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# PCBs in the Built Environment

White Paper

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*Sponsored by the AIHA® Indoor Environmental Quality Committee in conjunction with the Construction Committee, Environmental Issues Committee, Exposure Assessment Strategies Committee, and Risk Assessment Committee*

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## 1.0 EXECUTIVE SUMMARY

Polychlorinated biphenyls (PCBs) are a group of man-made chemicals associated with a potential risk to human health and the environment. They were used in many building materials, particularly caulking, grout, expansion joint material and paint, from approximately 1950 to 1978. Both the U.S. Environmental Protection Agency (EPA) and the Agency for Toxic Substances and Disease Registry (ATSDR) have published extensive material evaluating human health impacts from exposure to PCBs. The apparent public health risks, including developmental effects in children, reproductive effects and long-term risks for cancer development, have driven consideration for actions, including further research into chronic health effects, mechanisms of contact, and assessing actual and potential exposures, both in public and commercial buildings, and in the workplace, where direct and incidental exposures may occur.

Two major legislative and legal efforts in the U.S. bring us to the current consideration of PCBs as the next potential public health hazard abatement initiative. The Toxic Substances Control Act of 1976 (TSCA), implemented restrictions and prohibitions regarding the manufacture, use and disposal of PCBs in the U.S. The second involved legal action initiated by the New York Lawyers for the Public Interest (NYLPI) after a concerned parent read a 2004 publication on PCB investigations in Boston, Massachusetts schools and other buildings and subsequently investigated his own child's school. Currently, the EPA and the City of New York are working together, under a Consent Agreement, to study and establish a policy for management of PCBs in K-12 schools.

There is growing evidence that PCB exposures, in both vapor and particulate matter form, emanate from PCB-containing products in the building environment. Additionally, secondary sources of PCBs, including materials that have become contaminated due to absorption from direct contact with PCB sources, or through adsorption of PCBs in the air that have been emitted by primary sources, such as caulk or light ballasts, can contribute to the overall exposures. In most cases, the building owners and occupants are not even aware of the existence of these materials and their potential hazards. It is not clear what the risk from these PCB-containing building materials is when compared to other PCB exposures (e.g. diet), due to a lack of data on potential exposures from sources in the built environment.

The purpose of this white paper is to 1) provide an overview of currently available information pertaining to PCBs in construction materials; 2) evaluate the exposure potential for building occupants, maintenance and construction personnel; and 3) identify gaps in the current knowledge base that would help occupational and environmental health professionals to better understand the risk to public health from PCBs in building materials. AIHA's findings and recommendations will be updated as new information becomes available.

## 2.0 ACRONYMS AND DEFINITIONS

**ACGIH** – American Conference of Governmental Industrial Hygienists. AIHA – American Industrial Hygiene Association.

**Aroclors** – Trade name for various mixtures of chlorinated biphenyl congeners manufactured by Monsanto Chemical Company which were sold in the United States. (See PCBs)

**Aryl Hydrocarbon Receptor (AHR)** – A cellular protein that is capable of binding to aryl hydrocarbons, leading to changes in gene expression within the cell nucleus which can result in abnormal cell function.

**ATSDR** – Agency for Toxic Substances and Disease Registry. EPA – United States Environmental Protection Agency.

**DOD** – United States Department of Defense. DOE – United States Department of Energy.

**HEPA** – High Efficiency Particulate Air. An air filter which can remove at least 99.97% of airborne particles greater than 0.3 microns in size.

**IARC** – International Agency for Research on Cancer. IRIS - Integrated Risk Information System.

**Liquid PCBs** – A homogeneous flowable material containing PCBs and no more than 0.5 percent by weight non-dissolved material.

**LOAEL** – Lowest Observed Adverse Effect Level. The lowest concentration of a chemical in a study, or group of studies, that produces a statistically or biologically significant increase in frequency or severity of adverse effects between the exposed population and an appropriate control.

**NIOSH** – National Institute for Occupational Safety and Health.

**NLPCBs** – Non-liquid Polychlorinated Biphenyls. Materials containing PCBs that by visual inspection do not flow at room temperature (25oC or 77oF) or from which no liquid passes when a 100 gram or 100 milliliter representative sample is placed in a mesh number 60 ±5 percent paint filter and allowed to drain at room temperature for 5 minutes. (From 40 CFR 761.3)

**NOAEL** – No Observed Adverse Effect Level. The highest concentration of a chemical in a study, or group of studies, at which there is no statistically or biologically significant increase in the frequency or severity of any adverse effects in the exposed population when compared to an appropriate control.

**Non-Legacy PCBs** – Unintentionally produced PCBs that occur as trace contaminants in certain products, particularly inks and dyes. Under TSCA, PCB concentrations of up to 50 ppm are allowed in certain products as a result of manufacturing processes.

**OSHA** – Occupational Safety and Health Administration.

**PCBs** – Polychlorinated biphenyls. A group of compounds in which chlorine atoms replace the hydrogen atoms in biphenyl. PCBs were used in industry in electrical insulators and in the manufacture of plastics until 1979.

**PCB bulk product waste** - Waste derived from manufactured products containing PCBs in a non-liquid state, at any concentration where the PCB concentration at the time of designation for disposal is greater than or equal to 50 parts per million. In 2012, the EPA proposed that building materials which have been "coated or serviced" with PCB-containing materials, such as caulk, mastics or sealants, can also be handled as PCB bulk product waste.

**PCB Congener** – Any single, unique well-defined chemical compound in the PCB category. The name of a congener specifies the total number of chlorine substitutes and the position of each chlorine. There are 209 separate PCB congeners based on the number and position of the chlorine atoms on the biphenyl ring structure.

**PCB Homolog** – A subcategory of PCB congeners having equal numbers of chlorine substituents. For example, tetrachlorobiphenyls are all PCB congeners with exactly 4 chlorine substituents that may be in any arrangement. There are 9 different homologs.

**PCB remediation waste** – Waste that has become contaminated as a result of a spill, release or other unauthorized disposal of PCBs. This includes environmental media, such as soil, sediments, gravel, sewage and industrial sludge, rags and other debris generated as a result of any PCB spill cleanup, as well as building materials (e.g., concrete, masonry).

**PPE** – Personal protective equipment.

**RfD** – Reference dose. A numerical estimate of a daily oral exposure to the human population, including sensitive subgroups such as children, that is not likely to cause harmful effects during a lifetime.

**TLV®** – Threshold Limit Value.

**TSCA** – Toxic Substances Control Act.

**Unauthorized use** – As per EPA TSCA regulations, any open applications (i.e., caulk) which contain PCBs greater than or equal to 50 parts per million by weight are considered an "unauthorized use" of non-liquid PCBs and requires removal of that material.

## 3.0 INTRODUCTION

Polychlorinated biphenyls (PCBs) are a group of man-made chemicals associated with risks to human health and the environment.[1,2] PCBs were manufactured in the United States from the late 1920s until 1979 for use in a variety of products including electrical equipment, hydraulic fluids, inks, lubricants, flame retardants, adhesives, surface coatings, insulating materials, pesticides, dyes, paints and plasticizers.[1,2,3,4,5] In the United States, TSCA promulgated a prohibition on the manufacture of PCBs, which became effective in 1979.[4,5]

In the past, PCB exposures were thought to occur primarily in industrial and commercial settings where transformers, capacitors or other electrical equipment containing PCB fluids were located.[6] Growing

evidence suggests that PCBs in construction materials may pose a previously unrecognized risk to building occupants, maintenance staff and those working in construction trades.[7] Building materials including caulking, adhesives, surface coatings, paint, ceiling tiles, window glazing, light ballasts and electrical wiring have been reported by various investigators inside and outside the United States to contain PCBs in the low parts per million (ppm) to percent (by weight or volume) quantities.[8]

PCB exposures can occur in the built environment from direct contact, volatilization, deterioration, or disturbance of PCB-containing materials. Children may be at particular risk due to epidemiological evidence that PCBs are developmental toxins, and the fact that many of the school buildings currently in use were either built or renovated during the time period that PCBs were in use.[2,6,7,8,9,10]

The potential public health implications from exposure to PCBs in construction materials are not well understood at this time. The evaluation of potential sources, pathways of human exposure and the collective health risk should assist the industrial hygienist in the selection of appropriate methods to control the exposure. Industrial hygienists are uniquely qualified to assist in the evaluation of this emerging issue and can apply the principles of industrial hygiene (i.e., anticipation, recognition, evaluation, control and confirmation) to PCBs in the built environment in order to reduce potential health risks for building occupants, maintenance staff and construction workers.

The purpose of this document is to provide an overview of the available science and information pertaining to PCBs in construction materials, to evaluate the PCB exposure potentials for building occupants, maintenance and construction personnel, and to identify critical information gaps that need to be addressed. This document also provides the user with background information on PCB production, uses and toxicity.

## 4.0 BACKGROUND

Polychlorinated biphenyls are a group of synthetic aromatic chemical compounds that have between one and ten chlorine atoms attached to a biphenyl ring structure.[1,2,6] There are 209 separate PCB congeners, based on the number and position of the chlorine atoms on the biphenyl ring structure.[1,2,6,11] Please refer to Appendix A for a table of the various PCB species by congener number.

PCBs exist in a variety of physical states ranging from oily, viscous liquids to waxy solids that are colorless to light yellow.[2,11] PCB chemical and physical properties include a high dielectric constant, high solubility in hydrocarbons, very low solubility in water, thermal stability, low vapor pressure, resistance to acids and bases, and chemical inertness under most circumstances.[1,2,6,12] The physical properties, however, vary with degree of chlorination, such that those congeners with fewer chlorine atoms are both more water soluble and more volatile than those with more chlorine atoms. These properties make PCBs, particularly the more highly chlorinated congeners, extremely persistent in the environment once released.[1,2,12,13] This persistence of PCBs, coupled with their distribution through the food chain, has resulted in continuing human uptake and exposure.

PCBs were manufactured in the United States from the late 1920s to approximately 1979.[1,2] PCB production was also reported in Austria, China, Czechoslovakia, France, Germany, Italy, Japan, the former Soviet Union,

Spain and the United Kingdom.[1,2,6] Commercially produced PCB products in countries outside the U.S. include the trade names Clophen (Germany), Kanechlor and Sanotherm (Japan), Phenoclor (France) and Fenclor (Italy).[1,2,6]

In the U.S., approximately 99 percent of all PCBs were manufactured by the Monsanto Chemical Company in Anniston, Alabama and Sauget, Illinois under the trade names Aroclor, Therminol, and Askarel.[1,2,6] Peak production of PCBs in the United States occurred in 1970 with a reported production volume of 85 million pounds of Aroclors.[2,6] Reportedly, only approximately 130 of the 209 congeners were used in commercial production of PCBs.[1] Commercial PCB products were manufactured as a mixture of various PCB congeners, some of which could include 50 or more congeners.[1,2,6,11] PCBs were manufactured through progressive chlorination of biphenyls using anhydrous chlorine and iron filings or ferric chloride catalysts.[6] Common trace impurities include chlorinated naphthalenes and chlorinated dibenzofurans, which may play a role in the observed toxicity of PCBs.[1,2,6,11] From 1929 to 1971, Monsanto produced eight separate Aroclors (1221, 1232, 1242, 1248, 1254, 1260, 1262 and 1268).[2] After 1971, Monsanto voluntarily restricted production to Aroclor 1016, 1242, 1254 and 1221.[2]

Due to their unique chemical and physical properties, PCBs were used in a variety of commercial products. The commercial products are categorized into three basic types: closed applications, partially closed applications and open applications.[1,6]

Closed applications include use as dielectric fluids in:

- transformers,
- capacitors,
- microwave ovens,
- air conditioners,
- fluid-cooled electric motors, and
- electrical light ballasts and fluid-cooled electromagnets.[1,2,6]

Partially closed applications include use in:

- hydraulic fluids,
- heat transfer fluids,
- switches,
- voltage regulators,
- circuit breakers,
- vacuum pumps, and
- electrical cables.[1,2,6]

Open applications include use in:

- inks,
- lubricants,
- waxes,
- flame retardants,
- adhesives,
- electrical and thermal insulating materials,
- pesticides,
- dyes,
- paints and other surface coatings,
- asphalt, and
- caulks and sealants (e.g. as plasticizers).[1,2,6]

At peak production in 1970, approximately 56 percent of PCBs were produced for use in closed applications, 30 percent in use in open applications, such as plasticizers, and 12 percent in use as hydraulic fluids and lubricants.[1,6] Aroclors manufactured by Monsanto were identified using a standardized four-digit numbering system, where the first two digits indicate the type of mixture and the last two digits indicate the approximate chlorine content, although there were exceptions to the naming convention (e.g. Aroclor 1016 which contains mono- through hexachlorinated homologs with an average chlorine content of 41 percent).[1,2,11]

During their period of production, PCBs entered the environment from a number of different pathways, including accidental spills, leaks, fires, land disposal of PCB-containing products, and manufacturing processes and wastes.[1,2,13] PCBs are still entering the environment today through runoff from urban areas where PCB-containing buildings are prevalent, as well as improper land disposal of PCB-containing products and the resulting leachate from hazardous waste sites where PCBs are not properly contained.[2,13,14] PCB contamination can be taken up by small organisms such as plankton and invertebrates in marine and fresh water environments.[1,2,13] The smaller organisms are then consumed by larger organisms, which can lead to bioaccumulation, where the highest concentrations of PCBs are found in animals at the top of the food chain, such as mammals, including humans.[1,2,13] While ingestion of animal fats is the major route of human exposure, exposures can also occur from breathing air contaminated with PCBs, drinking PCB-contaminated water or absorbing PCBs through the skin. Additionally, animal studies suggest that PCBs are more readily absorbed via inhalation than by ingestion.[15]

Evidence of PCB toxicity in humans first appeared as early as the late 1930s.[16,17] It was not until the 1970s, however, that the U.S. Congress authorized the EPA to regulate PCBs due to concerns, including PCB bioaccumulation and long-term persistence in the environment.[2,4,13] The authority to regulate PCBs falls under TSCA, which implemented a number of restrictions and prohibitions regarding the manufacture, use and disposal of PCBs in the United States.[2,4,5,11,13] The goal of the TSCA regulation is the complete removal of PCBs as a health risk, although this goal is based on hazard identification and not necessarily applied risk.

