

The University of San Francisco

## USF Scholarship: a digital repository @ Gleeson Library | Geschke Center

---

Master's Projects and Capstones

Theses, Dissertations, Capstones and Projects


---

Spring 5-21-2021

### Addressing Uncertainties of Polychlorinated Biphenyls in Schools

Alice Fan  
afan5@dons.usfca.edu

Follow this and additional works at: <https://repository.usfca.edu/capstone>

 Part of the [Environmental Chemistry Commons](#), [Environmental Health Commons](#), [Environmental Health and Protection Commons](#), [Other Pharmacology, Toxicology and Environmental Health Commons](#), and the [Toxicology Commons](#)

---

#### Recommended Citation

Fan, Alice, "Addressing Uncertainties of Polychlorinated Biphenyls in Schools" (2021). *Master's Projects and Capstones*. 1202.  
<https://repository.usfca.edu/capstone/1202>

This Project/Capstone - Global access is brought to you for free and open access by the Theses, Dissertations, Capstones and Projects at USF Scholarship: a digital repository @ Gleeson Library | Geschke Center. It has been accepted for inclusion in Master's Projects and Capstones by an authorized administrator of USF Scholarship: a digital repository @ Gleeson Library | Geschke Center. For more information, please contact [repository@usfca.edu](mailto:repository@usfca.edu).

This Master's Project

**Addressing Uncertainties of Polychlorinated Biphenyls in Schools**

by

**Alice Fan**

is submitted in partial fulfillment of the requirements  
for the degree of:

**Master of Science  
in  
Environmental Management**

at the

**University of San Francisco**

Submitted:

Received:

.....  
Your Name                      Date

.....  
Allison Luengen, Ph.D.      Date

## Table of Contents

Table of Contents.....	i
List of Tables.....	iii
List of Figures.....	iv
Acronyms.....	v
I. Abstract.....	1
II. Introduction.....	2
III. Background.....	6
A. Chemistry.....	6
B. Fate and Transport.....	8
IV. Methodology.....	10
V. Scope of Problem.....	12
VI. Sources and Sinks.....	17
VII. Congener Analysis.....	19
VIII. Estimation of the Number of Detections of PCBs in Los Angeles County Schools.....	21
A. Determination of the PCB Detection Application.....	21
B. Execution of the PCB Detection Application to Los Angeles County.....	23
IX. Review of Current US EPA Exposure Tools.....	26
A. IRIS Assessments for Aroclor 1254 and 1016.....	26
B. PCB Exposure Estimation Tool.....	27
C. PCB Protocol for Preliminary Assessment.....	30
D. Regional Screening Levels for PCBs.....	31
X. Literature Review of the Potential Health Effects.....	32
A. Breakdown of Toxicological Health Effects Associated with PCB Exposure.....	32
i. Nervous System.....	33
ii. Immune System.....	33
iii. Endocrine System.....	34
iv. Integumentary System.....	35
v. Reproductive System.....	35
vi. Cellular Mutation.....	36
vii. Bioaccumulation, Metabolism, and Excretion.....	36
XI. International Health Risk Assessments.....	38
A. Uncertainty in Health Risk Assessments.....	40
XII. Management Recommendations.....	41

A.	Recommendation 1: Addressing Uncertainties For Schools in Los Angeles/California.....	41
B.	Recommendation 2: Mitigative Actions to Remove PCBs From Secondary Sources .....	42
C.	Recommendation 3: Next Steps for EPA’s IRIS PCB Assessment .....	45
D.	Recommendation 4: Data Gap for IRIS Toxicity Values .....	45
E.	Recommendation 5: Data Gap For Weathered Aroclors .....	46
F.	Recommendation 6: Cleanup Grant.....	46
XIII.	Conclusion .....	47
XIV.	References.....	50
XV.	Appendix.....	57
1.	Interview with Geniece Lehmann 9-14-2020 (Lehmann, US EPA, per. comm.) .....	57
2.	Interview with Patrick Wilson 9-14-2020 (Wilson, US EPA, per. comm. September 14, 2020) .....	58
3.	Follow-up interview with Patrick Wilson 4-6-2021 (Wilson, US EPA, per. comm. April 6, 2021) .....	62
4.	Tables 6-16 .....	64

## List of Tables

Table 1: Number of Studies, Average PCB Concentration, Standard Deviation Relative to Environmental Media (Weitekamp et al. 2021)

Table 2: Average Number and Range of PCB Congeners Relative to Exposure Pathway (Weitekamp et al. 2021)

