al. 1983).

7. POTENTIAL FOR HUMAN EXPOSURE

7.1 OVERVIEW

PCBs partition significantly from water to aquatic organisms such as fish and can result in extremely high bioconcentration factors. Consumption of contaminated fish then results in human exposure to PCBs. Consumption of fish has been identified as a primary route of human exposure to PCBs. The general population is also exposed, on a continual basis, to PCB levels in the breathable air. A review of environmental PCB monitoring data is available (EPA 1987a).

7.2 LEVELS MONITORED OR ESTIMATED IN THE ENVIRONMENT

7.2.1 Air

Eisenreich et al. (1981) reported the following typical atmospheric concentrations of PCBs:

Location	Concentration range (ng/m ³)	Mean
Urban	0.5 to 30	5-10
Rural	0.1 to 2	0.8
Great Lakes	0.4 to 3	1
Marine	0.05 to 2	0.5
Remote	0.02 to 0.5	0.1

These values were derived from monitoring data reported in the literature.

Ambient atmospheric PCB concentrations of 7.1 and 4.4 ng/m³ were detected in Boston, Massachusetts, and Columbia, South Carolina, respectively, during the summer of 1978 (Bidleman 1981). These concentrations are a composite for Aroclors 1016, 1242, and 1254. Analysis of ambient air in Antarctica between 1981 and 1982 found PCB levels of 0.02 to 0.18 ng/m³ (Tanabe et al. 1983).

The average PCB concentration (Aroclors 1242 and 1260) emitted from gas vents at a hazardous waste landfill in North Carolina was found to be 0.126 mg/m³ (Lewis et al. 1985). PCB concentrations of 0.01 to 1.5 ppm were detected in the fly ash from five municipal incinerators operating under different technological and working conditions (Morselli et al. 1985). Stack effluents from several midwest municipal refuse and sewage incinerators contained PCB levels of 300 to 3000 ng/m³ (Murphy et al. 1985). The total PCB concentration measured in the flue gas effluent from a municipal waste incinerator in Ohio was 260 ng/m³ (Tiernan et al. 1983). PCBs were detected in effluents from combustion of coal and refuse at Ames, Iowa, at levels of 2 to 10 ng/m³ (EPA 1987a).

The average adult male inhales approximately 20 m^3 of air per day. Assuming the breathable outdoor air at a typical urban location contains an average PCB concentration of 5 ng/m^3 , the average daily intake via inhalation would be 100 ng. This estimate pertains to background levels of PCBs in outdoor air. As reported in Sect. 7.4 (populations at high risk), PCB levels in certain indoor air may be an order of magnitude higher than in outdoor air.

7.2.2 Water

The concentration of PCBs in the oceans is an indication of the environmental background level in water. Concentrations reported for various seawaters include 0.04 to 0.59 ng/L in the north Pacific, 0.035 to 0.069 ng/L in the Antarctic, 0.3 to 3 ng/L in the southern North Sea, and 0.02 to 0.20 ng/L in the North Atlantic (Tanabe et al. 1983, 1984; Boon and Duinker 1986, Giam et al. 1978).

Mean PCB concentrations of 0.63 to 3.3 ng/L were detected in the waters of western Lake Superior during 1978 to 1983 monitoring (Baker et al. 1985). Mean levels of 3.0 to 9.0 ng/L (1974 to 1976) and 0.49 to 17.15 ng/L (1979 to 1981) were found in the water columns of Lake Michigan and Lake Huron, respectively (Rodgers and Swain 1983). Analysis of water from eight sites in Galveston Bay resulted in an average PCB level of 3.1 ng/L between 1978 and 1979 (Murray et al. 1981). Thirty-two of 163 wells monitored in industrialized areas of New Jersey were found to contain PCB levels ranging from 60 to 1270 ng/L (EPA 1987a). Mean PCB levels of 25 to 38 ng/L were detected in waters collected from 11 agricultural watersheds in Ontario during 1975 to 1977 (Frank et al. 1982). A discussion of a number of PCB monitoring studies conducted on the Hudson River can be found in EPA (1987).

Although PCBs are widespread in the aquatic environment, their low solubility generally prevents them from reaching high concentrations in drinking water supplies (EPA 1980a). The National Organic Monitoring Survey (NOMS) was conducted by the EPA to determine the frequency of occurrence of specific organic chemicals (including PCBs) in finished water supplies of 113 cities nationwide (EPA 1987a). Data from the three phases (referred to as NOMS I, II, and III) of the study were collected between March 1975 and January 1977. PCBs were not found in groundwater supplies sampled in NOMS I (minimum quantifiable limit of 0.12 ppb). Only a single finished groundwater sample in each of NOMS I and II contained detectable levels of PCBs; the concentration of each was reported to be 0.1 ppb (detection limits of 0.1 to 0.2 ppb). PCBs were detected in two finished surface water supplies in each of NOMS I and II and in one surface water in NOMS III; the concentrations of the five positive samples ranged from 0.1 to 1.4 ppb. A total mean PCB level of 0.12 to 0.8 ppb was found in tap water from the Waterford Water Co. (Hudson River source) in 1976 and 1977 (EPA 1987a, Kim and Stone, n.d.)