The TSCA regulations focused on liquid forms of PCBs (intact, predominantly in use as dielectric fluids) and the consequences of spilled liquids to surfaces, substrates and soils. Other downstream purchasers and consumers of manufactured PCBs were omitted from the regulations. As a result, materials which are identified to contain PCBs greater than 50 ppm, other than those allowances cited in the regulations (i.e., transformers), are considered an "unauthorized use" of PCBs and must be removed.

In addition to the industrial and commercial sources of PCB pollution mentioned above, there is now growing evidence that PCBs are entering the environment through PCB-containing products in the built environment.[3,8,10,11,16,17,18,19,20] It has been estimated that over 154 million pounds of PCBs were sold in the United States between 1958 and 1971 for use in various open-application products as listed above.[3] One study of buildings in Toronto, Canada found that 27% of the non-residential buildings surveyed contain detectable quantities of PCBs in sealants.[21] Published reports indicate that approximately 46% of all U.S. public and private schools currently in use were constructed between 1958 and 1971. Many of these schools may therefore have PCB-containing caulks, paints, adhesives and other open-application products.[3]

Published studies indicate that airborne PCBs in concentrations exceeding EPA recommended public health guidelines can be present in buildings with PCB-containing components and construction materials.[3,18,19,20, 22] The nature and extent of the release of PCBs from construction materials within the built environment is not well understood at this time. One limited study found that teachers working in buildings with PCBs had higher serum PCB levels when compared to a similar population that did not work in buildings with PCBs.[23] Given the apparent widespread use of PCBs in construction materials, it appears that PCBs in the built environment may be an underestimated public health risk for building occupants. Further research is needed to help determine the role that construction materials may have in the exposure of building occupants to PCBs.

For the purposes of this white paper, the term "toxicity" is the inherent property of PCBs to cause health consequences in humans; "exposure" is the sum of opportunities, through inhalation, skin permeation, ingestion and/or injection, to deliver PCBs where they can affect the human physiology; and "risk" is the probability of an adverse health effect and is dependent upon the exposure dose and toxicity of the agent(s) of concern.

## 5.0 HEALTH EFFECTS

PCB exposures have been associated, both directly and indirectly, with a number of acute and chronic health effects. Reported adverse health effects from PCB exposures include damage to the hepatic, endocrine, dermal/ocular, immunological, neurological, and reproductive systems, as well as cancer end points.[1,2,6,13] The reported health effects are based on studies of community exposures from ingestion of contaminated foodstuffs, occupational exposures during the manufacture of PCB mixtures (e.g. Aroclors) or PCB-containing components, and various animal studies.[2,24,25] Determination of the mechanisms for the associated health effects is complicated by a number of factors including the presence of other toxic contaminants from the manufacturing process, such as chlorinated dibenzofurans (CDFs) within PCB mixtures, and differences in the congener composition within commercially produced PCB mixtures compared to the congener profiles that are found in the soil, air, water, or food chain months or even years after release.[2,22,23] The presence of

multiple PCB congeners and contaminants like CDFs, which have the potential to exert similar toxic effects, make determination of the specific agents responsible for a noted health effect difficult.[2,22,26] In addition, toxicity of PCB mixtures that are released into the environment may change due to effects of volatilization and chemical or biological transformation.[2,22,23,27]

Highly chlorinated PCB congeners have traditionally been thought to present a greater risk of adverse health effects due to their persistence in the environment and ability to bioaccumulate.[2,22,23,25,28] Highly chlorinated PCB congeners tend to be less volatile, less water soluble, more likely to bind to sediment or soils and have higher bioaccumulation factors. [22,23] Conversely, less chlorinated congeners tend to be more volatile, more water soluble and more easily metabolized in animals.[22,23] However, while lower chlorinated congeners do not bioaccumulate to the degree that the higher chlorinated congeners do, this does not mean they do not cause adverse health effects. This is a particularly important consideration when exposure to lower chlorinated congeners is via inhalation, which occurs almost continuously when an individual in an indoor environment with PCB-containing materials present, but which is not reflected as clearly by measurement of blood concentrations due to the short half-lives of those congeners.

Of the 209 PCB congeners, 12 have been categorized as "dioxin-like" and have been assigned toxic equivalency factors (TEFs) due to their ability to act upon the aryl hydrocarbon receptor (AHR) and cause toxic effects similar to those caused by 2,3,7,8-tetrachlorodibenzo-p-dioxin.[2,23,26, 29] Of the 12 dioxin-like PCB congeners, four are non-ortho substituted PCBs (congeners 77, 81, 126 and 169) and eight are mono-ortho substituted PCBs (congeners 105, 114, 118, 123, 156, 157, 167 and 189).[23,26,27] The remaining 197 PCB congeners are sometimes referred to as "non-coplanar" or "non-dioxin like" congeners.[23] These non-dioxin- like congeners are thought to exert toxic effects through multiple non-AHR mediated pathways.[23]

### *5.1 Hepatic Effects*

Animal studies indicate that PCBs are capable of causing hepatic damage, including microsomal enzyme induction, liver enlargement, increased liver enzymes, fatty lesions, necrosis and tumors.[1,2,6,13] Studies of humans with high concentrations of PCBs in their blood have revealed the presence of abnormal liver indices such as cholesterol, liver enzymes and lipids.[2] PCBs are known to induce a great variety of gene expression, by both AHR and non-AHR-dependent mechanisms.[ 30 ] Human hepatotoxicity from PCBs, however, is not conclusive due to limitations including study designs, lack of controls, susceptibility differences among species and other confounding variables.[2]

### *5.2 Endocrine Effects*

Evidence of direct endocrine effects from PCB exposures in humans is limited.[2] High exposures to PCBs in humans have been associated with goiter (enlargement of the thyroid gland).[2] Animal studies in rodents and non-human primates indicate that exposures to PCBs in utero and in early development (e.g. breast feeding) can deplete circulating levels of thyroid hormones and lead to hypothyroidism.[2]

### *5.3 Dermal and Ocular Effects*

Dermal and ocular effects from PCB exposures in humans are well documented among occupational and community PCB exposure groups, the latter through accidental ingestion of PCB-contaminated food.[2,6,13]

These effects include chloracne, pigmentation of the skin and nails, excessive eye discharge, swelling of the eyelids, distinctive hair follicles and edema of the hands and face.[2,6]

### *5.4 Immunological Effects*

Immunological effects have been associated with PCB exposures in humans.[1,2] The strongest evidence of such effects is based on studies of communities that consumed PCB-contaminated food.[2] Increased susceptibility to infection was reported, although interpretation of the data was hampered due to the presence of multiple other persistent organic pollutants.[2] Animal studies indicate an association between high PCB exposures and morphological and functional changes in the immune system.[2]

### *5.5 Neurological Effects*

Neurological effects have been associated with PCB exposures in humans.[1,2] The primary evidence is based on epidemiological studies of communities that consume fish with high PCB concentrations.[2] Abnormal reflexes, memory, learning and IQ have been reported as neurologic outcomes associated with the PCB exposures. Human exposure studies have identified associations between behavioral effects and highly chlorinated congeners, while animal studies have shown an association between PCB exposures and central nervous system effects and have linked dioxin-like and non dioxin-like congeners to neurological effects.[2]

### *5.6 Reproductive Effects*

Reproductive effects from PCB exposures have been reported, but human data are limited.[1,2,13] Animal studies in rodents and monkeys indicated that PCB exposures may be associated with menstrual changes.[2] Confounding variables in humans, however, make confirmation of similar menstrual disturbances, as well as effects on sperm morphology and production, difficult.[2]

### *5.7 Developmental Effects*

Developmental effects have been associated with PCB exposures in animals and human studies.[2] Animal studies have linked PCB exposures in utero and during early development with hypothyroidism.[2] Thyroid deficiencies during fetal and neonatal development in humans can lead to auditory, motor and intellectual deficiencies.[2] A number of studies have associated developmental effects, including cognitive and motor skill deficiencies, delayed development, and behavioral problems, in children born to mothers who were exposed to PCBs and polychlorinated dibenzofurans (PCDFs) from eating contaminated food in Japan and Taiwan.[2,31,32,33,34,35] Other studies have found associations with behavioral and intelligence deficits among children whose mothers were exposed to PCBs from eating contaminated food.[2,36,37,38,39,40,41,42] Prenatal PCB exposures have been associated with low birth weight, smaller head circumference and shorter gestational age in newborns, although the evidence is not conclusive.[2,34]

### *5.8 Cancer*

Evidence of the association between PCBs and cancer in humans is supported by both retrospective epidemiological studies of workers exposed during manufacturing and repair of capacitors, and case-control studies of the general population, which looked at associations between adipose PCB concentrations and cancer.[1,2] These studies indicate an association between PCB exposures and cancers of the liver, biliary tract,

intestines and melanoma.[2] In the late 1980s, the International Agency for Research on Cancer (IARC), the U.S. EPA and the National Toxicity Program (NTP) all classified PCBs as probable human carcinogens (IARC Group 2A) based on extensive evidence in animal studies.[1,2] The American Conference of Governmental Industrial Hygienists (ACGIH) did the same in 1996. Finally, the U.S. Department of Health and Human Services (HHS) Agency for Toxic Substances and Disease Registry (ATSDR) addressed PCB carcinogenicity in 2000 and its addendum, issued in April 2011, added reference studies noting non-Hodgkins lymphoma and prostate cancer risks.[43]

IARC recently revisited the issue of carcinogenicity of PCBs and has declared all PCBs to be Group 1, known human carcinogens, based on strong evidence for exposure increasing the risk of malignant melanoma, with less strong evidence for breast cancer and non-Hodgkins lymphoma.[44] Other cancers have also been reported to be increased in relation to PCB exposure, but overall evidence is limited.

### *5.9 Diabetes, Cardiovascular Disease and Hypertension*

There is increasing evidence that the major chronic diseases of older age, including diabetes, cardiovascular disease and hypertension, but excluding cancer, are also associated with exposure to PCBs and other persistent organics, including dioxins and chlorinated pesticides.[45,46] Because these chemicals are all lipophilic and found in body fat, it is difficult to identify which chemical is responsible for the associations with these diseases. The exception is hypertension, which is strongly associated with serum PCBs levels but unrelated to concentrations of pesticides.[47]

## 6.0 EXPOSURE EVALUATIONS

### *6.1 Exposure Assessment*

The nature of the complete exposure profile from PCB-containing materials for building occupants and for the occupationally exposed is a complex one. Exposures to PCBs in the built environment can occur via inhalation of PCB vapors and contaminated particulates, as well as via ingestion and dermal pathways. The determination of the predominant pathways is key to controlling any potential exposures. Consideration should be given for modeling and then validating (through confirmatory sampling) the possible exposure pathways. Identification of the specific PCB congeners present should be considered, as the current literature suggests that lower molecular weight PCBs are more likely to be released before the higher molecular weight PCBs.

### *6.2 Exposure Pathways*

#### 6.2.1 Inhalation

The inhalation pathway for exposure to PCBs includes both vapor and particulate exposures. Depending upon the nature of occupancy and activities occurring within the building, the inhalation pathway may be dominated by either of the physical forms, or the contributions may be equal. The release of PCBs into the built environment is largely dependent on the condition of the PCB-containing materials, presence (or absence) of impermeable coatings, air temperature, ventilation dynamics and air flow rates. All of these factors must be taken into consideration when considering potential inhalation exposure pathways.

*6.2.1.1 Vapor Exposure Contribution*

Vapor exposure can occur from virtually any PCB-containing materials within a room or building. The predominant potential sources are failed fluorescent light fixture ballasts. These are, however, typically discrete, episodic exposures that are usually easily identified by failure of the light fixture. Of a more chronic nature is the vapor release of PCBs from caulking, as well as from other building materials that have absorbed PCBs over time and then subsequently re- release them into the indoor environment. One study found a sum of 440 nanograms per cubic meter of air (ng/$m^3$) of six PCB congeners in indoor air of a building constructed in 1969 of prefabricated concrete panels and sulfur-based caulk (Thiokols).[48] Other PCB sources within the building, however, could not be ruled out. Another study reported airborne PCB levels of 610 micrograms per cubic meter of air (µg/$m^3$) in inhabited apartments prior to testing various abatement methods.[49]

During an initial assessment of airborne concentrations in school systems in Massachusetts, researchers detected Aroclor 1254 at concentrations ranging from 111 to 393 ng/$m^3$.[50] Swedish researchers investigating biomarkers of exposure found that higher chlorinated PCB mixtures (Aroclor 1248, 1254 or 1260) were used in the manufacture of caulks, but that lower chlorinated PCB congeners (mainly PCBs 28, 52 and 66) were present in the air samples due to their higher volatility.[51]

During testing of the efficacy of a variety of intervention methods at a school, researchers reported an initial mean indoor air total PCB concentration of 533 ng/$m^3$.[3] The authors reported that by increasing outdoor air ventilation, encapsulating the caulk, and constructing a physical barrier over the encapsulated material, they were able to reduce indoor airborne PCB concentrations to a mean value of 76 ng/$m^3$.