Table 3: Summary of Four Surveys Focused on Commercial, Industrial, and Institutional Buildings (Herrick et al. 2015)

Table 4: Summary of Estimated PCB Detections For Schools Built Between 1950 to 1984 Within Los Angeles County

Table 5: US EPA PCB Exposure Estimation Tool Spreadsheet Tabs Breakdown (EPA and PCBs 2009)

Table 6: Dust Ingestion Mathematical Model for Background Exposure with Relative Variables (EPA and PCBs 2009)

Table 7: Soil Ingestion Mathematical Model for Background Exposure with Relative Variables (EPA and PCBs 2009)

Table 8: Indoor Inhalation Mathematical Model for Background Exposure with Relative Variables (EPA and PCBs 2009)

Table 9: Outdoor Inhalation Mathematical Model for Background Exposure with Relative Variables (EPA and PCBs 2009)

Table 10: Dermal Absorption Mathematical Model for Background Exposure with Relative Variables (EPA and PCBs 2009)

Table 11: Dietary Ingestion Mathematical Model for Background Exposure with Relative Variable (EPA and PCBs 2009)

Table 12: Dust Ingestion Mathematical Model for Direct School Exposure with Relative Variables (EPA and PCBs 2009)

Table 13: Soil Ingestion Mathematical Model for Direct School Exposure with Relative Variables (EPA and PCBs 2009)

Table 14: Indoor Inhalation Mathematical Model for Direct School Exposure with Relative Variables (EPA and PCBs 2009)

Table 15: Outdoor Inhalation Mathematical Model for Direct School Exposure with Relative Variables (EPA and PCBs 2009)

Table 16: Dermal Absorption Mathematical Model for Direct School Exposure with Relative Variables (EPA and PCBs 2009)

Table 17: Total PCBs in Maternal Blood and Breast Milk (Davis and Wade 2003)

Table 18: Comparison of Allowable Indoor Air Exposure and Actions Levels Between Denmark, Switzerland, and the United States (Jensen 2013)

Table 19: Allowable Indoor Air Exposure Per Age Group (Jensen 2013)

## List of Figures

Figure 1: Structure of Polychlorinated Biphenyl (NRC 2001)

Figure 2: Diagram of Multimedia Fate and Transport (US EPA 2013)

Figure 3: Box and Whisker Plot Comparing Inside and Outside  $\Sigma$ PCB Concentrations at 6 Schools (Marek et al. 2017)

Figure 4: Box and Whisker Plot Comparing Air Concentration Samples Collected Inside and Outside Schools and Outside of Chicago (Market et al. 2017)

Figure 5: Graph of PCB-28 Concentration in Blood and Weekly Teaching Hours For Teachers in PCB-Contaminated Schools (Gabrio et al. 2000)

Figure 6: Diagram of Multiple Primary PCB Sources and Secondary PCB Sources and Sinks (Thomas et al. 2002)

Figure 7: Flow Diagram of How to Manage PCBs in School Buildings (EPA 2018)