7.2.3 Soil

An analysis of 99 soil samples from rural and urban sites throughout Great Britain was conducted to determine background levels of PCBs in British soils (Creaser and Fernandes 1986). PCBs were identified in all samples within the range of 2.3 to 444 ppb ($\mu\text{g/kg}$). The mean and

median values found for all samples were 22.8 and 7.2 ppb, respectively. PCB levels ranging from 4.5 to 47.7 $\mu\text{g}/\text{kg}$ have been detected in soil samples collected in the vicinity of incineration facilities in South Wales and Scotland during 1984 to 1985 (Eduljee et al. 1985, 1986). An analysis of Japanese soils detected PCB levels as high as 100 $\mu\text{g}/\text{kg}$; however, 40% of the samples had levels <10 $\mu\text{g}/\text{kg}$ (Creaser and Fernandes 1986).

PCB concentrations ranging from <1 to 33 ppb have been detected in the soils of the Everglades National Forest in Florida (Requejo et al. 1979), which is consistent with the monitoring data from Great Britain. Carey et al. (1979a) analyzed soils from 37 states in 1972 as part of the National Soils Monitoring Program and found PCB in only 2 of 1483 soil samples; however, the analytical technique used had a minimum detectable limit of only 0.05 to 0.1 ppm, which was not low enough to detect the mean and median levels reported in Great Britain. Carey et al. (1979b) used the same analytical technique to analyze soils from five U.S. urban areas in 1971; positive detections were reported for three areas with PCB levels ranging from 0.02 to 11.94 ppm.

PCB levels of 0.098 to 0.54 mg/kg have been detected in the sediments from four remote high-altitude lakes in the Rocky Mountain National Park (Heit et al. 1984), which indicates levels of PCBs that can accumulate in sediments from natural deposition. Sediment core samples from the Milwaukee harbor, which has received industrial effluents of PCBs, have been found to contain levels of 1.03 to 13.4 mg/kg (Christensen and Lo 1986). Analysis of sediments from 19 selected streams in the Potomac River Basin found maximum PCB levels of 1.2 mg/kg (Feltz 1980). Upper sediment layers from the Hudson River and New York Harbor in 1977 contained Aroclor 1254 levels of 0.56 to 1.95 ppm and Aroclor 1242 levels of 3.95 to 33.3 ppm (Bopp et al. 1982). Analysis of surficial sediments from the Great Lakes and various associated waters found Aroclor 1254 levels of 2.5 to 251.7 ng/g, with the higher levels detected in Lake Erie (Thomas and Frank 1981). An average Aroclor 1260 concentration of 120 ng/g has been detected in sediment samples from eight sites along the coast of Maine (Ray et al. 1983).

7.2.4 Other

7.2.4.1 Foodstuffs

Table 7.1 lists the amounts of PCBs detected in raw domestic agricultural commodities during fiscal years 1970 to 1976. These commodities were analyzed as part of federal monitoring programs conducted by the U.S. Food and Drug Administration (FDA) and the U.S. Department of Agriculture. It appears from Table 7.1 that fish are the primary foodstuff containing environmental background levels of PCBs; additional fish monitoring data are cited below. The contamination of fish is a consequence of the contamination of the aquatic environment and resulting bioconcentration (EPA 1980a).

Since the early 1960s, the FDA has conducted the Total Diet Studies, which have also been known as the Market Basket surveys. These studies, conducted on an annual basis, analyze ready-to-eat foods collected in markets from a number of cities nationwide to determine the

Table 7.1. Aroclor residues in raw domestic agricultural commodities for fiscal years 1970-1976

Commodity	Number of samples analyzed	Percent with positive detections	Average concentration (ppm)
Fish	2,901	46.0	0.892
Shellfish	291	18.2	0.056
Eggs	2,303	9.6	0.072
Red meat ^a	15,200	0.4	0.008
Poultry	11,340	0.6	0.006
Fluid milk	4,638	4.1	0.067
Cheese	784	0.9	0.011

^aFiscal years 1973-1976.

Source: Duggan et al. 1983.

intake of selected contaminants in the American diet. Table 7.2 presents the recent results of the Total Diet Studies with respect to PCBs. Since the mid-1970s, individual diets for adult males (19 years old), infants, and toddlers have been analyzed. Assuming that the average adult male weighs 70 kg and that the estimated dietary intake of PCBs is approximately 0.008 $\mu\text{g/kg/day}$ (average of the three most recent figures reported in Table 7.2), the average daily intake via diet would be 0.56 μg (560 ng). This estimate indicates that consumption of food may be a major source of PCB exposure in humans; however, the source of the PCBs in food may be significant. In the recent years of the Total Diet Study, the primary source of PCBs in the diet has been in the food category meat-fish-poultry (Gartrell et al. 1986a, 1985a,b). FDA chemists have found that the source of the PCBs in the meat-fish-poultry composite is almost always due to the fish component (Jelinek and Corneliussen 1976). This suggests that persons consuming less than the average amounts of fish will be exposed to lower quantities of PCBs.

7.2.4.2 Fish and precipitation

The U.S. Fish and Wildlife Service has analyzed whole fish samples collected nationwide for PCB residues as part of the National Pesticide Monitoring Program (Schmitt et al. 1985). Between 1980 and 1981, 315 fish were collected from 107 stations nationwide. PCB residues were detected in 94% of all fish, with the geometric mean concentration of all Aroclors (wet weight) found to be 0.53 $\mu\text{g/g}$. This concentration is lower than previous monitoring in 1976 to 1977 and 1978 to 1979, which found concentrations of 0.88 and 0.85 $\mu\text{g/g}$, respectively. It should be noted that these fish analyses pertain to whole fish samples, which are composites of both the edible and nonedible portions of the fish. Therefore, the concentrations reported may not necessarily reflect the actual human exposure which will occur from oral consumption. Composite fish samples taken from major tributaries and embayments of Lake Superior and Lake Huron in 1983 contained PCB levels of 600 to 72,000 ng/g on a lipid basis (Jaffe et al. 1985). Analysis of 62 samples of commercial fish (primarily from Lake Ontario) collected in 1980 found levels of 0.11 to 4.90 ppm (Ryan et al. 1984).