*6.2.1.2 Particulate Exposures Contribution*

Exposure to PCB-containing particulates is more likely to pose an inhalation risk to construction workers and remediation contractors than is exposure to PCB vapors, due to the generation of particulates during the dismantlement of structures and gross removal of PCB caulk and other materials. A number of studies have examined airborne exposures during these types of activities.

Swedish researchers examined determining factors for controlling PCB exposures during the cleanup of PCB-containing sealants. A variety of methods and control sets were utilized, which resulted in worker breathing zone PCB concentrations ranging from 5.5 µg/$m^3$ to 120 µg/$m^3$.[49] Finnish researchers studied workers during a national abatement effort.[52] Both particulate and vapor phase samples for seven different PCB congeners (28, 52, 77, 101, 138, 153 and 180) were collected. No differentiation of the relative contributions of the various congeners, however, was made. Reported airborne concentrations ranged from none detected to 3.1 µg/$m^3$.[52]

From the variety of studies in the literature, it is clear that source identification and selection of PCB congeners for characterization is important when assessing the exposure opportunities to both public occupants and potential construction or maintenance forces.

### 6.2.2 Ingestion

Ingestion pathways are a consideration for both public and occupational exposures. When establishing the collective risk of PCBs in a structure, the behaviors of the occupants must be understood and taken into account. Small children are more likely to have ingestion pathway opportunities than older children, based simply on hand-to-mouth behavior. However, personal hygiene habits may also lead to ingestion paths for both older children in public exposures and workers in occupational exposures. Mapping of all occupants and their opportunities for coming into contact and possibly ingesting PCB-bearing particulates and settled dust is necessary for understanding this contribution to a total exposure determination.

### 6.2.3 Dermal

Skin notations exist in the ACGIH documentation for PCB 1242 based on reported fatty degeneration of the liver following dermal application to animals, and for PCB 1254 based on liver toxicity reported among animals treated dermally.[53] The designation of a "skin" notation indicates that there is the potential for significant contribution to the overall exposure by the cutaneous route, including mucous membranes and the eyes, through contact with vapors, liquids, and/or solids. Where dermal application studies have demonstrated that absorption could cause systemic effects following exposure, a skin notation would be considered.[54]

### 6.2.4 Injection

Injection exposures have not been identified in the literature as a potential pathway for PCB exposures.

### *6.3 Biomonitoring*

Cumulative past exposure to PCBs can generally be determined through measurement of serum PCB levels. Adult age-related accumulations of non-dioxin-like PCBs have been observed in a number of studies.[55,56,57] Such studies can provide physicians and public health officials with reference values with which to determine whether or not individuals have been exposed to higher levels of PCBs than those found in the general population. Many PCBs can remain in the body for years after exposure, though some of the lower chlorinated PCB congeners have relatively short residence times.[58] Concentrations of individual PCB congeners in the body will vary with the exposure source(s) and differences in pharmacokinetics (i.e., congeners with longer half-lives will accumulate to higher levels within the body). Serum concentrations of the di-*ortho*-substituted PCBs are typically higher than concentrations of the mono-*ortho*-substituted PCBs which, in turn, are greater than the coplanar PCBs.[57,58,59,60] Non-dioxin-like PCBs 138, 153 and 180 are the most frequently detected di-*ortho*-substituted PCBs reported in population studies and typically account for a substantial portion of total measured PCBs.[57,58,61,62]

## 7.0 REGULATIONS

### *7.1 Toxic Substances Control Act*

In the U.S., PCBs are regulated under TSCA, which was enacted by Congress in October 1976. The regulations are designed to protect public health and the environment from toxic chemicals, and those related to PCBs are codified in code of *Federal Regulations*, under 40 CFR 761, which includes regulations on the manufacture, processing, importation, distribution, use and disposal of PCBs. TSCA first established a ban

on production of PCBs effective July 1979, with distribution in commerce banned after 1984. The regulation then established management policies for those materials that had already been produced prior to the ban.

There is currently no requirement for a building owner or property manager to conduct air or bulk sampling to determine if PCBs are present in, or released from, building materials. The TSCA regulations do require that materials which may contain PCBs be characterized to ensure proper disposal if PCB wastes will be generated. This means that PCBs in the built environment may be identified during routine sampling of waste streams that will be generated during building renovation or demolition activities.

If PCB-containing building materials are identified within a building or in the surrounding soils, specific actions are required based on the following criteria:

1. Concentration of PCBs present in the identified building material;
2. Classification of identified materials as either "PCB bulk product waste" or "PCB remediation waste";
3. Location of the PCB-containing materials; and
4. Extent of any additional contamination that may have occurred to surrounding or adjacent building materials.

Some of the key provisions of the TSCA rules that relate to PCBs in the built environment are summarized below.

- Subpart A – General:
  - Defines the applicability of the rule, PCB concentration assumptions for use and definitions.
  - Defines "*PCB bulk product waste*" as waste derived from manufactured products containing PCBs in a non-liquid state, at any concentration in which the concentration at the time of designation for disposal was greater than or equal to 50 ppm PCBs. PCB bulk product waste includes, but is not limited to:
    - Non-liquid bulk waste or debris from the demolition of buildings and other man-made structures manufactured, coated, or serviced with PCBs. PCB bulk product waste does not include debris from the demolition of buildings or other man-made structures that is contaminated by spills from regulated PCBs that have not been disposed of, decontaminated, or otherwise cleaned up in accordance with subpart D of this part.
    - PCB-containing wastes from the shredding of automobiles, household appliances, or industrial appliances.
    - Plastics (such as plastic insulation from wire or cable; radio, television and computer casings; vehicle parts; or furniture laminates); preformed or molded rubber parts and components; applied dried paints, varnishes, waxes or other similar coatings or sealants; caulking; adhesives; paper; Galbestos; sound deadening or other types of insulation; and felt or fabric products such as gaskets.
    - Fluorescent light ballasts containing PCBs in the potting material.
  - Defines "*PCB remediation waste*" as waste containing PCBs as a result of a spill, release, or other unauthorized disposal, at the following concentrations: Materials disposed of prior to April 18, 1978, that are currently at concentrations ≥ 50 ppm PCBs, regardless of the concentration of the original spill; materials

that are currently at any volume or concentration in which the original source was ≥ 500 ppm PCBs beginning on April 18, 1978, or ≥ 50 ppm PCBs beginning on July 2, 1979; and materials that are currently at any concentration if the PCBs are spilled or released from a source not authorized for use under this part. PCB remediation waste means soil, rags, and other debris generated as a result of any PCB spill cleanup, including, but not limited to:

  - Environmental media containing PCBs, such as soil and gravel; dredged materials, such as sediments, settled sediment fines, and aqueous decantate from sediment.
  - Sewage sludge containing < 50 ppm PCBs and not in use according to § 761.20(a)(4); PCB sewage sludge; commercial or industrial sludge contaminated as the result of a spill of PCBs including sludge located in or removed from any pollution control device; or aqueous decantate from an industrial sludge.
  - Buildings and other man-made structures (such as concrete floors, wood floors, or walls contaminated from a leaking PCB or PCB-contaminated transformer), porous surfaces, and non-porous surfaces.

- Defines "*Totally Enclosed Manner*" as any manner that will ensure no exposure of human beings or the environment to any concentration of PCBs.

- Subpart B – Manufacturing, Processing, Distribution in Commerce, and Use of PCBs and PCB Items:
  - Defines the prohibitions, exceptions, authorizations and storage requirements for the use and reuse of PCBs.
  - Bans the use of PCBs in anything but closed system applications.
- Subpart C – Marking of PCBs and PCB Items
  - Defines the marking and labeling of PCB-containing items.
- Subpart D – Storage and Disposal
  - Defines the storage and disposal requirements of PCBs
  - Defines cleanup levels for porous surfaces, non-porous surfaces in both high and low-occupancy areas.
- Subpart G – PCB Spill Cleanup Policy
  - Defines the requirements for cleanup of PCB spills
- Subpart K – PCB Waste Disposal Records and Reports
  - Defines the requirements related to waste disposal activities including EPA identification numbers, notifications, waste manifests, retention of records and exception reporting.
- Subpart N – Cleanup Site Characterization Sampling for PCB Remediation Waste
  - Defines the sampling of PCB bulk remediation waste, porous surfaces, non- porous surfaces, and liquid PCB samples.
- Subpart O – Sampling to Verify Completion of Self-Implementing Cleanup and On-Site Disposal of Bulk PCB Remediation Waste and Porous Surfaces.
  - Defines the sampling methods including sample size, sample collection procedures, compositing of samples, sample extraction and analysis and reporting and record keeping of PCB concentrations in samples.

### *7.2 Department of Transportation*

The Department of Transportation, under 49 CFR Part 172, designated PCBs as hazardous materials and prescribes requirements for shipping papers, package marking, labeling, and transport vehicle placarding applicable to the shipment and transportation of PCBs.

### *7.3 Comprehensive Environmental Response, Compensation and Liability Act*

PCBs are designated as hazardous substances under section 102(a) of the Comprehensive Environmental Response, Compensation and Liability Act of 1980 (CERCLA), as amended by the Superfund Amendments and Reauthorization Act (SARA) and section 311(b)(2)(A) of the Clean Water Act. The EPA has established a threshold reportable quantity of one pound for PCB mixtures. If a PCB release exceeds this threshold quantity, then the EPA must be notified (40 CFR Part 302).

### *7.4 Emergency Planning and Community Right to Know Act*

Under the Emergency Planning and Community Right to Know Act (EPCRA), which was an act amending CERCLA, PCB releases are included in the Toxic Release Inventory (TRI) database which is maintained by the EPA. The TRI database is publicly accessible and is intended to inform the general public and communities surrounding covered facilities about releases of toxic chemicals.

### *7.5 Occupational Exposure Limits*

OSHA has established Permissible Exposure Limits (PELs) for two Aroclors that are expressed as eight-hour time-weighted average (TWA) exposure concentrations. The PELs, which are listed in 29 CFR 1910.1000, Table Z-1, are for chlorodiphenyl compounds containing 42 percent (Aroclor 1242) and 54 percent chlorine (Aroclor 1254). The PELs are 1.0 milligram per cubic meter of air ($mg/m^3$) and 0.5 $mg/m^3$, respectively, and both compounds have a “skin” notation, designating that significant exposure may occur through the dermal route.

The National Institute for Occupational Safety and Health (NIOSH) has established a 10-hour Recommended Exposure Limit (REL) of 0.001 $mg/m^3$ for both Aroclor 1242 and 1254, and lists both compounds as carcinogens.

The 2013 ACGIH Threshold Limit Values (TLVs) for Aroclor 1242 and 1254 are identical to the OSHA PELs. [53,54]

### *7.6 Department of Energy*

The Department of Energy (DOE) does not have any regulations that specifically address PCBs. However, the DOE, through the Worker Safety and Health Program found in 10 CFR Part 851, has codified the ACGIH TLVs for Aroclors 1242 and 1254. In addition, there is an expectation for a comprehensive exposure assessment program that would imply an effort at hazard identification.

# 8.0 RISK ASSESSMENT

## *8.1 Background*

There are four basic steps in the risk assessment process, whether focused on human health or toward environmental stressors. The steps include: 1) *hazard identification*, 2) *dose-response assessment*, 3) *exposure assessment*, and 4) *risk characterization*. These four steps are designed with the goal of formulating a detailed understanding of the potential severity and scope of a hazard — in this case, the risk of PCB exposure in the built environment. This process is used by various U.S. government agencies, as well as some state, local and regional agencies, and other countries when performing risk assessments. The risk assessment for PCBs evaluates health impacts including both cancer and non-cancer end points. The hazard identification and exposure assessment components of the risk assessment process have been discussed in detail in section 6.1 of this document and are mentioned again briefly below to clarify the risk characterization.

Exposed populations include building occupants (both adults and children), as well as construction workers renovating buildings and removing PCB-containing materials. Understanding the actual health risks will allow for cost-effective mitigation of PCB materials from indoor environments. In addition, the identification of target concentrations of PCBs in the indoor air will provide practitioners the values that can aid in the design and performance evaluation of various abatement activities.

The current U.S. EPA-recommended levels for PCBs in indoor school air were set at varying concentrations, based on the children's age, ranging from 70 ng/m$^3$ for 1-3 year olds to 600 ng/m$^3$ for 15-19 year olds. The aim of these EPA levels was to keep children's overall PCB intake to below the reference dose of 20 ng PCB/kg-day. An example of international guidelines for PCBs includes those established in Germany in 1995, which require the remediation of buildings with elevated indoor air concentrations. The action limit for remediation was set at 3000 ng/m$^3$, while tolerable PCB indoor air concentration was defined as 300 ng/m$^3$. The aim of the German guidelines is to reduce airborne PCB concentrations in all living environments to below 300 ng/m$^3$.[49]

Figure 1 is an illustration of the concentrations of various congeners that were emitted into the indoor air from two different PCB-containing products, Thiokol rubber sealant and flame retardant coating on acoustic ceiling tiles. Clearly, the Thiokol sealant emitted greater levels of PCB 28 and 52 congeners than did the flame retardant material. Conversely, the flame retardant material emitted higher levels of PCB 101, 138 and 153 congeners than did the Thiokol sealant. The figure above illustrates one of the challenges in conducting a risk assessment for PCBs, namely the uncertainty associated with an understanding of the source materials and the mixture of congeners within, and emitted by, those sources.