## Acronyms

AESOP: Airborne Exposures to Semivolatile Organic Pollutants Study

BAC: International Union of Bricklayers and Allied Craft

BPM: Best Management Practice

IRIS: Integrated Risk Information System

FDA: United States Food and Drug Administration

LOAEL: Lowest Observed Adverse Effects Level

PCB: Polychlorinated Biphenyl

PRG: Preliminary Remediation Goals

PUF: Polyurethane Foam

RCRA: Resource Conservation and Recovery Act

RSL: Regional Screening Level

SHEDS: Stochastic Human Exposure and Dose Simulation

SVOC: Semi-Volatile Organic Compound

TSCA: Toxic Substances Control Act

TEQ: Toxicity Equivalency Quotients

US EPA: United States Environmental Protection Agency

WOE: Weight of Evidence

$\Sigma$ PCB: Sum of PCB Concentrations

## I. Abstract

Despite the potential neurological health deficits resulting from polychlorinated biphenyls, there is a lack of inhalation studies and regulations to protect students and teachers who are widely exposed to PCBs in older (1950 to 1979) schools. To estimate the extent of PCB detections in Los Angeles County schools, I applied a mathematical model to estimate the range of PCB detections in schools built between 1950 and 1984. I estimate the range of 17-34% PCB detections of open schools within Los Angeles County. Next, I reviewed exposure tools provided by the US EPA to bridge the uncertainty gaps between ingestion and inhalation studies available. I identified the following uncertainties: toxicity values derived from animal studies, data gaps related to weathered PCB congeners and Aroclors, and using extrapolated measures to minimize uncertainty gaps. Lastly, I completed an extensive literature review of toxicological health effects associated with PCBs that revealed liver toxicity and its relative harm to other organs and systems. Based on my findings, I have formulated six management recommendations: 1) quantifying PCB detections in LA County; 2) mitigating secondary sources; 3) identifying helpful inclusions for the upcoming EPA Integrated Risk Information System (IRIS) PCB assessment; 4) bridging the data gap for IRIS toxicity values; 5) complementing the data gap associated with weathered Aroclors; and 6) proposing a cleanup grant. By addressing these uncertainties, the general public, scientific community, and regulatory agencies may pursue in minimizing the adverse health risks associated with the lack of inhalation toxicity values and updated regulations.



## II. Introduction

Polychlorinated biphenyls (PCBs) are contaminants that have historically caused numerous health concerns ranging from stunting neurodevelopment to causing liver toxicity to acting as endocrine disruptors. These examples of toxicological health effects may apply to all ages, but particularly in students from prolonged exposure to PCBs in schools. As students are still developing physiologically, PCBs may stunt their growth and development.

PCB exposure to humans may occur through the following three routes: inhalation, ingestion, and dermal absorption (Ododo and Wabalo 2019). Ingestion can occur through eating dust, soil, and food. Dermal absorption can occur through a number of routes, such as sitting on a couch that has also PCB-contaminated dust or leaning against a wall that was painted with PCB-contaminated paint. Inhalation can occur by PCB vapors that result when PCBs volatilize.

Because PCBs are semi-volatile organic compounds (SVOCs), there is a lack of research available for inhalation studies. If a toxicant is not extensively researched, then toxicity values can not be established as a recommended or regulatory standard. An unestablished standard may be dangerous in the context of unregulated past use. Before 1979, PCBs became one of the most widespread useful products for its stability and resiliency, ranging from paint, sealants, and caulking.

At the height of PCB production, there was an increased case reporting of human illnesses that were potentially related to PCB products. In 1954, there were 14 reported cases of chloracne for 14 chemical operators (Markowitz 2018). Chloracne symptomizes as acne-like rashes and lesions. In 1955, there was an extreme case in which three people developed liver damage after high exposure to PCBs within a week (Markowitz 2018). In 1957, Bucyrus Erie Company used PCB-included sealants within their hydraulic system, and due to the broken pipes, PCBs were accidentally sprayed onto their workers and as a result, workers had burn injuries on their eyes (Markowitz 2018). These are a handful of examples that caused PCBs to be called into question about their safety.

Although PCB production was banned in 1979 due to potentially related toxicity in humans, not all PCB products were recalled and corrected for equipment already in use. With the continued use of PCBs, people have continued to be exposed to PCBs until today. Today, as buildings grow old, their paints and light ballasts are no longer functioning and holding as well as when first applied; therefore, paint chipping and leaking light ballasts are creating high

exposure environments for its occupants. Paints and light ballasts are popular products because PCBs were previously used as plasticizers in paints and high thermal conductors in fluorescent light ballasts. For example, schools built before 1979 present high PCB exposure conditions for students and teachers because light ballasts are leaking high concentrations of PCB liquids, walls are chipping, and window sealants are cracking. Throughout this project, I will refer to high concentrations of PCBs as above 50 ppm (LII n.d.).

As buildings deteriorate, PCBs will gradually concentrate indoors. Weitekamp et al. (2021) identifies that indoor air has the highest average of PCB concentration with the largest range of concentrations. This is in comparison with dust, soil, indoor air, outdoor air, and dietary exposures. Although indoor air has only 10 studies of the total 70 reviewed, there is still a wider range of detected concentrations and may be considered a cause for concern to duplicate such experiments. Duplicating experiments will not only deduce the variable uncertainty, but also encompass the extent to which more inspections and sample characterizations must be conducted in schools. Table 1 shows the average PCB concentration with its range relative to the exposure pathway for humans.

Table 1 (Weitekamp et al. 2021). This table lists the exposure pathways and its relative number of studies to back the average concentration of PCBs. Along with the average, Weitekamp et al. (2021) has calculated the standard deviation and listed the range of concentrations.