Based on available monitoring data from the literature, the following PCB ranges (in ng/L) in rainwater appear to be typical at the various locations (Eisenreich et al. 1981): urban (10 to 250), rural (1 to 50), Great Lakes (10 to 150), marine (0.5 to 10), and remote (1 to 30). PCB levels of 0.160 to 1.0 ng/L have been detected in snow from the Antarctic (Tanabe et al. 1983). A review of PCB monitoring of precipitation is available (Mazurek and Simoneitt 1985).

7.3 OCCUPATIONAL EXPOSURES

It was estimated that approximately 12,000 U.S. workers were potentially exposed to PCBs annually from 1970 to 1976 (NIOSH 1977a). At present, however, PCBs are no longer industrially manufactured or used in the United States. Therefore, occupational exposure to those workers involved in producing PCBs or manufacturing products with PCBs should no longer occur. The potential for occupational exposure still exists, however, since PCB-containing transformers and capacitors remain in use.

Table 7.2. Estimated dietary intake of PCBs for adults, infants, and toddlers ($\mu\text{g}/\text{kg}/\text{day}$)

Fiscal year	Adult	Infant	Toddler
1981-1982	0.003	ND ^a	ND
1980	0.008	ND	ND
1979	0.014	ND	ND
1978	0.027	0.011	0.099
1977	0.016	0.025	0.030
1976	T ^b	T	ND

^aND = not detected.

^bT = trace.

Source: Gartrell et al. 1985a,b,c and 1986a,b.

Exposure may occur during repair or accidents of electrical equipment containing PCBs (Wolff 1985). Occupational exposure may also occur during waste site clean-up of PCB-containing waste sites.

7.4 POPULATIONS AT HIGH RISK

Several groups are at high risk from PCBs because of unusually high exposures. Persons occupationally exposed to PCBs are at high risk. Nursing infants may be exposed to high PCB concentrations in the breast milk of lactating women (EPA 1985a), especially if the women consume large amounts of contaminated fish.

Other subpopulations are at high risk from PCBs because they are more sensitive to toxic effects of exposure. Embryos, fetuses, and neonates are potentially susceptible because of physiological differences from adults. They generally lack the hepatic microsomal enzyme systems that facilitate detoxification and excretion of PCBs (Calabrese and Sorenson 1977, Gillette 1967, Nyhan 1961). Breast-fed infants have additional risk caused by a steroid excreted in human breast milk, but not cow's milk, that inhibits glucuronyl transferase activity and thus glucuronidation and excretion of PCBs (Calabrese and Sorenson 1977, Gartner and Arias 1966). Children exposed to the antibiotic novobiocin may also be at greater risk because novobiocin noncompetitively inhibits glucuronyl transferase activity in vitro (Lokietz et al. 1963, Calabrese and Sorenson 1977).

Other subpopulations that are potentially more sensitive to PCBs include those with incompletely developed glucuronide conjugation mechanisms, such as those with Gilbert's syndrome or Crigler and Najjar syndrome (Lester and Schmid 1964, Calabrese and Sorenson 1977). Persons with hepatic infections may have decreased glucuronide synthesis, making them more sensitive because of their decreased capacity to detoxify and excrete PCBs (Calabrese and Sorenson 1977).

The indoor air in a number of public buildings (schools, offices) was monitored in Minnesota during 1984 for Aroclors 1242, 1254, and 1260 (Oatman and Roy 1986). The total mean Aroclor concentration in the indoor air of buildings using PCB transformers was found to be nearly twice as high as buildings not using PCB transformers (457 vs 229 ng/m³). It is also noteworthy that the levels found in all the indoor airs were significantly higher than in typical ambient outdoor air.

The indoor air in a number of laboratories, offices, and homes was monitored for various Aroclors. It was found that "normal" indoor air concentrations of PCBs can be 1 order of magnitude higher than those in the surrounding outdoor atmosphere (MacLeod 1981). It was suggested that certain electrical appliances and devices (such as fluorescent lighting ballast), which have PCB-containing components, can emit PCBs into the indoor air, thereby elevating indoor PCB levels significantly above outdoor background levels.

8. ANALYTICAL METHODS

8.1 ENVIRONMENTAL MEDIA

The method widely used in laboratories for the analysis of PCBs in complex environmental samples is capillary column gas chromatography with electron capture (EC) detection (Schneider et al. 1984, Alford-Stevens et al. 1986). The use of mass spectrometry (MS) detectors has increased significantly, but most laboratories rely on EC detectors. EC detectors are more sensitive than MS detectors operated in electron ionization mode; the sensitivity difference can be as much as 2 or 3 orders of magnitude (Alford-Stevens et al. 1986). Table 8.1 lists several analytical methods, which have been standardized by either the EPA or NIOSH, for PCB analysis. Details of sample collection, storage, and analysis of PCBs are available (Erickson 1986).