Using the common four-step risk framework discussed above, the risks of exposure to PCBs can be examined. However, the numbers must be considered a reference point for decision- making instead of a defining line between safe and unsafe. The exposures and dose-response relationships used to conduct any risk assessment are products of research publications and, while informative and thought provoking, the data are generally not appropriate for decision-making. Understanding the uncertainties of a risk assessment will provide decision makers and stake holders the necessary information to take appropriate corrective actions.[64]

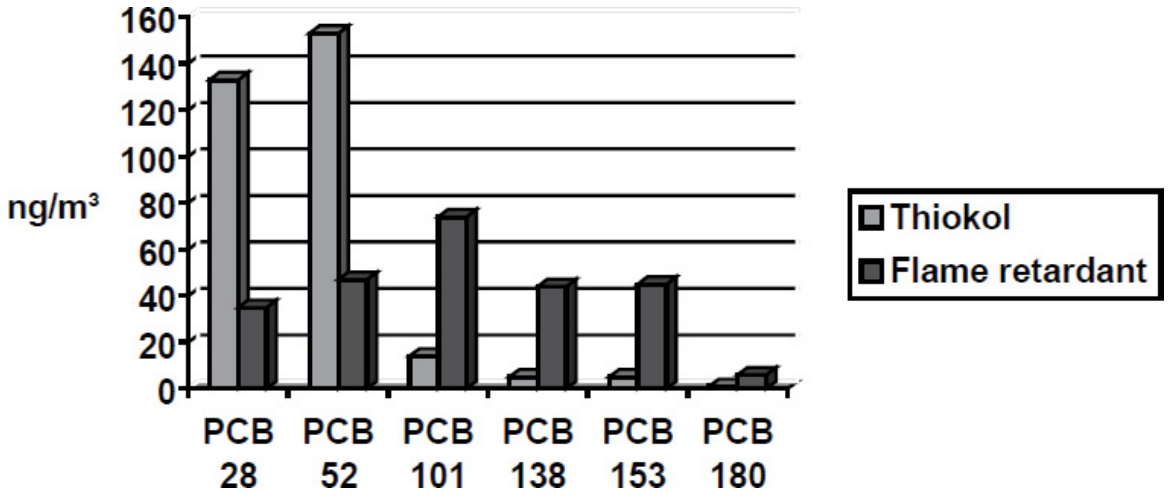


**Figure 1. Histogram of mean PCB congener pattern in indoor air in rooms with two different PCB sources[63]**

### *8.2 Hazard Identification*

The U.S. EPA and ATSDR have published an extensive amount of material evaluating the human health impacts from exposure to PCBs. A useful summary can be found on the EPA's Integrated Risk Information System (IRIS). Based on the weight of evidence in humans and experimental animals, the IARC upgraded PCBs from Group 2A, probably carcinogenic to humans, to Group 1, carcinogenic to humans in 2013.[44] More than 70 independent epidemiological studies with data for carcinogenicity of PCBs in humans were considered. Excess risks for melanoma were reported in several studies and a significant linear exposure- response trend was noted in the largest study. The association between PCBs and melanoma was consistently noted in different North American and European industries.[44] The weight of the evidence is what will allow for the reduced uncertainty factors used to develop a Reference Dose (RfD) or slope factor.

### *8.3 Dose Response*

The EPA's IRIS provides a detailed assessment of the toxicity of PCBs. Table 1 is a summary of the information from the literature.

**Table 1.** Carcinogenicity data, Oral Exposure

| Aroclor Type | Dose (ppm) | Human Equivalent (mg/kg/day) | Tumor Incidence |
|---|---|---|---|
| Aroclor 1260 | 0 | 0 | 1/85 |
| | 25 | 0.35 | 10/49 |
| | 50 | 0.72 | 11/45 |
| | 100 | 1.52 | 24/50 |
| Aroclor 1254 | 0 | 0 | 1/85 |
| | 25 | 0.35 | 19/45 |
| | 50 | 0.76 | 28/49 |
| | 100 | 1.59 | 28/49 |
| Aroclor 1242 | 0 | 0 | 1/85 |
| | 50 | 0.75 | 11/49 |
| | 100 | 1.53 | 15/45 |
| Aroclor 1016 | 0 | 0 | 1/85 |
| | 50 | 0.72 | 1/48 |
| | 100 | 1.43 | 7/45 |
| | 200 | 2.99 | 6/50 |

Reference – EPA IRIS for PCBs and Brunner et al., 1997 [65]

Slope factors are multiplied by lifetime average daily doses to estimate the cancer risk. PCB exposures are often characterized in terms of Aroclors, but this manner of profiling PCBs may not be precise as toxicity is linked more closely to specific congeners. Either central estimates or upper bounds can be used as appropriate measures of risk. In general, the central estimates describe an individual's risk, and the upper bounds provide a risk for a population. The EPA IRIS published central slope factor and upper bound slope factor for PCBs are 1.0 and 2.0 (mg/kg)/day respectively for high risk persistence, while the slope factors for low risk and persistent exposure are 0.3 and 0.4 (mg/kg)/day, respectively. The above slope factors are generally used for ingestion of PCBs. The Unit Risk factor is often used for inhalation of evaporated congeners, where the low risk and persistent exposure slope factor (0.3 (mg/kg)/day) is converted to a unit risk factor of $1 \times 10^{-4}$ µg/m$^3$.

EPA has also published RfDs for non-carcinogenic endpoints. Oral RfDs for Aroclor 1254 of 20 (ng/kg/day) and Aroclor 1016 of 70 (ng/kg) day have been published, where each RfD has an uncertainty factor of 300. The uncertainty factor of 300 was established to compensate for uncertainties when extrapolating data from a lowest observed adverse exposure level (LOAEL) to a no-observed adverse exposure level (NOAEL). It is important to understand, however, that PCB animal testing was conducted with the manufactured Aroclor material, and not with a mixture of PCB congeners that are more persistent in the environment. This again provides an uncertainty associated with the animal testing data and an understanding of human

health impacts. Children's exposure presents an additional uncertainty in that there may be greater- than-proportional effects from less-than-lifetime exposure, especially for persistent mixtures and early-life exposures.

### *8.4 Exposure Assessment*

As previously discussed in section 6.1, research into risk from airborne PCB exposures in buildings has been conducted in the U.S. and other countries by numerous scientists. Exposure data from a number of published studies is presented in Table 2.

While the data are limited for both airborne exposures and serum levels for a specific study, a number of researchers have examined serum and airborne PCB concentrations at different times. Researchers studied the serum levels of six U.S. construction workers involved in removing PCB-containing caulk. The workers were found to have statistically higher serum PCB levels than the reference population for specific congeners, namely PCBs 6, 16, 26, 32, 36, 41, 70, 97 and 136.[66] The reported findings were similar to the results of studies previously done in both Finland and Sweden.[51,52] It should be noted, however, that the U.S. study quantified 57 congeners, as compared to 24 congeners in the Finnish study and 19 congeners in the Swedish study.

**Table 2.** Summary of select airborne exposures to PCBs from caulking/sealant

| Location | PCB Source | Total PCB Exposure (ng/m3) | | | | Reference for the Exposures |
|---|---|---|---|---|---|---|
| | | *Mean* | *Min* | *Max* | *95 CI* | |
| School | Window Caulk | 533 | 350 | 780 | | MacIntosh, 2012 [3] |
| Office Building | Window Caulk | 1740 | | 4280 | 3740 | Schettegen, 2012 [67] |
| School | Window Caulk | | 2.4 | 30 | | Sullivan, 2008 [68] |
| University Office Building | Caulk, Gaskets, Foamboard Insulation | | 111 | 393 | | Coughlan, 2002 [50] |
| Worker - Construction | Expansion Joint Removal with LEV* | 600 | | | | Sundahl, 1999 [49] |
| Office Buildings | Joints and Window | 45 | | | | Hazarati, 2006 [69] |
| Office Buildings | Sealants & Flame Retardants | 715 | 715 | 2253 | | Heinzow, 2004 [63] |

*LEV – local exhaust ventilation

### *8.5 Risk Characterization*

In risk characterization, the hazard quotient and cancer risk for exposure to PCBs can be calculated. The Hazard Quotient (HQ) is a scaling factor and is not statistically based. If the HQ is greater than 1, then there may be an increased risk, while an HQ below 1.0 suggests no concerns for adverse health effects are present. The excess lifetime cancer risk is an incremental probability of the exposed persons developing cancer over a lifetime. Using the information from the ATSDR and IRIS for PCBs, along with published exposure levels, one

can estimate the cancer risks and Hazard Quotients. However, as with all risk assessments, the calculated numbers must be viewed in the light of the multitude of uncertainties. As an example, if one considers only the variability in the exposures for building occupants, and keeps all the other variables constant, the cancer risks range over two orders of magnitude from 4/1000 to 4.5/100,000. However, the non-cancer risk is significantly below unity for building occupants and workers from the published exposure data, although there are reasons to question whether the non-cancer risks have been adequately identified.

$$\text{Hazard Quotient (HQ)} = \text{Chronic Daily Intake/RfD}$$

$$\text{Cancer Risk} = \text{Chronic Daily Intake} \times \text{Slope factor or Unit Risk Factor}$$

Of greater interest for those concerned with the health of workers, building occupants and school children is the paucity of data with respect to the exposure to specific congeners. Several different studies have shown increased serum PCB levels among construction workers when compared to control groups. These studies examined the ratio of light to heavy congeners to understand the source of PCB exposure.[51,52,66] In a comparison of congener profiles for PCB 6 to 74, one study found that the control group values for lighter congeners did not exceed those of the construction workers.[46] Researchers in a 2006 study proposed that a set of marker PCB congeners — specifically PCBs 44, 56, 60, 66, 70, 110, 153 and 180 — be used to track occupational exposures. Their general conclusion was that the traditional set of serum markers used to measure PCB exposures (PCBs 28, 52, 101, 101, 118, 138, 153 and 180) were not well suited for identifying occupational exposures.[51] While there are relatively few studies linking PCB congener airborne concentrations to PCB serum congener levels for the same set of workers, the limited results have observed a relationship between occupational exposure and serum levels. However, the limited number of studies and the varying number of congeners evaluated by each of those studies does result in a significant uncertainty within the risk assessment process.

While only limited congener-specific airborne data are available, protective measures have been shown to reduce worker exposures. Two recent studies identified a series of control measures to protect workers and building occupants.[3,70] Reductions in airborne levels of PCBs and reduced PCB serum levels over time were observed even though individuals continued working as PCB abatement workers.

## 9.0 IDENTIFICATION AND EVALUATION OF PCBs IN BUILDINGS

### *9.1 Inspection and Material Testing*

As noted above, buildings constructed, renovated and/or repaired between 1950 and 1978 are likely to contain a variety of building materials containing PCBs.[5] To assess if building materials contain PCBs, bulk samples must be collected and analyzed. Analysis should be done by an environmental laboratory that is certified to analyze such samples. Additionally, PCBs from caulking, mastics, paint and other coatings are often absorbed into the porous building materials on which they were applied.[71] As a result, significant levels of PCBs can migrate into adjacent materials and be present several inches deep into adjacent wood, concrete, cinder block, brick or masonry. Additionally, PCBs from exterior caulks, sealants and paints can migrate into and contaminate surrounding soil as a result of natural weathering. Accordingly, sampling of any exposed soil around the perimeter of the building may also be warranted.

Assessment and sampling must be done correctly and the building occupants must be protected from excessive exposure to PCBs during those activities. For this reason, inspection and sample collection are usually done off hours or on weekends when building occupants are not present. Some materials, like caulking, may also contain other regulated contaminants, such as asbestos or lead, in addition to PCBs. Therefore, assessment protocols and methodologies similar to those used for these materials can be used as a template. While there are no nationally recognized PCB inspector certifications, facility owners may want to consider using inspectors accredited under the EPA Asbestos Hazard Emergency Response Act (AHERA) or Lead-Based Paint Renovation, Repair and Painting (RRP) certification programs. All individuals should also have PCB awareness training.

Training for individuals who will be collecting samples should include the following:

- Hazard Communication training for PCBs that, at a minimum, meets the requirements of 29 CFR 1910.1200;
- The importance of safe work practices to minimize the release of, and exposure to, potential PCB materials during sample collection;
- Information on other hazardous materials (e.g. lead, asbestos) that may also be present;
- Materials that should be suspected to contain PCBs, including surrounding materials that PCBs may have migrated to over time;
- Sample collection methodology, including information on collecting sufficient quantity for analysis, proper storage containers, utilizing sampling techniques that minimize release of PCBs into the environment;
- Proper use of PPE per the manufacturers' user instructions; and,
- Instructions that eating, drinking and smoking are prohibited during sample collection and not allowed until mandatory hand and face washing has been completed

Additional information on sampling building materials for PCBs is available on the U.S. EPA website.