	# of studies	Mean $\pm$ SD (range of concentrations)
Dust ( $\mu\text{g/g}$ )	7	0.10 $\pm$ 0.08 (0.0025–0.86)
Soil ( $\mu\text{g/g}$ )	29	0.017 $\pm$ 0.03 (0–2.6)
Indoor air ( $\text{ng/m}^3$ )	10	3.5 $\pm$ 5.1 (0.01–233)
Outdoor air ( $\text{ng/m}^3$ )	31	0.53 $\pm$ 1.0 (0.0002–13.0)
Dietary ( $\mu\text{g/day}$ )	6	0.29 $\pm$ 0.21 (0.053–0.54)

As building deteriorating conditions present themselves, they are further exacerbated by dust accumulation and PCB vapors will attach to the large surface areas of dust particles. Students and teachers will have prolonged exposure to these PCB-contaminated dust particles in the classroom and will inhale them for several hours per day. This prolonged exposure may be

addressed through inspections, but how will the public know to ask the districts for inspections unless information is spread after a notable broadcast?

In 2013, Santa Monica Malibu Unified School District came to light in the media because a group of parents, including celebrity Cindy Crawford, were concerned about the PCB exposure that their children were surrounded by on campus. Jeff Scott, US EPA Region 9 director of the Land, Chemicals, and Redevelopment Division, approved of the Toxic Substances Control Act (TSCA) application for the remediation, excavation, and disposal that took place at Malibu High School and Juan Cabrillo Elementary School (SMMCTA 2015). This approval came after Santa Monica Malibu Unified School District took over 1000 wipe and air samples and proposed numerous drafts of a cleanup plan. PCBs over 50 ppm were found in window caulk, light ballasts, ventilation systems, etc. (SMMUSD 2019). The schools within Santa Monica Malibu Unified School District were built between 1955 and 1963, which falls within the height of PCB production (DTSC 2021).

In September 2016, a federal court granted a motion requiring Santa Monica Malibu Unified School District to either replace the door and window frames that were installed before 1979 or to halt entry and use for PCB-contaminated buildings by December 31, 2019 (PEER 2018). In December 2018, the federal court granted a motion that was filed by the school district a month prior for a five-year extension. This five-year extension would focus on tearing down these PCB-contaminated buildings and rebuilding new ones instead of spending millions of dollars on remediation activity. Because this district is located in a higher-income geographic area, the district was able to consider rebuilding campus buildings as part of its docket without the pressure of PCB contaminant remediation.

As mentioned earlier, parents, such as Cindy Crawford, were famous voices that publicized PCBs in schools. Publicizing PCB contamination in Santa Monica Malibu Unified School District was crucial in passing Measure M in 2018 (Patel 2018, SMMUSD 2018). Measure M is a \$195 million bond that would be dedicated to improving Malibu pathway school facilities through technology, security measures, and modernizing or building new facilities (SMMUSD 2018).

Had this been in a community that was lower income or predominantly colored, there may not have been as much of prioritization for sample characterizations, inspections, and cleanups. This imbalance may be perceived as a situation with environmental justice concerns.

The US EPA defines environmental justice as “fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income, with respect to the development, implementation, and enforcement of environmental laws, regulations and policies” (US EPA 2014). This definition is very exact in its phrasing to exclude any opportunities of inequality. In communities with fewer opportunities, there is not “the same degree of protection from environmental and health hazards” (US EPA 2014). If school districts are unable to prioritize environmental and health hazards, then what role can the community play in asking school districts to shift their focus of schools “to a healthy environment in which to live, learn, and work” (US EPA 2014)?

With the lack of awareness of potentially high exposure of PCBs in schools, this prompts the question of what the estimated range of PCB detections is in Los Angeles County schools? This question is important because it is quantifying the potential hazards that our community members are exposed to on a day to day basis on campus. By being able to associate a numerical value with PCB exposure in schools, this allows officials in regulatory agencies to consider implementing an inspection requirement. Implementing an inspection requirement will be more plausible as research surrounding PCBs indoors becomes available.

PCBs are emerging and legacy contaminants that are difficult to research. PCBs are emerging contaminants in the broader context of contaminants with emerging concerns as research laboratories now have more advanced analytical equipment to retrieve PCB detections and to reveal more PCB environmental- and health- related issues. PCBs are also considered legacy contaminants because they remain in the environment for a very long time after they have been introduced.

Current PCB risk assessments and analytical research conducted by the EPA and other research labs will describe the reference dosage used, PCB concentration measurements, and the risk. All of this research has not been well established in the universe of PCB-contaminated sites. The collective total of PCB-contaminated buildings across the United States is very extensive, and so it would be best to start with schools given that PCBs are more frequently exposed to a number of sensitive individuals, specifically children (P. Wilson, USEPA, pers. comm.).