The analytical methods referenced in Table 8.1 pertain to the detection of Aroclor formulations and not individual PCB isomers. With EPA Method 680, however, PCBs are identified and measured by the level of chlorination (EPA 1985c). This method has been used only since 1981, and most environmental data reported before that were probably underestimated.

The determination of Aroclor concentrations (rather than the level of chlorination) in environmental samples is complex and can produce significantly different results from different laboratories even though the analytical procedures have been standardized (Alford-Stevens et al. 1985). As a result of the difference in biodegradability, water solubility, and volatility of individual PCB isomers, the concentrations of these individual isomers in environmental samples can be strikingly different from the commercial PCB analytical reference standards.

8.2 BIOMEDICAL SAMPLES

Analytical methods used for biomedical samples are listed in Table 8.2. Gas chromatography-mass spectrometry procedures developed to determine milligram-per-kilogram levels of PCBs in breast milk and fat (Hutzinger et al. 1974) usually have lower sensitivity than EC detectors (Safe et al. 1985, Smrek and Needham 1982). No accepted quantitative procedure for the determination of the total PCB content in human tissue sample exists. The PCB standard mixture selected for quantification varies between investigators since no standard mixture exists with the same peak pattern as in human tissues because of differences in metabolism of the various PCB isomers. In recent years, high-resolution gas chromatography has made it possible to use single PCB congeners for quantitation. The selection of the congeners may be made on the basis of their abundance in the samples, their toxicity, or their availability in analytical standards. In general, if only 1 to 3 major peaks are selected,

Table 8.1. Analytical methods for environmental media^a

Sample matrix	Sample preparation	Analytical method	Detection limit	Accuracy/precision	References
Air	Adsorption on glass filter and Florisil; hexane desorption	GC/EC	0.0006 mg/m ³ for 50-L sample	4.4% RSD (analytical) at concentrations <10 mg/m ³	NIOSH 1984a [method No. 5503]
Air	Adsorption on Florisil; hexane desorption; perchlorination	GC/EC	0.01 mg/m ³ (32 pg/injection)	2.8% RSD (analytical and perchlorination) at concentrations <10 mg/m ³	NIOSH 1977a [method No. P & CAM 253]
Water	Extraction with methylene chloride; dry extract; exchange to hexane	GC/EC	0.065 µg/L (PCB-1242)	Standard deviation 1.6-5.5% and accuracy 88-96% at 25-110 µg/L	EPA 1982a [method 608]
Water	Extraction with methylene chloride	GC/MS	30-36 µg/L (PCB-1221, 1254)	Standard deviation 11-13% and accuracy 77-80% at 5-2400 µg/L	EPA 1982a [method 625]
Air	Adsorption on water-deactivated Florisil; hexane desorption; perchlorination with antimony pentachloride at 288°C	GC/EC	NR	NR	Lin and Que Hee 1985, 1987
Soil, sediments, and other solid sample matrices	Extraction with hexane-acetone mixture, Florisil column chromatographic clean-up and desulfurization by copper or mercury if necessary	GC/EC	<1 µg/g	NR	EPA 1982b [method 8080]

^aGC = gas chromatography; EC = electron capture; MS = mass spectroscopy; RSD = relative standard deviation; NR = not reported.

Table 8.2. Analytical methods for biological samples

Sample matrix	Sample preparation	Analytical method ^a	Detection limit	Accuracy/precision	References
Blood serum	Extract serum with ethyl ether and <i>n</i> -hexane; treat with methanolic KOH; extract with hexane and column chromatographic cleanup by silica gel	HRGC/EC	1.0 ng/mL on 10-mL sample	>80% accuracy at 25–400 ng/mL	NIOSH 1984b [method No. 8004]
Tissue, eggs, fat	See Bush and Lo 1973	TLC	0.5 mg/kg	Precision ± 0.05 mg/kg at 0.5 mg/kg	IARC 1978
Serum	Mixed solvent extraction, column chromatographic cleanup on silica gel	GC/EC	NR	Accuracy 92.6% at 50 μ g/L and 114.1% at 10 μ g/L; accuracy 89.6–138.1% at 9.9–74.2 μ g/L for inter-laboratory determinations	Burse et al. 1983a,b
Serum	Solvent extraction, column chromatographic cleanup on 10% silver nitrate on silica gel	GC/EC	NR	Accuracy 93.7% at 41 μ g/L	Needham et al. 1980
Serum	Mixed solvent extraction, column chromatographic cleanup with hydrated silica gel for separation of PCBs from PBBs	GC/EC	2.5 ng/mL	Accuracy 95.3% at 100 μ g/L and 105–127% at 10 μ g/L	Needham et al. 1981
Adipose tissue	Solvent extraction, column chromatographic cleanup on sulfuric acid/silica gel and 10% silver nitrate/silica gel columns	GC/EC	NR	Accuracy 91–93% at 3 μ g/g	Smrcek and Needham 1982
Human milk	Mixed solvent extraction, cleanup on Florisil-silicic acid column	HRGC/EC	NR	NR	Mes et al. 1984
Serum	Solvent extraction with diethyl ether and hexane, sulfuric acid, and silica column cleanup	HRGC/EC	0.1 ng/mL	85% at 25–125 ng/mL	Luotamo et al. 1985
Blood	Solvent extraction with hexane, methanolic KOH hydrolysis, silica gel, and alumina column cleanup and perchlorination	GC/EC	NR	NR	Lin and Que Hee 1985, 1987