As previously mentioned, TSCA considers materials containing greater than 50 ppm PCBs to be an unauthorized use of PCBs and such materials must be removed.[4] There is no requirement under current federal regulations, however, for building owners to perform sampling for PCBs in building materials. Currently, the EPA recommends conducting preliminary air testing in school buildings to determine airborne PCB levels prior to deciding whether or not to inspect for PCB- containing building materials, although again there is no legal obligation to do so.

Prior to performing an inspection, construction records (if available) should be reviewed to help identify suspect materials and possible PCB-containing equipment (e.g., transformers, light ballasts and heat transfer systems). Sampling of caulking and other suspect materials should include a visual assessment for different ages and types of applications, homogeneity of materials, applicability and use of the products, the condition of the materials and other field observations. Additionally, the potential for human exposure to materials (i.e., accessibility, frequency and duration of contact) should be determined and noted.

When performing bulk material or soil sampling, disposable sampling tools should be utilized and discarded after each sample in order to avoid cross contamination. Alternatively, stainless steel sampling instruments

may be used but must be properly decontaminated between samples. Sampling of adjacent porous building materials, such as concrete or masonry, is more labor-intensive and requires core sampling in order to identify how deeply the PCBs have been absorbed. Core sampling involves drilling into the substrate material and collecting the dust or debris that is generated. Proper decontamination of the drill bits and equipment between samples is essential.

Analysis of bulk material samples for PCBs is typically performed via EPA Method 8082A using gas chromatography (GC). The method can be used to determine concentrations of either Aroclors or as certain individual congeners (the method can only detect 19 of the 209 PCB congeners). Alternately, a high-resolution gas chromatography/high resolution mass spectrometry (GC/MS) method, such as EPA Method 1668B, can be used to quantify individual PCB congeners, although such methods can be quite costly to perform. In addition to PCBs, the sampled materials should also be assessed for other possible contaminants (i.e., asbestos and lead).

Surface wipe sampling may also be performed to assess visual staining of surfaces from liquid PCB sources and dust accumulation from deteriorated building materials in accordance with EPA Method SW-846-8082 as described in 40 CFR 761.123 and 761.130.

Personal protective equipment (PPE) used during sample collection will depend on the material being sampled and its condition. Intact items like light fixture ballasts, or soft, pliable caulking, will likely not require any PPE other than chemical protective gloves, such as nitrile, to minimize skin contact and American National Standards Institute (ANSI) Z87.1-compliant eye protection. The glove manufacturer should be consulted for suitability of the glove for incidental contact with PCBs. If the suspect PCB-containing material is friable (e.g. dry, brittle caulk), will be mechanically disturbed (e.g. concrete drilling) or is leaking (e.g. ballasts, transformers), respiratory protection may also be required. Depending on the condition of the material and the extent of sampling required, task-specific PPE may be required.

## 10.0 AIR MONITORING

For determining the presence of PCBs in indoor air, the EPA currently has two approved methods: Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air – Compendium Method TO-4A (high air volume); and Compendium Method TO- 10A (low air volume).[72,73] Both methods utilize sorbent cartridges containing pre-cleaned open-cell polyurethane foam (PUF) as the sampling media, and analysis by GC coupled with an electron capture detector (ECD), nitrogen-phosphorus detector (NPD), flame photometric detector (FPD), Hall electrolytic conductivity detector (HECD) or a mass spectrometer (MS).

Personal sampling for Aroclors 1242 and 1254 can be accomplished utilizing the National Institute for Occupational Safety and Health (NIOSH) 5503 method. Samples are collected utilizing a sampling train consisting of a 13 mm glass fiber filter followed by a solid sorbent tube containing deactivated Florisil. Analysis of the samples is performed using GC/ECD.[74] Analysis should be done by a certified laboratory, such as those accredited under the AIHA Industrial Hygiene Laboratory Accreditation Program.[75]

## 11.0 REMEDIATION

The EPA published the findings of a literature review of remediation methods for PCBs and PCB-containing building materials in January 2012.[8] PCB remediation is broadly defined as removing PCB sources from buildings, removing PCBs from building materials, or limiting their migration or release from sources in buildings. PCB remediation methods are generally classified as either abatement or mitigation. The purpose of abatement is to remove or reduce the amount of PCBs in building materials through physical removal or chemical treatment of source materials. Mitigation is intended to control human exposures to PCBs by limiting their release from building materials and accumulation in indoor air and surface dust. Mitigation is often considered a complement to abatement operations.

### *11.1 Abatement*

Abatement methods include the physical removal of primary and secondary PCB sources by various manual or mechanical means and chemical treatment or decontamination techniques to reduce PCB concentrations in PCB sources. Abatement is considered a permanent solution to PCB-containing building materials through source removal or reduction of PCB concentrations in those materials to below the clearance criteria for residual PCBs as defined in 40 CFR Part 761.

Physical removal is the method of choice for primary source materials such as caulk, glazing, paint, ceiling tiles and other bulk materials. Hand tools are readily available for removal of various building materials, including utility knives, putty knives, scrapers, ripping chisels and bush hammers. Manual methods generally generate less dust, waste, noise, vibration and odor than do mechanical and chemical removal methods. Caulk found on building exteriors is generally hard and brittle, whereas caulk found in building interiors is often soft and flexible, making manual removal somewhat less challenging. Mechanical methods are typically used for other PCB sources such as surfacing materials (e.g., paints, adhesives, etc.). Abrasive blasting methods include sand, shot, bead, hydro and carbon dioxide (dry ice) blasting. Mechanical tools, including various hand-held or large-scale grinding, scraping and cutting equipment (e.g., scabblers), are generally employed for removal of secondary sources such as brick and concrete. HEPA-filtered vacuum attachments should be used to contain the dust generated during mechanical removal activities. Tools and removal methods that produce heat above 212 degrees Fahrenheit may generate gases that contain PCBs and should be avoided.[76]

Chemical treatments of PCB-containing building materials include chemical degradation or extraction methods intended to reduce the PCB concentration of the source materials. Commercially available chemical degradation products are typically applied to sources as a slurry or paste, covered with an overlying material and left in place for days to weeks for the chemical reaction to produce less hazardous substances. One dechlorination product has been reported to reduce PCB concentrations on various surfaces, including steel ship bulkheads, railroad ballast, soils and bulk oils, by 90 to 99 percent.[8] Its effectiveness on caulks and painted surfaces is being studied but findings have not yet been made available. Another chemical degradation method, known as the Activated Metal Treatment System, has been used on caulk, concrete and painted surfaces and is reportedly more cost-effective on porous materials such as concrete than building demolition and disposal.[8] Waste materials to be managed and disposed of include both the spent product and the degradation products.

Chemical extraction and cleaning methods are typically employed as a precursor step to source encapsulation or as a follow-up step to bulk removal.[8] One commercially available product for PCB extraction is a water-based solvent with emulsifiers, which has been used on concrete with varying results. Odor complaints and significant waste streams are reported concerns with the use of this product.[8] Another chemical extraction method used on brick and concrete is the EPA-prescribed double wash and rinse procedure (under 40 CFR 761 Subpart S) with detergent and solvent washes and potable water and solvent rinses. There are several commercially available degreaser solvents that can be used. Other chemical cleaning methods for removal of residual PCBs from nonporous surfaces employ solvents such as mineral spirits, kerosene, diesel and terpene hydrocarbons, in addition to commercially available cleaning agents such as trisodium phosphate. The EPA study, however, noted that "bleed-back" of oils and PCBs in concrete occurred within days of chemical cleaning efforts with all solvents used. This finding was attributed to the capillary rise of the oil in which the PCBs are dissolved.[8]

For leaks involving liquids containing PCBs, such as those found in old fluorescent light ballasts, the EPA requires special source removal and waste disposal procedures.[4,8] EPA indicates that building owners should consider proactive replacement of PCB-containing light fixtures as a cost-saving control measure as compared to the significant costs for PCB clean-up and building occupant displacement associated with a ballast leak or failure.

If PCBs have contaminated the adjacent soil and concentrations exceed 1 ppm, the soil is considered PCB remediation waste and is subject to the cleanup and disposal requirements specified under 40 CFR 761.61. As such, excavation of PCB-contaminated soils that result from spills or releases from PCB-containing building materials, as well as from improper abatement, handling and disposal practices, may be required in some instances.

### *11.2 Mitigation*

PCB mitigation is an interim control measure intended to limit PCB release from building materials, reduce airborne and surface PCB accumulations inside buildings, and minimize exposure of building occupants to PCB sources. If properly planned and implemented, mitigation methods may be as effective as permanent controls in the protection of human and environmental health. Mitigation, which is often a complement to abatement methods, includes engineering and administrative control measures, which can be employed individually or in various combinations. Priorities for mitigation efforts should be based on the material's PCB concentration, condition, accessibility and building occupancy.[8,77,78,79]

#### 11.2.1 Engineering Controls

Engineering controls are modifications to the building's systems and structures that serve to reduce the exposure potential of building occupants to PCB sources and releases. Engineering controls in this application include encapsulation, physical barriers (enclosure), ventilation and air cleaning.

Encapsulation involves covering PCB sources such as caulk, paints and adhesive with an impermeable film or sealant to reduce the potential for dermal contact and to reduce PCB release through mechanical disturbance, deterioration (aging) or volatilization.[8,77,78,79] Encapsulants include tapes, sealants (acrylic,

polyurethane and silicone) and epoxy coatings. Epoxy coatings have been widely used in joints after caulk removal. In an April 2012 publication, the EPA reported the major findings of its laboratory study of various encapsulating materials.[80] The report noted that encapsulation was most effective for contaminated surfaces with low PCB levels (maximum allowable PCB concentration was estimated to be 430 ppm), that multiple layers of coatings enhance performance, and that encapsulation offers a significant cost reduction by not removing PCB-contaminated secondary source materials (e.g., brick, concrete) from buildings. The EPA indicated that the encapsulation of primary sources, such as old caulk, which contain high PCB concentrations, may not adequately reduce air and surface PCB concentrations to recommended levels. EPA also cautioned that building owners need to implement long-term inspection and monitoring plans to ensure encapsulant seals remain intact. PCBs have been shown to transfer from secondary sources to encapsulating products intended to inhibit PCB migration. In one reported case, new silicone caulk applied directly to PCB- containing caulk absorbed the PCBs and reached levels up to 4,200 ppm.[8]

Physical barriers include the use of interior walls, sealants and foam to enclose PCB sources. Fences have been used to prevent access to exterior PCB-containing building materials. Geofabrics, clean stone and new landscaping mulch have been used to prevent access to contaminated soils resulting from disturbance or degradation of exterior PCB-containing building materials.

Increased building ventilation with outdoor air (greater than 5 air exchanges per hour) has been shown to reduce PCB concentrations in indoor air.[8] Energy costs due to heating and cooling of outdoor air may be significant for building owners. The building ventilation system should be checked to ensure that it is functioning as designed and, if necessary, owners should make appropriate repairs to increase or improve ventilation. Exhaust fans can be added to improve removal of air contaminants.

If elevated levels of airborne PCBs are found in a mechanically ventilated building, the ventilation system should be evaluated to determine if it is contaminated with PCBs. Although it is unlikely that the ventilation system is the original source of PCB contamination, it could be contaminated from other sources of PCBs and be contributing to the overall airborne levels. Contaminated ventilation systems should be carefully cleaned and, if possible, such cleaning should be conducted at the same time as the removal of any known sources of PCBs in order to avoid re-contamination of the system. The use of air cleaners equipped with activated charcoal filters operating at 400 cubic feet of air per minute (cfm) was shown to be effective in the reduction of indoor airborne PCB concentrations in one study.[8]

### 11.2.2 Administrative Controls

Administrative controls involve changes to the use or maintenance of a building that reduce the magnitude of potential occupant exposure to PCBs or the likelihood of uncontrolled PCB releases from source materials. Building spaces with low PCB exposure potential (e.g., storage areas, attics, etc.) or confirmed indoor air concentrations well below established indoor air targets are good locations for implementation of administrative controls. Special consideration should be given to vulnerable populations (i.e., young children) to ensure that accessibility and exposure to primary and secondary PCB sources are prevented.

Operations and maintenance (O&M) plans for residual PCBs in building materials should be a major component of an overall facility management plan. O&M plans should address PCB source materials and

concentrations, locations, conditions, accessibility, abatement and mitigation controls in place, inspections, work practices and controls for contacting and cleaning PCB source materials and the need for additional remediation actions. The O&M plan should also include provisions for periodic air and surface sampling to assess PCB concentrations and effectiveness of mitigation controls and awareness training of building occupants.

Management-in-place of PCB-containing building materials can present significant costs to building owners.[8,79] Prohibited work practices, such as use of compressed air and dry sweeping and dusting, should be clearly identified in the O&M plans. Building occupants and workers should be instructed to avoid or minimize direct contact with PCB-containing materials. For caulk used on windows, walls, columns and other vertical structures that occupants may contact, metallic tape can be used to isolate the material so that caulk or dust and debris from the surrounding masonry do not escape. The metallic tape should cover the caulk and surrounding areas of masonry.

In addition, disintegrating PCB caulk, paints and other coatings may also shed dust that can contaminate window sills and other nearby surfaces. Best management practices should be developed for dealing with dust, including:

- Frequent cleaning to reduce dust and residue inside buildings;
- Using wet or damp cloths and/or mops to clean surfaces;
- Using vacuums equipped with high efficiency particulate air (HEPA) filters;
- Do not dry sweep and minimize the use of dusters;
- Wear the appropriate protective clothing when conducting this cleanup;
- Dispose of all cleanup materials (mops, rags, filters, water, etc.) in accordance with all federal, state, and county regulations; and
- Wash hands and face with soap and water after cleaning, and before eating or drinking.