Another topic that will be discussed in this paper are the uncertainties associated with health risk assessments and exposure tools that our regulatory agencies rely and use as best available tools. How do we address these uncertainties associated with exposure tools covered by

the US EPA and health risk assessments? Despite the numerous health risk assessments associated with PCB exposure, PCBs continue to not be required to be inspected by regulatory agencies. PCB experts at US EPA feel as though PCB exposure tools have been devised with such high confidence that the uncertainties are not of high concern. Addressing uncertainties allows the public who are not very familiar with the adverse toxicological effects of PCBs to have a sense of security that their authority officials are familiar with common everyday toxicant exposure.

I will address these uncertainties by breaking down this Master's Project into two research objectives. The first research objective is to predict the potential range of PCB detections in schools within Los Angeles County. The second research objective is to extensively outline the exposure tools that the US EPA has created to bridge data gaps and to identify potential adverse health effects associated with exposure to PCBs.

### III. Background

#### A. Chemistry

PCBs are composed of two benzene rings connected by a single bond and have up to three chlorine atoms attached to each benzene ring. Based on stability, there are 209 PCB congeners, which are different combinations of a chemical structure accounting a variable number of chlorine atoms attached in this particular case. Figure 1 shows the structure of a PCB and its possible chlorine attachments.

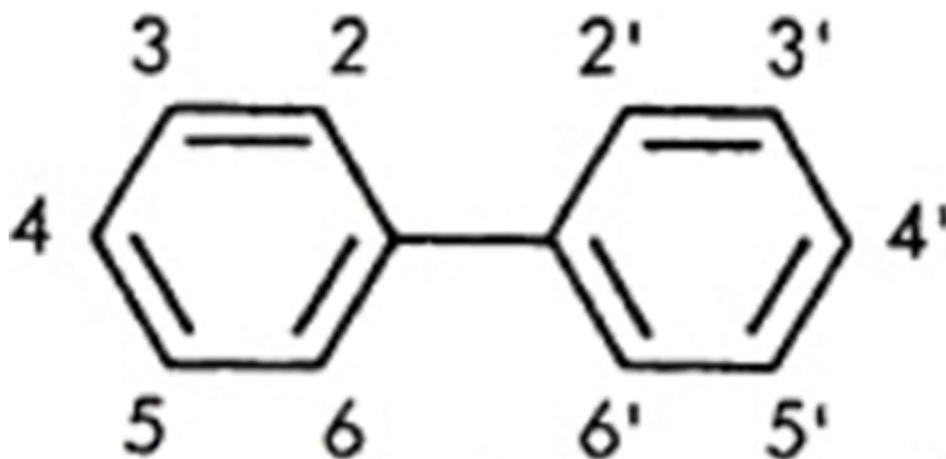


Figure 1 (NRC 2001). This figure shows the structure of a PCB molecule with ten possible chlorine attachments. Each phenyl group may have up to three chlorine atoms at a time.

Although there are 209 PCB congeners that are theoretically possible, scientists have been able to identify 130 PCB stable congeners that were actually marketed as mixtures (Ododo and Wabalo 2019). These PCB mixtures became trademarked in various countries as Aroclor for the United States, Clophens for Germany, and Phenoclor in France (Ododo and Wabalo 2019). Each Aroclor is named by the weight of chlorine in its last two digits (NRC 2001). For example, the weight of chlorine in Aroclor 1254 is 54%.

There are PCBs molecules that produce dioxin-like effects (NRC 2001). Dioxin-like PCBs are coplanar congeners, which are PCB congeners missing two chlorine atoms in the ortho position (Davis and Wade 2003). Dioxin-like PCB molecules attach to the aryl hydrocarbon receptor within the human body and mimics the potency of dioxins, which can be quantified through Toxicity Equivalency Quotients (TEQs) (NRC 2001). TEQs are weighted values of the toxicity of a dioxin or dioxin-like substance as a factor of the most toxic substances (US EPA 2015a). The highest TEQ value is 1.0 and this is assigned to 2,3,7,8-tetrachlorodibenzo-p-dioxin, otherwise known as dioxin). TEQs can range from 0.0001 to 1.0 and are unitless (US EPA 2015a).