^aHRGC = high-resolution gas chromatography; GC = gas chromatography; EC = electron capture; TLC = thin-layer chromatography; NR = not reported.

the results will be greater by a factor of approximately 2 than those obtained if a dozen peaks are selected. A congener-specific analysis of a commercial PCB preparation and the PCB composition of a human milk sample have been reported by Safe et al. (1985). Variables in sampling method may also greatly influence results. For example, PCB level in milk fat may decrease during lactation and with maternal age, weight, and purity (Jensen 1987). It has been shown by Lawton et al. (1985) that random error, interlaboratory variations in procedure, and methods used for reporting data can all have considerable impact on the reported PCB levels in human tissues. Such effects, however, should not deter investigators from using serum PCB data for assessing environmental exposure to populations or for statistical correlations with clinical parameters in epidemiological studies. Caution should be exercised when comparing exposure estimates or health effect studies reported by different investigators or when considering "the use of a specific serum PCB tolerance limit as a basis for administration action" (Lawton et al. 1985).

9. REGULATORY AND ADVISORY STATUS

9.1 INTERNATIONAL

No data were located in the available literature.

9.2 NATIONAL

9.2.1 Regulations

9.2.1.1 Food--FDA temporary tolerances

Agency	Standard	Value (ppm)	References
FDA	Foods	0.2-3.0	EPA 1987a
FDA	Packaging	10.0	EPA 1987a

9.2.2 Advisory Guidance

9.2.2.1 Air

AGENCY

ADVISORY

PCBs

NIOSH
TLV-TWA--1.0 $\mu\text{g}/\text{m}^3$ (NIOSH 1977b)

National Academy of
Sciences (NAS)
Suggested no adverse response level
(SNARL)--350 $\mu\text{g}/\text{L}$ (NAS 1977)

Aroclor 1254

American Conference of
Government Industrial
Hygienist (ACGIH)
TLV-TWA--0.5 mg/m^3 (ACGIH 1986)

Aroclor 1242

ACGIH
TLV-TWA--1 mg/m^3 (ACGIH 1986)

9.2.2.2 Water

AGENCY

ADVISORY

EPA
Ambient water quality criteria (AWQC)--0.79 to 0.0079 ng/L for
carcinogenicity at 10^{-5} to 10^{-7} risk levels (EPA 1980a)
Drinking water criteria (DWC)--0.5 to 0.005 $\mu\text{g}/\text{L}$ for
carcinogenicity at 10^{-4} to 10^{-6} risk levels (EPA 1987a)

Aroclor 1016

EPA Longer-term health advisory (HA) (adult)--0.0035 mg/L (EPA 1987a)
 Longer-term HA (child)--0.001 mg/L (EPA 1987a)

9.2.2.3 Soil

AGENCY ADVISORY

EPA Permissible PCB soil contamination levels corresponding to:
 Noncancer 10-day HA (adult)--700 µg/day
 Noncancer 10-day HA (child)--100 µg/day
 Cancer risk specific doses: 1.75 to 0.00175 µg/day at 10^{-4} to 10^{-7} risk levels (EPA 1986d)

9.2.2.4 Others

AGENCY ADVISORY

EPA Reportable quantity (RQ) (statutory) - 10 lb (EPA 1985d)
 RQ (proposed) - 1 lb (EPA 1987d)

9.2.3 Data Analysis

Reference dose. The EPA (1987a) derived an oral reference dose (RfD) of 0.0001 mg/kg/day for Aroclor 1016 based on the study by Barsotti and Van Miller (1984) using an uncertainty factor of 100. This RfD was used to calculate longer-term HAs for adults and children. In this study, rhesus monkeys were maintained on diets containing Aroclor 1016 at 0.025, 0.25, and 1.0 ppm for approximately 7 months prior to mating and during gestation. The offspring of the 1.0-ppm group were significantly smaller than the controls. No effects were observed at 0.25 ppm, which was considered a NOAEL and is equivalent to a dose of 0.0105 mg/kg/day, assuming that a monkey consumes a daily amount of food equal to 4.2% of its body weight. The RfD was calculated according to methods outlined in Barnes et al. (1987) as follows:

$$\text{RfD} = (0.01 \text{ mg/kg/day}) / (100) = 0.0001 \text{ mg/kg/day,}$$

where: 0.01 mg/kg/day - NOAEL

100 - uncertainty factor for interspecies (10) and intraspecies (10) extrapolation, appropriate for use with an animal NOAEL.

Carcinogenic potency. EPA (1987a) determined that the positive evidence for carcinogenicity of Aroclor 1254, Aroclor 1260, Kaneclor 500, and Clophen A-30 and A-60 in animals, along with inadequate evidence in humans places these PCBs in category B2, probable human carcinogens. Because any PCB mixture that contains appreciable amounts of the components in Aroclors 1254 and 1260, Kaneclor 500, and Clophen A-30 and A-60 are likely to present a carcinogenic risk and because of the variety and variability of PCB mixtures, EPA (1987a) recommended that all commercial PCB mixtures be considered to have a similar carcinogenic potential and classified all PCB mixtures in category B2.

IARC (1982) has classified PCBs in Group 2B based on sufficient evidence in animals, inadequate evidence in humans and inadequate evidence for mutagenicity.