### *11.3 Remediation Work Plans*

U.S. EPA PCB regulations require that a work plan be prepared prior to starting any PCB remediation action in a building.[4] The self-implementing procedures required by the EPA for removal or cleanup of PCB-contaminated building materials require notification and submission of a work plan to the EPA at least 30 days prior to the site cleanup under 40 CFR 761.61. The plan must include description of abatement and mitigation activities, proposed cleanup levels, removal and abatement procedures, verification sampling procedures, waste storage and handling procedures and disposal options.

As previously stated in this paper, building owners should also confirm the presence of asbestos and lead in the suspect or identified PCB-containing building materials. Work plans should identify the additional hazardous materials and contractor workers must meet OSHA, state and local requirements for abatement of these materials.

A California study evaluated the potential impacts of PCB-containing caulks and sealants released into storm water runoff during building demolition and renovation projects and a Model Implementation Process has been initially proposed to establish a regulatory process to manage PCBs in caulks and sealants to protect water quality.[76] Similar to building demolition projects involving asbestos and lead, industrial hygienists can play a significant role in community and environmental protection through careful planning and oversight of work area containment, dust suppression methods, site erosion and sediment controls and protection of storm water drains.

### *11.4 Evaluation of Remediation Methods*

The EPA's PCB regulations (40 CFR 761) do not specify a schedule for the determination of PCB-containing materials as waste or for the remediation of PCB waste.[4] Building owners are thus able to evaluate site-specific conditions, various remediation options, establish practical remediation goals and select the remediation strategy that is most appropriate for their buildings with PCB-containing materials. Building owners should also understand that interim control of identified PCB releases to the environment may be required while options for permanent remedies are evaluated. Significant costs are associated with managing PCBs in place.

Several studies have demonstrated that the available abatement and mitigation methods are effective for complying with current PCB regulations, especially when multiple methods are used concurrently for PCB hazard reduction. Additional factors that may drive a remedial response are PCB concentrations in indoor air and surface dust, regardless of the PCB content of the building materials themselves.

### *11.5 Post-Remediation Verification*

40 CFR 761.79 provides for measurement-based methods (i.e., post-remediation wipe sampling and analysis) as well as performance-based methods (e.g., incineration). These may proceed without prior EPA approval. However, if an alternate remediation strategy is to be used, then EPA approval must be obtained. This rule defines decontamination standards and procedures for the removal of PCBs from a variety of media, such as water, concrete, organic liquids, and non-porous surfaces. For the built/building environment, there are two specific applications: concrete and non-porous surfaces covered with a porous surface, such as paint or coatings on metals.

40 CFR 761.79(f) requires confirmatory sampling per Subpart P, which addresses sampling of wastes for proper disposal methods under 761.61(a)(6), as well as decontamination verification under 761.79 (b)(3).

Decontamination verification for abated non-porous surfaces that were covered with PCB paint or caulk is a visual examination followed by a standard wipe test per 761.123. A variety of solvents may be selected for sampling, but many of these solvents are flammable and have their own toxicity concerns. A wipe sample is typically acquired from a 10 centimeter by 10 centimeter surface area; sufficient numbers of samples must be collected to meet statistical treatments.

### *11.6 Personal Protective Equipment*

Workers performing PCB remediation normally wear disposable whole body clothing and shoe covers, respiratory protection, chemical-resistant gloves, and safety glasses or protective goggles to protect against inhalation and dermal exposure to PCBs.

As noted above, in addition to PCBs, caulking and other construction materials may also contain lead or asbestos. In many cases remediation should proceed in a manner similar to lead or asbestos removal. While there are no nationally recognized PCB removal certifications, facility owners may want to consider utilizing contractors with AHERA or RRP abatement certifications.

- Respirators – air purifying respirators are typically worn by workers during remediation work. While half facepiece respirators may be acceptable based on the exposure levels, some employers prefer to use full facepiece respirators or powered air purifying respirators (PAPRs). Both full-facepiece (with quantitative fit testing) and PAPRs provide higher assigned protection factors than half-facepiece respirators. The full-facepiece respirator also provides eye protection and additional skin protection by covering the whole face. PAPRs, when used with hoods or helmets, can protect the entire head, neck and shoulder area. Depending on the system, PAPRs may offer additional advantages, such as allowing limited facial hair and waiving of fit-testing. PCBs are primarily a particulate hazard and a P95 filter would be appropriate. However, a P100 filter is required if lead or asbestos co-exists with the PCBs. Therefore, employers may want to consider routine use of P100 filters as a precaution in case previously unidentified asbestos or lead is encountered during remediation. At this time, PAPRs use only the high efficiency (HE) designation — not 95 or 100 designations.

  PCBs may also be present in a vapor form, especially if the material has been heated. If there is any possibility of a vapor phase being present, employers should use a combination P100/organic vapor cartridge.[81] A respiratory protection program that complies with the requirements of 29 CFR Part 1910.134 must be established. Respirator users must understand and follow the respirator user instructions and any other manufacturer's recommendations and warnings.
- Worker protective clothing (WPC) – Full-body WPC should be worn during remediation to minimize skin contact and also to minimize the risk of bringing contaminated clothing back to the worker's home. Employers may want to look for WPC that meets the requirements of EN ISO 13982-1 Type 5 - Protective Clothing for Use against Solid Particles or ANSI/ISEA 103-2010 American National Standard for Classification and Performance Requirements for Chemical Protective Clothing.[82,83]
- Gloves – PCBs may be absorbed to a significant extent through the skin. Therefore, chemical-protective gloves should be worn when handling PCB-contaminated material. EPA suggests using gloves made of nitrile butadiene rubber.[81] Butyl rubber or neoprene may also offer sufficient protection for incidental contact during remediation.[84] The glove manufacturer should always be consulted to determine the best product for the specific tasks and expected exposures.

### *11.7 Training*

Training for remediation workers should, at a minimum, include the following:

- Location of PCB-containing materials in the worksite;
- Hazard Communication training for PCBs that, at a minimum, meets the requirements of 29 CFR 1910.1200 and the importance of minimizing worker exposure (both inhalation and skin exposure);
- Other hazardous materials (e.g. lead, asbestos) that may also be present. If present, training and other requirements per 29 CFR 1926.62 and 29 CFR 1926.1101 must be followed;
- Engineering controls that will be used to minimize release of PCB materials (e.g. HEPA filtered vacuums, wet methods, local exhausted power tools);
- Eating, drinking and smoking are prohibited during handling of PCB materials and not allowed until required decontamination has been completed; and
- Proper inspection, use, cleaning, and storage of PPE per the manufacturer's user instructions. Eating, drinking and smoking are prohibited during handling of PCB materials and not allowed until required decontamination has been completed.

### *11.8 Waste Disposal*

#### 11.8.1 PCB Waste Categories

Under 40 CFR 761.3, a building material that is identified as an unauthorized use of PCBs and designated for disposal must be properly classified as either a PCB Bulk Product Waste or a PCB Remediation Waste. Materials that were "manufactured, coated or serviced with PCBs" and that contain 50 ppm or greater PCBs are subject to the requirements for PCB Bulk Product Waste. Primary sources of PCB-containing building materials such as caulks, glazing, mastics, sealants, paints and surface coatings are generally classified as PCB Bulk Product Waste.

On October 24, 2012, EPA issued a memorandum on the proposed reinterpretation of the PCB Bulk Product Waste definition noting that building materials (i.e., substrates) that are "coated or serviced with PCB Bulk Product Waste (e.g., caulk, paint, mastic, sealants) at the time of designation of disposal are to be managed as a PCB bulk product waste, even if the PCBs have migrated from the overlying bulk product waste into the substrate, provided there is no other source of PCB contamination on or in the substrate."[85] If the bulk product waste has been removed or separated (no longer coated or serviced) from the substrate at the time of designation for disposal and the substrate is contaminated with PCBs that have migrated from the bulk product waste, the substrate would be considered a PCB remediation waste. EPA recommends that the building owner document in the abatement plan the decision to designate building materials as bulk product waste at the time of designation for disposal. EPA notes that this proposed reinterpretation will allow for prompt PCB removal and disposal and thereby reduce potential exposure of building occupants and workers. EPA notes that it received no opposition in public comments to its proposed reinterpretation.

Secondary sources or materials that contain PCBs as a result of a release from primary sources are subject to the PCB Remediation Waste regulations. These include building materials such as brick, concrete and other building materials contaminated by PCB spills, waste materials from clean-up activities, and contaminated soil. Leaching is considered by EPA to be a release of PCBs.

### 11.8.2 Waste Disposal

Disposal options for PCB Bulk Product Waste (40 CFR Part 761.62) include performance-based disposal by landfill, incineration or decontamination at a Resource Conservation and Recovery Act (RCRA) permitted facility. EPA may also approve a risk-based disposal method if it can be demonstrated that it will not pose an unreasonable risk of injury to health or the environment.

EPA regulations allow PCB Remediation Waste to be managed according to a method that is termed self-implementing onsite clean-up and disposal. This disposal option allows residual levels of PCB Remediation Waste to remain in a building, the amount depending on the use characteristics of the property and the disposition of the PCBs: high occupancy (e.g., school classroom, plant assembly line, cafeteria) versus low occupancy (e.g., non-office space in a warehouse or electrical equipment vault) areas; bulk concentrations versus surface loading levels; and unrestricted land use versus a deed restriction. The surface clearance criteria for PCB Remediation Waste for a nonporous surface is less than or equal to ten micrograms of PCBs per 100 square centimeters (µg/100 $cm^2$) in a high-occupancy area and less than 100 µg/100 $cm^2$ for a low-occupancy area.[4,8] The clearance criteria for PCB Remediation Waste for a bulk or porous material is less than or equal to one ppm in a high-occupancy area and less than or equal to 25 ppm in a low-occupancy area.[4,8]

## 12.0 DISCUSSION

Review of the current state of PCB knowledge has identified critical information gaps pertaining to the health risks that PCBs in the built environment may pose to occupants and workers. While it is beyond the scope of this white paper to quantify the risk of PCBs ingested from contaminated food, as compared to the risk associated with exposure to PCBs arising from the built environment, it should be kept in mind that most of the human PCB exposure historically has been mainly through the ingestion of contaminated food or from occupational exposures (e.g. manufacturing PCB-containing components, etc.). The health risks posed by PCBs in the built environment are not well understood. Hence, improved exposure assessments in the built environment are necessary to further understand the short and long-term risks to building occupants, building maintenance and construction personnel from PCB-containing construction materials.

Some of the potentially significant data gaps identified include:

- The paucity of exposure assessment data with congener-specific identification and resulting exposure profiles to building occupants, maintenance personnel and construction workers. In addition, there is inconsistency within published studies on the selection of congeners studied; some use methods of analysis that provide results for prescribed congeners, while others attempt to link source-confirmed congeners to air sampling data. There is a need for standardized approaches to the selection of congeners under study in the built environment, whether for biological, environmental or structural characterization purposes.

- There is a lack of complete exposure profiles across the variety of building types, with consideration of the populations occupying them. Few of the studies cited reported on occupancy characteristics of the populations (i.e., times of day and days of week the building was occupied, etc.), which would serve to refine risk and exposure assessments from source materials.
- In the United States, current TSCA regulations do not require identification of PCB- containing building materials, unless activities are planned that may generate PCB wastes (i.e. renovation or demolition activities). Additionally, very few international regulations have, as a starting point, an obligation to identify and confirm open sources of PCBs. As a result, many environments with PCB exposures go unrecognized, or are mischaracterized because the primary exposure sources may be unidentified (such as assessing airborne concentrations of PCBs released from PCB-containing caulk when concrete in the same room had previously been contaminated from leaking light ballasts). Thorough hazard identification should always be the first step prior to determining risk to the occupants.
- Currently prescribed respiratory protection levels for abatement/remediation/mitigation activities do not appear to suitably address work involving PCBs in their vapor phase. The use of air-purifying respiratory protection equipped with combination HEPA/organic vapor cartridges is recommended.
- Non-legacy PCBs in pigments continue to be produced. Such pigments may have consequences related to human health and the environment through contaminated drinking water or bioaccumulation in the food chain.

## 13.0 CONCLUSION

This white paper has reviewed and summarized the current scientific body of knowledge with respect to the hazard identification, exposure assessment and risk management related to PCBs in the built environment. In support of AIHA's current strategic plan, and based on a review of the issue, the authors call attention to the following needs for the development of public policy based on sound science. AIHA can assist in this endeavor by:

1. Promoting the need for additional scientific research into the relative exposure risks posed by PCB-containing building materials to building occupants, maintenance and construction personnel; and
2. Encouraging the collection of exposure assessment data by the industrial hygiene and scientific community to confirm and verify the extent of any such risks.

Development of PCB exposure assessment profiles for building occupants, as well as maintenance and construction personnel, can lead to a better understanding of the populations most at risk from PCBs in building materials. Risk assessment analyses, based on more comprehensive exposure data, could then serve as the technical basis for possible regulatory changes to help ensure that human health and the environment are appropriately protected based on an improved understanding of the role that PCBs in building materials may play in the overall exposure risk from PCBs (i.e. dietary versus building environment exposures).