PCBs have chemical and physical properties that have made them very attractive to produce as mixtures and market in various capacities, such as caulk, coolants, and light ballasts (Ododo and Wabalo 2019; Davis and Wade 2003). As chlorination of the biphenyls increase, the viscosity of PCBs also increases, which makes them very attractive to work with (Ododo and

Wabalo 2019). At ambient temperatures, PCBs present themselves as yellowish and crystalline structure. At low temperatures, PCBs present themselves as solid resins. At very high temperatures, PCBs may combust and produce similar semi-volatile organic compounds, such as dioxins and furans. SVOCs are a result of incomplete combustion and cause PCBs to transport in a widespread environmental capacity. Therefore, we can conclude that between normal and very high temperatures, PCBs are more liquid-like and more stable to work with.

Because of PCBs' chemical stability, they exhibit properties such as being lipophilic, heat insulating, and fire resistant; however, an issue that presents itself with PCBs is that they are semi-volatile, and so they can phase in between gas and liquid forms (Ododo and Wabalo 2019). PCBs can become more lipophilic and hydrophobic depending on the chlorination of the biphenyls (Ododo and Wabalo 2019). As chlorine attachments increase, solubility decreases. This can be both advantageous and disadvantageous in an environmental exposure capacity. On the one hand, if solubility decreases, then there is a decreased chance of the PCBs volatilizing; however, on the other hand, this can be a bad thing because this allows for the PCBs to persist in the environment in concentrated portions for a very long time. PCBs do not biodegrade in soils very well because they adsorb onto the soils, possibly for decades (Ododo and Wabalo 2019).

As mentioned earlier, PCBs have high thermal conductivity, which is an extension from being able to withstand high temperatures. Electrical companies took advantage of PCBs up until 1979, when they were banned, because they were especially handy when it came to electrical capacitors and transformers. These PCBs presented themselves as an oily liquid substance that was used to help seal and properly insulate heat so electrical equipment would not overheat and combust.

Lipophilic, heat insulating, and fire resistant are examples of favorable properties that resulted in PCBs being incorporated into numerous products. These numerous products were very popular in both construction and electrical industries. These favorable characteristics are also what makes them very persistent in the environment.

## B. Fate and Transport

Before PCB production was banned, PCBs were able to spread and bioaccumulate in the environment through accidental leaks and spills (Ododo and Wabalo 2019). In fact, this still happens today. According to 40 CFR 761 regulations, cleanup and disposal of PCB bulk waste

or remediation waste are results of accidental leaks and spills. Previous improper disposal of PCBs that led to leaks and spills is one of the biggest reasons as to why PCBs are still residing in the environment. Because PCBs are lipophilic, they do not travel through soil very well and they do not dissolve in water (Ododo and Wabalo 2019; Davis and Wade 2003). Bioaccumulation is a result of organisms that reside in soil and/or water, that unintentionally ingest PCBs and the PCBs bioconcentrate in their bodies. As these organisms decay or are consumed and move up the food chain, the PCBs bioaccumulate either in soil/water or in bigger bodies; thus, biomagnification is the process of PCBs that have been bioaccumulated in smaller organisms that are lower in the food chain and have now been magnified when consumed by bigger animals higher up the food chain (Ododo and Wabalo 2019).

Aside from accidental leaks and spills, there is the issue of incineration and further improper disposal. As mentioned earlier, incomplete combustion may occur resulting in further production of semi volatile organic compounds (Ododo and Wabalo 2019). During this time, best available technology is used to prevent an excessive number of PCBs from being released into the atmosphere; however, such technology is not one hundred percent effective. Once PCBs volatilize, they are subject to atmospheric transport and deposition (Davis and Wade 2003). Atmospheric transport allows PCBs to travel to very far distances, and eventually, they may reach a region where atmospheric deposition is more likely to occur. While PCBs are dispersed throughout the atmosphere, they are subject to photochemical degradation and depending on how chlorinated the PCB congeners are, the rates of photochemical degradation can vary. Typically, such rates will increase with decreasing chlorination (Davis and Wade 2003). Atmospheric deposition will result in PCBs being deposited into water bodies and land soil. PCBs that have adsorbed very strongly to soil are subjected to bacterial biodegradation. This means that bacteria break down the PCBs by dechlorinating the biphenyls into ortho-substituted rich congeners, which are PCB congeners missing two adjacent chlorine atoms and are replaced by other atoms (Davis and Wade 2003). The half-lives of PCB congeners in soils and sediments of water bodies can range from months to years.