EPA (1987a) used the Norback and Weltman (1985) study as the basis for a quantitative carcinogenicity risk assessment for PCBs. The dietary level of 100 ppm Aroclor 1260 was converted to an intake of 5 mg/kg/day by assuming that a rat consumes food equal to 5% of its body weight per day. This dosage was converted to a TWA dosage of 3.45 mg/kg/day to reflect the fact that rats received 100 ppm for 16 months, 50 ppm for 8 months, and 0 ppm for the last 5 months. The rat dosage was converted to an equivalent human dose of 0.59 mg/kg/day on the basis of relative body surface areas. Incidences of trabecular carcinomas, adenocarcinomas, and neoplastic nodules in the liver were combined to produce total incidences of 45/47 in treated females and 1/49 in controls. Using these data, EPA (1987a) calculated a human q_1^* of $7.7 \text{ (mg/kg/day)}^{-1}$. Because there is no information regarding which constituents of any PCB mixture might be carcinogenic, Aroclor 1260 is assumed to be representative of other mixtures, and this potency estimate applies to them as well (EPA 1987a). The q_1^* was verified by the EPA agency-wide CRAVE committee on April 22, 1987 (EPA 1987e).

9.3 STATE

(Regulations and advisory guidance from the states were still being compiled at the time of printing.)

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RESULTS

The results of the ignition temperature tests are tabulated below:

<u>Sample No.</u>	<u>Ignition Temperature</u> ⁽⁴⁾	
	<u>Quartz Flask</u>	<u>Iron Plate</u> ⁽⁵⁾
Pyranol No. 1488	548C (1018F)	703C (1297F)
Pyranol-oil mixture containing 2 per cent by volume transformer oil	569C (1056F)	703C (1297F)
Transformer oil	229C (444 F) ⁽⁶⁾	356C (673 F)

In the ignition tests of the Pyranol and Pyranol-oil mixture, using the heated iron plate, the combustion was very weak and did not show any tendency to propagate beyond the vicinity of the heated iron surface. It will be noted that there was no confinement of the vapors in the tests with the heated iron plate.

-
- (4) The main value of the ignition test is to determine the minimum temperature required to produce ignition under the most favorable conditions in the absence of a flame or spark, including ratio of vapor to air and ratio of heated surface to volume of vapor-air mixture. Under less favorable conditions, as when the liquid is applied to a hot plate, a higher temperature for ignition is required. A limitation of the ignition test in a small vessel is that it does not show whether flame propagation for any material distance will occur. After determining the ignition temperature, therefore, it is necessary to obtain additional data having a bearing on flame propagation. These data are given by tests with hot plate and by flammability tests with specially-designed apparatus.
- (5) Within experimental error the optical pyrometer and the thermocouple gave the same values for the temperature of the iron plate.
- (6) A glass flask was used in this test.

FLAMMABILITY TESTS IN SPECIALLY-DESIGNED APPARATUS:

METHOD

The apparatus consists of a cylindrical steel vessel 6 in. in diameter (internal) and 26 in. long. It is provided with a small mica window and an outlet to the atmosphere. The apparatus is heated externally by gas burners. Openings are provided half way between the ends of the vessel to admit electrode terminals connected to an induction coil. The electrode terminals are spaced to give a spark gap of 1/4 in. A gauge calibrated in ounces per square inch gives approximate measurements of pressure within the cylinder.

An iron-constantan thermocouple connected to a potentiometer is used for rough measurements of the temperature of the vapor inside of the vessel.

Samples (80cc) were introduced into the cylinder which had previously been heated to a temperature of 137C (278.6F). The outlet of the cylinder was closed with a loose asbestos plug. Sparks were passed between the electrode terminals at intervals of 1/2 min after the first four minutes of the test. The pressure within the cylinder, as indicated by the gauge, was noted together with the length of flame at the opening closed by the loose asbestos plug.

Residual gases and vapors were displaced from the cylinder by a stream of air in the interval between tests.

RESULTS

Preliminary tests indicated that Pyranol-oil mixtures containing 5 per cent by volume of transformer oil gave a marked propagation of flame and explosions definitely stronger than Pyranol unmixed with oil. The results of a series of tests of Pyranol and of Pyranol-oil mixtures containing 2 and 3 per cent of oil by volume are given in Table I.

TABLE I
RESULTS OF FLAMMABILITY TESTS IN
SPECIALLY-DESIGNED APPARATUS

Sample	Pres. After Ign. Oz per Sq In.	Length of Flame at Open. in Clyn. In.	Remarks
Pyranol No. 1488	1-1/2	0	Asbestos plug not blown
" "	5-1/2	4-5	Asbestos plug blown
" "	7	0	Asbestos plug not blown
" "	6	6	Asbestos plug blown
" "	6	7	"
Pyranol-oil mix- ture, 2% oil by vol.	2	4	Asbestos plug blown
"	5	7	"
"	3	6	"
"	-	6	"
"	6	6	"
Pyranol-oil mix- ture, 3% oil by vol.	11	6	Asbestos plug blown
"	15	7	"
"	10	7	"
"	13	7	"
"	10	7	"

C O N C L U S I O N SFIRE HAZARD:

It appears that the fire hazard of Pyranol-transformer oil mixtures containing not more than 2 per cent of oil by volume is not appreciably greater than that of Pyranol free from oil.

Mixtures containing 3 per cent of ordinary transformer oil by volume are appreciably more flammable than Pyranol.