## Appendix A: PCB Species by Congener Number

| IUPAC Name | BZ Congener Number | CASRN | Descriptors |
|---|---|---|---|
| Biphenyl | 0 | 92-52-4 | |
| 2-Chlorobiphenyl | 1 | 2051-60-7 | CP1 |
| 3-Chlorobiphenyl | 2 | 2051-61-8 | CP0 |
| 4-Chlorobiphenyl | 3 | 2051-62-9 | CP0 |
| 2,2'-Dichlorobiphenyl | 4 | 13029-08-8 | |
| 2,3-Dichlorobiphenyl | 5 | 16605-91-7 | CP1 |
| 2,3'-Dichlorobiphenyl | 6 | 25569-80-6 | CP1 |
| 2,4-Dichlorobiphenyl | 7 | 33284-50-3 | CP1 |
| 2,4'-Dichlorobiphenyl | 8 | 34883-43-7 | CP1 |
| 2,5-Dichlorobiphenyl | 9 | 34883-39-1 | CP1 |
| 2,6-Dichlorobiphenyl | 10 | 33146-45-1 | |
| 3,3'-Dichlorobiphenyl | 11 | 2050-67-1 | CP0, 2M |
| 3,4-Dichlorobiphenyl | 12 | 2974-92-7 | CP0 |
| 3,4'-Dichlorobiphenyl | 13 | 2974-90-5 | CP0 |
| 3,5-Dichlorobiphenyl | 14 | 34883-41-5 | CP0, 2M |
| 4,4'-Dichlorobiphenyl | 15 | 2050-68-2 | CP0, PP |
| 2,2',3-Trichlorobiphenyl | 16 | 38444-78-9 | |
| 2,2',4-Trichlorobiphenyl | 17 | 37680-66-3 | |
| 2,2',5-Trichlorobiphenyl | 18 | 37680-65-2 | |
| 2,2',6-Trichlorobiphenyl | 19 | 38444-73-4 | |
| 2,3,3'-Trichlorobiphenyl | 20 | 38444-84-7 | CP1, 2M |
| 2,3,4-Trichlorobiphenyl | 21 | 55702-46-0 | CP1 |
| 2,3,4'-Trichlorobiphenyl | 22 | 38444-85-8 | CP1 |
| 2,3,5-Trichlorobiphenyl | 23 | 55720-44-0 | CP1, 2M |
| 2,3,6-Trichlorobiphenyl | 24 | 55702-45-9 | |
| 2,3',4-Trichlorobiphenyl | 25 | 55712-37-3 | CP1 |
| 2,3',5-Trichlorobiphenyl | 26 | 38444-81-4 | CP1, 2M |
| 2,3',6-Trichlorobiphenyl | 27 | 38444-76-7 | |
| 2,4,4'-Trichlorobiphenyl | 28 | 7012-37-5 | CP1, PP |
| 2,4,5-Trichlorobiphenyl | 29 | 15862-07-4 | CP1 |
| 2,4,6-Trichlorobiphenyl | 30 | 35693-92-6 | |
| 2,4',5-Trichlorobiphenyl | 31 | 16606-02-3 | CP1 |
| 2,4',6-Trichlorobiphenyl | 32 | 38444-77-8 | |
| 2,3',4'-Trichlorobiphenyl | 33 | 38444-86-9 | CP1 |
| 2,3',5'-Trichlorobiphenyl | 34 | 37680-68-5 | CP1, 2M |
| 3,3',4-Trichlorobiphenyl | 35 | 37680-69-6 | CP0, 2M |
| 3,3',5-Trichlorobiphenyl | 36 | 38444-87-0 | CP0, 2M |
| 3,4,4'-Trichlorobiphenyl | 37 | 38444-90-5 | CP0, PP |
| 3,4,5-Trichlorobiphenyl | 38 | 53555-66-1 | CP0, 2M |
| 3,4',5-Trichlorobiphenyl | 39 | 38444-88-1 | CP0, 2M |
| 2,2',3,3'-Tetrachlorobiphenyl | 40 | 38444-93-8 | 4CL, 2M |
| 2,2',3,4-Tetrachlorobiphenyl | 41 | 52663-59-9 | 4CL |
| 2,2',3,4'-Tetrachlorobiphenyl | 42 | 36559-22-5 | 4CL |
| 2,2',3,5-Tetrachlorobiphenyl | 43 | 70362-46-8 | 4CL, 2M |
| 2,2',3,5'-Tetrachlorobiphenyl | 44 | 41464-39-5 | 4CL, 2M |
| 2,2',3,6-Tetrachlorobiphenyl | 45 | 70362-45-7 | 4CL |
| 2,2',3,6'-Tetrachlorobiphenyl | 46 | 41464-47-5 | 4CL |
| 2,2',4,4'-Tetrachlorobiphenyl | 47 | 2437-79-8 | 4CL, PP |
| 2,2',4,5-Tetrachlorobiphenyl | 48 | 70362-47-9 | 4CL |
| 2,2',4,5'-Tetrachlorobiphenyl | 49 | 41464-40-8 | 4CL |
| 2,2',4,6-Tetrachlorobiphenyl | 50 | 62796-65-0 | 4CL |
| 2,2',4,6'-Tetrachlorobiphenyl | 51 | 68194-04-7 | 4CL |
| 2,2',5,5'-Tetrachlorobiphenyl | 52 | 35693-99-3 | 4CL, 2M |
| 2,2',5,6'-Tetrachlorobiphenyl | 53 | 41464-41-9 | 4CL |
| 2,2',6,6'-Tetrachlorobiphenyl | 54 | 15968-05-5 | 4CL |
| 2,3,3',4-Tetrachlorobiphenyl | 55 | 74338-24-2 | CP1, 4CL, 2M |
| 2,3,3',4'-Tetrachlorobiphenyl | 56 | 41464-43-1 | CP1, 4CL, 2M |
| 2,3,3',5-Tetrachlorobiphenyl | 57 | 70424-67-8 | CP1, 4CL, 2M |
| 2,3,3',5'-Tetrachlorobiphenyl | 58 | 41464-49-7 | CP1, 4CL, 2M |

## Appendix A: PCB Species by Congener Number (continued)

| IUPAC Name | BZ Congener Number | CASRN | Descriptors |
|---|---|---|---|
| 2,3,3',6-Tetrachlorobiphenyl | 59 | 74472-33-6 | 4CL, 2M |
| 2,3,4,4'-Tetrachlorobiphenyl | 60 | 33025-41-1 | CP1, 4CL, PP |
| 2,3,4,5-Tetrachlorobiphenyl | 61 | 33284-53-6 | CP1, 4CL, 2M |
| 2,3,4,6-Tetrachlorobiphenyl | 62 | 54230-22-7 | 4CL |
| 2,3,4',5-Tetrachlorobiphenyl | 63 | 74472-34-7 | CP1, 4CL, 2M |
| 2,3,4',6-Tetrachlorobiphenyl | 64 | 52663-58-8 | 4CL |
| 2,3,5,6-Tetrachlorobiphenyl | 65 | 33284-54-7 | 4CL, 2M |
| 2,3',4,4'-Tetrachlorobiphenyl | 66 | 32598-10-0 | CP1, 4CL, PP |
| 2,3',4,5-Tetrachlorobiphenyl | 67 | 73575-53-8 | CP1, 4CL, 2M |
| 2,3',4,5'-Tetrachlorobiphenyl | 68 | 73575-52-7 | CP1, 4CL, 2M |
| 2,3',4,6-Tetrachlorobiphenyl | 69 | 60233-24-1 | 4CL |
| 2,3',4',5-Tetrachlorobiphenyl | 70 | 32598-11-1 | CP1, 4CL, 2M |
| 2,3',4',6-Tetrachlorobiphenyl | 71 | 41464-46-4 | 4CL |
| 2,3',5,5'-Tetrachlorobiphenyl | 72 | 41464-42-0 | CP1, 4CL, 2M |
| 2,3',5',6-Tetrachlorobiphenyl | 73 | 74338-23-1 | 4CL, 2M |
| 2,4,4',5-Tetrachlorobiphenyl | 74 | 32690-93-0 | CP1, 4CL, PP |
| 2,4,4',6-Tetrachlorobiphenyl | 75 | 32598-12-2 | 4CL, PP |
| 2,3',4',5'-Tetrachlorobiphenyl | 76 | 70362-48-0 | CP1, 4CL, 2M |
| 3,3',4,4'-Tetrachlorobiphenyl | 77 | 32598-13-3 | CP0, 4CL, PP, 2M |
| 3,3',4,5-Tetrachlorobiphenyl | 78 | 70362-49-1 | CP0, 4CL, 2M |
| 3,3',4,5'-Tetrachlorobiphenyl | 79 | 41464-48-6 | CP0, 4CL, 2M |
| 3,3',5,5'-Tetrachlorobiphenyl | 80 | 33284-52-5 | CP0, 4CL, 2M |
| 3,4,4',5-Tetrachlorobiphenyl | 81 | 70362-50-4 | CP0, 4CL, PP, 2M |
| 2,2',3,3',4-Pentachlorobiphenyl | 82 | 52663-62-4 | 4CL, 2M |
| 2,2',3,3',5-Pentachlorobiphenyl | 83 | 60145-20-2 | 4CL, 2M |
| 2,2',3,3',6-Pentachlorobiphenyl | 84 | 52663-60-2 | 4CL, 2M |
| 2,2',3,4,4'-Pentachlorobiphenyl | 85 | 65510-45-4 | 4CL, PP |
| 2,2',3,4,5-Pentachlorobiphenyl | 86 | 55312-69-1 | 4CL, 2M |
| 2,2',3,4,5'-Pentachlorobiphenyl | 87 | 38380-02-8 | 4CL, 2M |
| 2,2',3,4,6-Pentachlorobiphenyl | 88 | 55215-17-3 | 4CL |
| 2,2',3,4,6'-Pentachlorobiphenyl | 89 | 73575-57-2 | 4CL |
| 2,2',3,4',5-Pentachlorobiphenyl | 90 | 68194-07-0 | 4CL, 2M |
| 2,2',3,4',6-Pentachlorobiphenyl | 91 | 68194-05-8 | 4CL |
| 2,2',3,5,5'-Pentachlorobiphenyl | 92 | 52663-61-3 | 4CL, 2M |
| 2,2',3,5,6-Pentachlorobiphenyl | 93 | 73575-56-1 | 4CL, 2M |
| 2,2',3,5,6'-Pentachlorobiphenyl | 94 | 73575-55-0 | 4CL, 2M |
| 2,2',3,5',6-Pentachlorobiphenyl | 95 | 38379-99-6 | 4CL, 2M |
| 2,2',3,6,6'-Pentachlorobiphenyl | 96 | 73575-54-9 | 4CL |

## Appendix A: PCB Species by Congener Number (continued)

| IUPAC Name | BZ Congener Number | CASRN | Descriptors |
|---|---|---|---|
| 2,2',3,4',5'-Pentachlorobiphenyl | 97 | 41464-51-1 | 4CL, 2M |
| 2,2',3,4',6'-Pentachlorobiphenyl | 98 | 60233-25-2 | 4CL |
| 2,2',4,4',5-Pentachlorobiphenyl | 99 | 38380-01-7 | 4CL, PP |
| 2,2',4,4',6-Pentachlorobiphenyl | 100 | 39485-83-1 | 4CL, PP |
| 2,2',4,5,5'-Pentachlorobiphenyl | 101 | 37680-73-2 | 4CL, 2M |
| 2,2',4,5,6'-Pentachlorobiphenyl | 102 | 68194-06-9 | 4CL |
| 2,2',4,5',6-Pentachlorobiphenyl | 103 | 60145-21-3 | 4CL |
| 2,2',4,6,6'-Pentachlorobiphenyl | 104 | 56558-16-8 | 4CL |
| 2,3,3',4,4'-Pentachlorobiphenyl | 105 | 32598-14-4 | CP1, 4CL, PP, 2M |
| 2,3,3',4,5-Pentachlorobiphenyl | 106 | 70424-69-0 | CP1, 4CL, 2M |
| 2,3,3',4',5-Pentachlorobiphenyl | 107 | 70424-68-9 | CP1, 4CL, 2M |
| 2,3,3',4,5'-Pentachlorobiphenyl | 108 | 70362-41-3 | CP1, 4CL, 2M |
| 2,3,3',4,6-Pentachlorobiphenyl | 109 | 74472-35-8 | 4CL, 2M |
| 2,3,3',4',6-Pentachlorobiphenyl | 110 | 38380-03-9 | 4CL, 2M |
| 2,3,3',5,5'-Pentachlorobiphenyl | 111 | 39635-32-0 | CP1, 4CL, 2M |
| 2,3,3',5,6-Pentachlorobiphenyl | 112 | 74472-36-9 | 4CL, 2M |
| 2,3,3',5',6-Pentachlorobiphenyl | 113 | 68194-10-5 | 4CL, 2M |
| 2,3,4,4',5-Pentachlorobiphenyl | 114 | 74472-37-0 | CP1, 4CL, PP, 2M |
| 2,3,4,4',6-Pentachlorobiphenyl | 115 | 74472-38-1 | 4CL, PP |
| 2,3,4,5,6-Pentachlorobiphenyl | 116 | 18259-05-7 | 4CL, 2M |
| 2,3,4',5,6-Pentachlorobiphenyl | 117 | 68194-11-6 | 4CL, 2M |
| 2,3',4,4',5-Pentachlorobiphenyl | 118 | 31508-00-6 | CP1, 4CL, PP, 2M |
| 2,3',4,4',6-Pentachlorobiphenyl | 119 | 56558-17-9 | 4CL, PP |
| 2,3',4,5,5'-Pentachlorobiphenyl | 120 | 68194-12-7 | CP1, 4CL, 2M |
| 2,3',4,5',6-Pentachlorobiphenyl | 121 | 56558-18-0 | 4CL, 2M |
| 2,3,3',4',5'-Pentachlorobiphenyl | 122 | 76842-07-4 | CP1, 4CL, 2M |
| 2,3',4,4',5'-Pentachlorobiphenyl | 123 | 65510-44-3 | CP1, 4CL, PP, 2M |
| 2,3',4',5,5'-Pentachlorobiphenyl | 124 | 70424-70-3 | CP1, 4CL, 2M |
| 2,3',4',5',6-Pentachlorobiphenyl | 125 | 74472-39-2 | 4CL, 2M |
| 3,3',4,4',5-Pentachlorobiphenyl | 126 | 57465-28-8 | CP0, 4CL, PP, 2M |
| 3,3',4,5,5'-Pentachlorobiphenyl | 127 | 39635-33-1 | CP0, 4CL, 2M |
| 2,2',3,3',4,4'-Hexachlorobiphenyl | 128 | 38380-07-3 | 4CL, PP, 2M |
| 2,2',3,3',4,5-Hexachlorobiphenyl | 129 | 55215-18-4 | 4CL, 2M |
| 2,2',3,3',4,5'-Hexachlorobiphenyl | 130 | 52663-66-8 | 4CL, 2M |
| 2,2',3,3',4,6-Hexachlorobiphenyl | 131 | 61798-70-7 | 4CL, 2M |
| 2,2',3,3',4,6'-Hexachlorobiphenyl | 132 | 38380-05-1 | 4CL, 2M |