The persistence of PCBs in the environment is a widespread issue as they are still found in our surrounding environments, urban, rural, or natural, after the fact PCBs have been banned for almost 40 years. Persistence comes from their properties that also have allowed them to interact with other similar-property chemicals, such as dioxins and furans (Davis and Wade



2003). Their persistence is further exacerbated by the multiple fates and transports that PCBs undergo in atmospheric transport and deposition and photochemical and bacterial degradation. The interactions between such allow them to bioconcentrate in the same areas; thus, altering the possibility of synergistic toxicity from the PCBs and their interactions with similar chemicals. Figure 2 shows PCBs can transport and the multiple fates they can end up in.

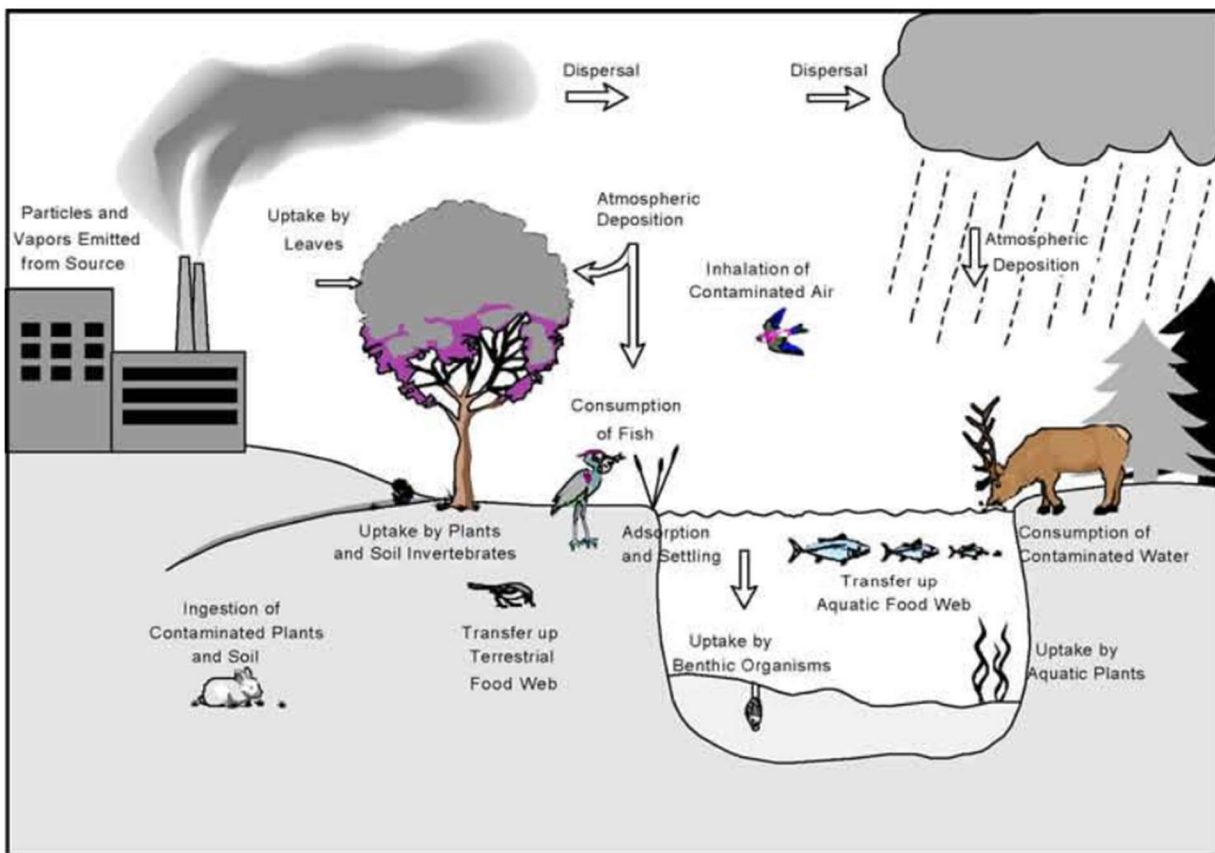


Figure 2 (US EPA 2013). This figure is a general diagram of multimedia transport and their eventual fates. Each transport and fate listed in this diagram is applicable to PCBs.