Results of flammability tests in specially-designed apparatus, summarized in Table I, show that the explosibility of the vapors of pyranol and of Pyranol-oil mixtures containing 2 per cent transformer oil by volume when mixed with air are of the same order under laboratory test conditions at higher temperatures (137C, 278.6F). The vapors of mixtures containing 3 per cent transformer oil by volume when mixed with air are more flammable, giving higher explosion pressures than Pyranol vapors alone under similar test conditions.

Results of flash point tests, fire tests, and ignition temperature tests of Pyranol admixed with small amounts of transformer oil are no lower than those obtained on Pyranol alone.

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**PLAINTIFF'S
EXHIBIT**

473

5004. Transformers and Apparatus.

a. Transformers installed in generating stations and substations shall be so located that fire and smoke from burning coils or boiling oil will be unlikely to do harm.

It is recommended that air-cooled transformers be isolated as much as possible, and that, if air blast is employed, the ducts be fireproof.

It is further recommended that transformers immersed in liquid that will burn be placed in a vault constructed in accordance with section 5006 of this code.

b. Transformers shall not be installed in buildings other than central stations or substations, except by permission of the authority enforcing this code. Where such permission has been granted, transformers shall be located as near as possible to the point at which the primary wires enter the building (see paragraph i of section 5008) and shall be contained in an enclosure of non-combustible material large enough to provide an air space of at least six inches on every side of the transformers. This enclosure shall be securely locked, access being allowed only to authorized persons, and shall be thoroughly ventilated. This shall not apply to the control-circuit transformer furnished with control equipment. These transformers shall be considered as subject to the requirements applying to the equipments with which they are used.

It is recommended that ventilation be secured by means of a chimney or flue leading out of doors.

c. For transformers filled with a liquid that will burn, the enclosure required by paragraph b of this section shall consist of fire-resistive vault construction as specified in section 5006.

d. For transformers filled with an approved liquid that will not burn and rated at more than 25 kva., a metal pan or concrete basin shall be provided, large enough to retain the liquid from the largest transformer involved. The name plate of such a transformer shall specify the liquid to be used. Such transformers may be installed on roofs without any enclosure or pan if

located away from doors and so that any leaking liquid will not reach windows or doors. By special permission, transformers containing an approved liquid that will not burn may be located inside buildings with no enclosing compartment and/or no pan (or basin), if provided with (1) a means for absorbing the gases which might be generated if arcing occurs inside the transformer case, or (2) a pressure relief vent connected to a chimney or flue which will carry such gases outside the building.

c. For transformers in electric furnace rooms the requirements of this section and of section 5006 of this article shall be followed so far as practicable; provided, however, that by permission of the authority enforcing this code, oil-filled transformers having a total rating of 75 k.v.a. or less, may be located in electric furnace rooms of fire-resistive construction, if surrounded by concrete curbs not less than six inches high and forming a basin of sufficient capacity to retain all the oil used in such transformers.

This is to guard against the possibility of molten metal from the furnace coming in contact with the transformer casing, and also to prevent oil from the transformers reaching the furnace.

f. Transformer cases shall be grounded as prescribed for the grounding of equipment in Article 9 of this code; provided, however, that cases or frames of transformers used exclusively to supply current to switchboard instruments need not be grounded if they are installed and guarded as required for the maximum potential at which they operate and provided that transformers mounted on wooden poles at a height of more than eight feet from the ground need not be grounded.

5005. Control and Protective Equipment.

The following paragraphs apply only to circuits and apparatus supplied through the service equipment specified in Section 5008 of this Article.

a. When operating at more than 600 volts, each motor, each transformer or bank of trans-

formers operating as a unit, and each other operating unit of apparatus shall, except as permitted in paragraph h, be separately controllable; and protected by a manually operable circuit-breaker which interrupts all ungrounded circuit wires and which is automatically actuated by excessive overcurrent, and the number of overcurrent units shall be as specified in the table of paragraph o of section 806 of Article 8. If an installation consists of a single motor operated at the supply voltage, the requirement for a circuit-breaker may be met by the service circuit-breaker.

b. Where a motor-starting device does not open all ungrounded leads to the motor, the circuit-breaker specified above shall be installed in sight of the person operating the motor-starting device or else have provision for locking in the open position.

c. Transformers operating in multiple shall not be considered as operating in bank and shall be separately protected on both the primary and secondary side. When a generator and a transformer, or bank of transformers, operate as a unit for stepping up or stepping down the voltage, they may be controlled and protected as an operating unit.

d. Oil circuit-breakers and switches shall be isolated from other switches and electrical apparatus wherever practicable. Where connected to circuits exceeding 5000 volts (grounded or ungrounded), oil circuit-breakers shall be mounted remote from the control panel. In place of remote control, metal enclosed equipments, such as metal-clad switchgear, trucks, cubicles and switchhouses may be used. When mounted in closed compartments, electrical or mechanical means shall be provided to indicate whether oil circuit-breakers are open or closed.

It is recommended that switches of the oil-immersed type used to control transformers be located in a vault, preferably separate from the transformers.

Safety control truck panels and metal-clad switch-gear units on circuits not exceeding 15,000 volts are considered to comply with this rule even though the circuit-breaker is not of the remote-control type.

e. Series trip coils connected directly to the circuit, unless adequately guarded or isolated by elevation, should not be used with panel or panel-frame-mounted oil circuit-breakers on circuits exceeding 750 volts.

f. Switches and control apparatus on circuits exceeding 2500 volts to ground shall be installed in a vault complying with section 5006, or in a fire-resistive switch room or motor room.