## Appendix A: PCB Species by Congener Number (continued)

| IUPAC Name | BZ Congener Number | CASRN | Descriptors |
|---|---|---|---|
| 2,2',3,3',5,5'-Hexachlorobiphenyl | 133 | 35694-04-3 | 4CL, 2M |
| 2,2',3,3',5,6-Hexachlorobiphenyl | 134 | 52704-70-8 | 4CL, 2M |
| 2,2',3,3',5,6'-Hexachlorobiphenyl | 135 | 52744-13-5 | 4CL, 2M |
| 2,2',3,3',6,6'-Hexachlorobiphenyl | 136 | 38411-22-2 | 4CL, 2M |
| 2,2',3,4,4',5-Hexachlorobiphenyl | 137 | 35694-06-5 | 4CL, PP, 2M |
| 2,2',3,4,4',5'-Hexachlorobiphenyl | 138 | 35065-28-2 | 4CL, PP, 2M |
| 2,2',3,4,4',6-Hexachlorobiphenyl | 139 | 56030-56-9 | 4CL, PP |
| 2,2',3,4,4',6'-Hexachlorobiphenyl | 140 | 59291-64-4 | 4CL, PP |
| 2,2',3,4,5,5'-Hexachlorobiphenyl | 141 | 52712-04-6 | 4CL, 2M |
| 2,2',3,4,5,6-Hexachlorobiphenyl | 142 | 41411-61-4 | 4CL, 2M |
| 2,2',3,4,5,6'-Hexachlorobiphenyl | 143 | 68194-15-0 | 4CL, 2M |
| 2,2',3,4,5',6-Hexachlorobiphenyl | 144 | 68194-14-9 | 4CL, 2M |
| 2,2',3,4,6,6'-Hexachlorobiphenyl | 145 | 74472-40-5 | 4CL |
| 2,2',3,4',5,5'-Hexachlorobiphenyl | 146 | 51908-16-8 | 4CL, 2M |
| 2,2',3,4',5,6-Hexachlorobiphenyl | 147 | 68194-13-8 | 4CL, 2M |
| 2,2',3,4',5,6'-Hexachlorobiphenyl | 148 | 74472-41-6 | 4CL, 2M |
| 2,2',3,4',5',6-Hexachlorobiphenyl | 149 | 38380-04-0 | 4CL, 2M |
| 2,2',3,4',6,6'-Hexachlorobiphenyl | 150 | 68194-08-1 | 4CL |
| 2,2',3,5,5',6-Hexachlorobiphenyl | 151 | 52663-63-5 | 4CL, 2M |
| 2,2',3,5,6,6'-Hexachlorobiphenyl | 152 | 68194-09-2 | 4CL, 2M |
| 2,2',4,4',5,5'-Hexachlorobiphenyl | 153 | 35065-27-1 | 4CL, PP, 2M |
| 2,2',4,4',5,6'-Hexachlorobiphenyl | 154 | 60145-22-4 | 4CL, PP |
| 2,2',4,4',6,6'-Hexachlorobiphenyl | 155 | 33979-03-2 | 4CL, PP |
| 2,3,3',4,4',5-Hexachlorobiphenyl | 156 | 38380-08-4 | CP1, 4CL, PP, 2M |
| 2,3,3',4,4',5'-Hexachlorobiphenyl | 157 | 69782-90-7 | CP1, 4CL, PP, 2M |
| 2,3,3',4,4',6-Hexachlorobiphenyl | 158 | 74472-42-7 | 4CL, PP, 2M |
| 2,3,3',4,5,5'-Hexachlorobiphenyl | 159 | 39635-35-3 | CP1, 4CL, 2M |
| 2,3,3',4,5,6-Hexachlorobiphenyl | 160 | 41411-62-5 | 4CL, 2M |
| 2,3,3',4,5',6-Hexachlorobiphenyl | 161 | 74472-43-8 | 4CL, 2M |
| 2,3,3',4',5,5'-Hexachlorobiphenyl | 162 | 39635-34-2 | CP1, 4CL, 2M |
| 2,3,3',4',5,6-Hexachlorobiphenyl | 163 | 74472-44-9 | 4CL, 2M |
| 2,3,3',4',5',6-Hexachlorobiphenyl | 164 | 74472-45-0 | 4CL, 2M |
| 2,3,3',5,5',6-Hexachlorobiphenyl | 165 | 74472-46-1 | 4CL, 2M |
| 2,3,4,4',5,6-Hexachlorobiphenyl | 166 | 41411-63-6 | 4CL, PP, 2M |
| 2,3',4,4',5,5'-Hexachlorobiphenyl | 167 | 52663-72-6 | CP1, 4CL, PP, 2M |
| 2,3',4,4',5',6-Hexachlorobiphenyl | 168 | 59291-65-5 | 4CL, PP, 2M |

## Appendix A: PCB Species by Congener Number (continued)

| IUPAC Name | BZ Congener Number | CASRN | Descriptors |
|---|---|---|---|
| 3,3',4,4',5,5'-Hexachlorobiphenyl | 169 | 32774-16-6 | CP0, 4CL, PP, 2M |
| 2,2',3,3',4,4',5-Heptachlorobiphenyl | 170 | 35065-30-6 | 4CL, PP, 2M |
| 2,2',3,3',4,4',6-Heptachlorobiphenyl | 171 | 52663-71-5 | 4CL, PP, 2M |
| 2,2',3,3',4,5,5'-Heptachlorobiphenyl | 172 | 52663-74-8 | 4CL, 2M |
| 2,2',3,3',4,5,6-Heptachlorobiphenyl | 173 | 68194-16-1 | 4CL, 2M |
| 2,2',3,3',4,5,6'-Heptachlorobiphenyl | 174 | 38411-25-5 | 4CL, 2M |
| 2,2',3,3',4,5',6-Heptachlorobiphenyl | 175 | 40186-70-7 | 4CL, 2M |
| 2,2',3,3',4,6,6'-Heptachlorobiphenyl | 176 | 52663-65-7 | 4CL, 2M |
| 2,2',3,3',4,5',6'-Heptachlorobiphenyl | 177 | 52663-70-4 | 4CL, 2M |
| 2,2',3,3',5,5',6-Heptachlorobiphenyl | 178 | 52663-67-9 | 4CL, 2M |
| 2,2',3,3',5,6,6'-Heptachlorobiphenyl | 179 | 52663-64-6 | 4CL, 2M |
| 2,2',3,4,4',5,5'-Heptachlorobiphenyl | 180 | 35065-29-3 | 4CL, PP, 2M |
| 2,2',3,4,4',5,6-Heptachlorobiphenyl | 181 | 74472-47-2 | 4CL, PP, 2M |
| 2,2',3,4,4',5,6'-Heptachlorobiphenyl | 182 | 60145-23-5 | 4CL, PP, 2M |
| 2,2',3,4,4',5',6-Heptachlorobiphenyl | 183 | 52663-69-1 | 4CL, PP, 2M |
| 2,2',3,4,4',6,6'-Heptachlorobiphenyl | 184 | 74472-48-3 | 4CL, PP |
| 2,2',3,4,5,5',6-Heptachlorobiphenyl | 185 | 52712-05-7 | 4CL, 2M |
| 2,2',3,4,5,6,6'-Heptachlorobiphenyl | 186 | 74472-49-4 | 4CL, 2M |

| IUPAC Name | BZ Congener Number | CASRN | Descriptors |
|---|---|---|---|
| 2,2',3,4',5,5',6-Heptachlorobiphenyl | 187 | 52663-68-0 | 4CL, 2M |
| 2,2',3,4',5,6,6'-Heptachlorobiphenyl | 188 | 74487-85-7 | 4CL, 2M |
| 2,3,3',4,4',5,5'-Heptachlorobiphenyl | 189 | 39635-31-9 | CP1, 4CL, PP, 2M |
| 2,3,3',4,4',5,6-Heptachlorobiphenyl | 190 | 41411-64-7 | 4CL, PP, 2M |
| 2,3,3',4,4',5',6-Heptachlorobiphenyl | 191 | 74472-50-7 | 4CL, PP, 2M |
| 2,3,3',4,5,5',6-Heptachlorobiphenyl | 192 | 74472-51-8 | 4CL, 2M |
| 2,3,3',4',5,5',6-Heptachlorobiphenyl | 193 | 69782-91-8 | 4CL, 2M |
| 2,2',3,3',4,4',5,5'-Octachlorobiphenyl | 194 | 35694-08-7 | 4CL, PP, 2M |
| 2,2',3,3',4,4',5,6-Octachlorobiphenyl | 195 | 52663-78-2 | 4CL, PP, 2M |
| 2,2',3,3',4,4',5,6'-Octachlorobiphenyl | 196 | 42740-50-1 | 4CL, PP, 2M |
| 2,2',3,3',4,4',6,6'-Octachlorobiphenyl | 197 | 33091-17-7 | 4CL, PP, 2M |
| 2,2',3,3',4,5,5',6-Octachlorobiphenyl | 198 | 68194-17-2 | 4CL, 2M |
| 2,2',3,3',4,5,5',6'-Octachlorobiphenyl | 199 | 52663-75-9 | 4CL, 2M |
| 2,2',3,3',4,5,6,6'-Octachlorobiphenyl | 200 | 52663-73-7 | 4CL, 2M |
| 2,2',3,3',4,5',6,6'-Octachlorobiphenyl | 201 | 40186-71-8 | 4CL, 2M |
| 2,2',3,3',5,5',6,6'-Octachlorobiphenyl | 202 | 2136-99-4 | 4CL, 2M |
| 2,2',3,4,4',5,5',6-Octachlorobiphenyl | 203 | 52663-76-0 | 4CL, PP, 2M |
| 2,2',3,4,4',5,6,6'-Octachlorobiphenyl | 204 | 74472-52-9 | 4CL, PP, 2M |

## Appendix A: PCB Species by Congener Number (continued)

| IUPAC Name | BZ Congener Number | CASRN | Descriptors |
|---|---|---|---|
| 2,3,3',4,4',5,5',6-Octachlorobiphenyl | 205 | 74472-53-0 | 4CL, PP, 2M |
| 2,2',3,3',4,4',5,5',6-Nonachlorobiphenyl | 206 | 40186-72-9 | 4CL, PP, 2M |
| 2,2',3,3',4,4',5,6,6'-Nonachlorobiphenyl | 207 | 52663-79-3 | 4CL, PP, 2M |
| 2,2',3,3',4,5,5',6,6'-Nonachlorobiphenyl | 208 | 52663-77-1 | 4CL, 2M |
| Decachlorobiphenyl | 209 | 2051-24-3 | 4CL, PP, 2M |

IUPAC – International Union of Pure and Applied Chemistry

BZ Congener Number – the congener numbering is identical to that published by K. Ballschmiter, R. Bacher, A. Mennel, R. Fischer, U. Riehle, and M. Swerev. Determination of chlorinated biphenyls, chlorinated ibenzodioxins, and chlorinated dibenzofurans by GC-MS. *J. High Resol. Chromatogr.* 15:260-270. April 1992.

CASRN – Chemical Abstracts Service Registry Number

CP0 / CP1 - These 68 coplanar congeners fall into one of two groups. The first group of 20 congeners consists of those with chlorine substitution at none of the ortho positions on the biphenyl backbone and are referred to as CP0 or non-ortho congeners. The second group of 48 congeners includes those with chlorine substitution at only one of the ortho positions and are referred to as CP1 or mono-ortho congeners.

4CL - These 169 congeners have a total of four or more chlorine substituents, regardless of position.

PP - These 54 congeners have both para positions chlorinated.

2M - These 140 congeners have two or more of the meta positions chlorinated.

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