Safety control truck panels and metal-clad switch-gear units are considered to comply with this rule.

g. All switches including disconnectors shall be so located that the point from which they are operated is safely accessible to qualified and authorized persons. Barriers should be provided on both sides of isolating switches. Unless interlocking arrangements are provided, signs shall be installed at isolating switches warning against opening them while they are carrying current.

h. Oil-filled or other suitable types of fuses may be used on circuits not exceeding 2500 volts to ground and rated at not more than 300 amperes or not exceeding 7500 volts and 100 amperes, for the following purposes:

1. For the protection of individual feeder or branch circuits at the point where they receive their supply. If there is more than one such circuit there shall be a manually operable circuit-breaker between the point of origin of such circuits and the source of supply.

2. For the protection of individual transformers or banks of transformers operating as a unit when such transformers are supplied by a common feeder, provided that such feeder at the point where it receives its supply shall be protected by a manually operable or remote-control circuit-breaker. A circuit supplying a single transformer or bank of trans-

formers need not have circuit-breaker protection.

3. For the protection of motors and their controllers and protective devices against short-circuit or locked-rotor currents, provided such controllers are automatically actuated through time-limit overcurrent relays or other similar protective devices and open all ungrounded wires simultaneously, and are provided with the number of overcurrent units as specified in table of paragraph c of Section 808.

4. For the protection of apparatus other than motors and transformers by special permission.

i. Fusible cutouts shall be so installed that the blowing of the fuse will not result in injury to persons or damage to other equipment.

5000. Transformer Vaults.

Not applicable to central stations and substations in buildings used for no other purpose.

a. The walls and also the roof shall consist of reinforced concrete not less than six inches in thickness, or of brick not less than eight inches in thickness, or of load-bearing hollow tile not less than twelve inches in thickness coated on the inside with cement plaster, or of construction of equivalent strength and equivalent fire rating as determined by tests conducted according to the standard fire-test specifications; except that if the total transformer capacity so enclosed is not more than 100 kva., reinforced concrete four inches thick may be employed by special permission.

It is recommended that outside walls of the building, if of fireproof construction, constitute one or more of the walls of the vault or enclosure.

b. The enclosure shall be provided with means for ventilation which will prevent the development of room temperatures in excess of those at which the transformers installed therein may be safely operated. Temperatures shall be deter-

mined as prescribed in Standard No. 13 of the American Institute of Electrical Engineers, and temperatures under full load shall not exceed the values there given. All ventilating openings not connected to chimneys or flues or directly to outside air shall be provided with automatic dampers made of metal of thickness not less than No. 10 (U. S. standard gauge for sheet steel) to prevent the emission of smoke or fire. Openings for illumination or ventilation shall be protected by louvres or by substantial fixed metal screens with mesh not larger than one inch, and shall be so constructed that snow or rain will not reach wiring or apparatus of other than weather-proof construction.

Ventilating openings should be proportioned to the kva. capacity of the transformers, and should be so located as to facilitate air movement.

c. Where practicable, a suitable drain shall be provided which will carry off any accumulation of oil or water that may collect in the vault. Floor and drain shall have a pitch of not less than $\frac{1}{4}$ inch per foot. In vaults containing transformers having a total capacity of 100 kilovolt-amperes or less the drain may be omitted if the enclosure is so constructed as to retain all the oil used within the vault.

d. Any doorway leading from the vault into the building shall be thoroughly closed by means of a tight-fitting fire door approved for openings in Class A situations as defined in the Regulations of the National Board of Fire Underwriters for the Protection of Openings in Walls and Partitions Against Fire. A door sill not less than four inches in height shall be provided. In all cases the sill shall be of sufficient height to confine within the vault the oil from the largest transformer installed. Entrance doors shall be equipped with locks where necessary to prevent unauthorized access. Doors, if equipped with spring or other automatic locks, shall be so arranged that they may be readily and quickly opened from the inside.

e. Pipes for water, steam, gas, sewers, or other purposes and such accessories as faucets and sprinkler heads and ducts for ventilating other parts of the building should not be installed in transformer vaults. Where conditions are such that the presence of these pipes cannot be entirely avoided, they shall be so located or so protected by non-flammable waterproof barriers as to prevent any leakage or moisture from condensation reaching high-voltage wiring or apparatus, and such pipes shall be installed without valves or traps within the vault or room.

5007. Capacitors (Static Condensers).

a. Capacitors of the type made up of small units, separately or collectively protected by adequate fuses, may be installed in powerhouses or factory buildings if combustibles are kept well away from them; provided that if a liquid that will burn is used, each unit shall contain not more than three gallons in a container made substantially liquid tight without use of solder (although use of solder to prevent slight seepage of liquid is not prohibited). In rooms containing combustible dust or flying material, capacitors shall be enclosed.

If capacitors are accessible to other than qualified persons, a non-combustible grille or guard around them should be provided.

b. Capacitors containing liquid that will burn, but not meeting the requirements of the previous paragraph, shall be installed as specified for transformers in section 5004 of this Article.

c. For transformers used with capacitors, the requirements of section 5004 shall be followed; provided, however, that by permission of the authority enforcing this code, oil-filled transformers intended for and used only with capacitor installations and not subject to lightning disturbances may be installed in rooms of non-combustible construction and occupancy. Such transformers shall be of sufficient capacity to allow for ordinary rises in voltage; they shall