#### IV. Methodology

My first research objective is to predict the potential range of PCB detections in schools within Los Angeles County. I plan to approach the estimated range of PCB detections by applying a mathematical model provided by Herrick et al. (2015) to the number of schools built between 1950 and 1984 and are currently in operation. I will collect data on the number of schools built and in operation within Los Angeles County between 1950 and 1984 from the

database provided by the California Office of Education. Currently, the California Office of Education does not have up-to-date records for schools' open and close dates for Los Angeles County, and so this calculation will be based on the schools' open or closed status (CDE 2021). Afterwards, I will apply the mathematical model from Herrick et al. (2015) in determining an estimated percentage range of how many schools are potentially PCB contaminated between 1950 and 1984. Herrick et al. (2015) completed a comprehensive comparative analysis of five studies to determine the mathematical model of PCB detections in schools nationwide. Upon reviewing these five studies, I looked specifically at the data related to institutional and commercial buildings, not residential buildings. By doing so, this will allow me to estimate how extensive PCBs are within Los Angeles County as one of the booming cities across the United States and to determine the urgency as to why inhalation studies are needed for PCBs within schools.

My second research objective is to extensively cover the exposure tools produced by the US EPA that are used to bridge uncertainty gaps and to identify PCB-associated toxicological health effects. Through this, I will be able to identify uncertainties that result from data gaps and health risks. Current US EPA exposure tools include the following: 1) IRIS database cancer reference values for Aroclor 1254 and 1016; 2) exposure estimation tool; 3) PCB Protocol published in 2019; and 4) regional screening levels.

Afterwards, I plan to compare health risk assessments published by international countries, such as Denmark and Bucharest, Romania. I selected these two health risk assessments in particular because they displayed two different approaches to a health risk assessment. The Denmark publication looks at case studies and the resulting health effects to recommend background levels of PCBs (Jensen 2013). The Romanian publication calculates risk through software and uses that process to determine land redevelopment potential (Ivanescu 2015). I also plan to compare health risk assessments conducted by research teams based within the United States. Next, I will be conducting a literature review of the potential health effects presented by PCBs. Lastly, I will identify uncertainties and apply scenarios that will ultimately conclude the issues resulting from these uncertainties. I plan to provide management recommendations to narrow these informational gaps.

## V. Scope of Problem

PCBs are problematic contaminants because they are able to volatilize and accumulate to high concentrations indoors. Unfortunately, as PCBs are regulated primarily through 40 CFR 761, PCB inspections are not mandatory in schools, and so it may be difficult for case studies to be developed. Some researchers will consider pilot studies, which are typically small-scaled studies to determine the cost and feasibility that can potentially be duplicated for large-scaled projects. Pilot studies can also be purposed for trying to understand how PCBs concentrate in an interactive environment, such as classrooms. These pilot studies are conducted in lieu of the lack of case studies available for PCB-impacted schools to understand the PCB movement and settling in classrooms.

Marek et al. (2017) conducted a sampling characterization study at six schools in Indiana and Iowa and took concentration measurements indoors and outdoors accordingly. These schools are enrolled in the Airborne Exposures to Semivolatile Organic Pollutants (AESOP) Study, which is an exposure assessment study of PCBs and other persistent pollutants that children and mothers are exposed to. This is the first cohort-specific analysis that focused on comparing children's PCB inhalation exposure to that of dietary exposure. This study was trying to understand the variation in concentration, congener profiles, and inhalation exposures between six schools and if the estimation of one school could be used to estimate the concentration of another school within the same community (Marek et al. 2017).

The methods used in this survey ranged from sample collection, sample extraction, quality control, sample concentration, to exposure concentrations (Marek et al. 2017). Sample collections were done with polyurethane foam (PUF) passive air sampling disks. These disks were placed inside and outside of schools. Sample extraction was using an acid wash and extraction with hexane. Quality control was addressed to make sure that the extraction efficiency, reproducibility, and accuracy met specific surrogate standards (Marek et al. 2017). Recreating this data with a high confidence level is important. Sample concentrations were determined using a model that compared previous passive and active sampling results, accounted for temperature fluctuations, and corrected for PUF saturation (Marek et al. 2017). This was especially important for outdoor samples' accuracy. Exposure calculations were done for dietary exposure, particularly looking at food ingestion rates and inhalation rates with regards to gender

and the number of days with each season in school to extrapolate data based on activity level during each season.

Marek et al. (2017) findings indicate that PCBs were at a higher total concentration inside versus outside. Because each school had statistically significant differences between indoor and outdoor concentrations, it is not reasonable to estimate one campus's concentrations for another campus's, regardless of them being in the same community (Marek et al. 2017). It is apparent that schools built before 1979, the banning of PCB production, seem to have a greater difference of the sum of PCB ( $\sum$ PCB) concentrations inside versus outside the school by 3 orders of magnitude. Figure 3 shows a side by side comparison of the total PCB concentrations at each school for both indoors and outdoors.

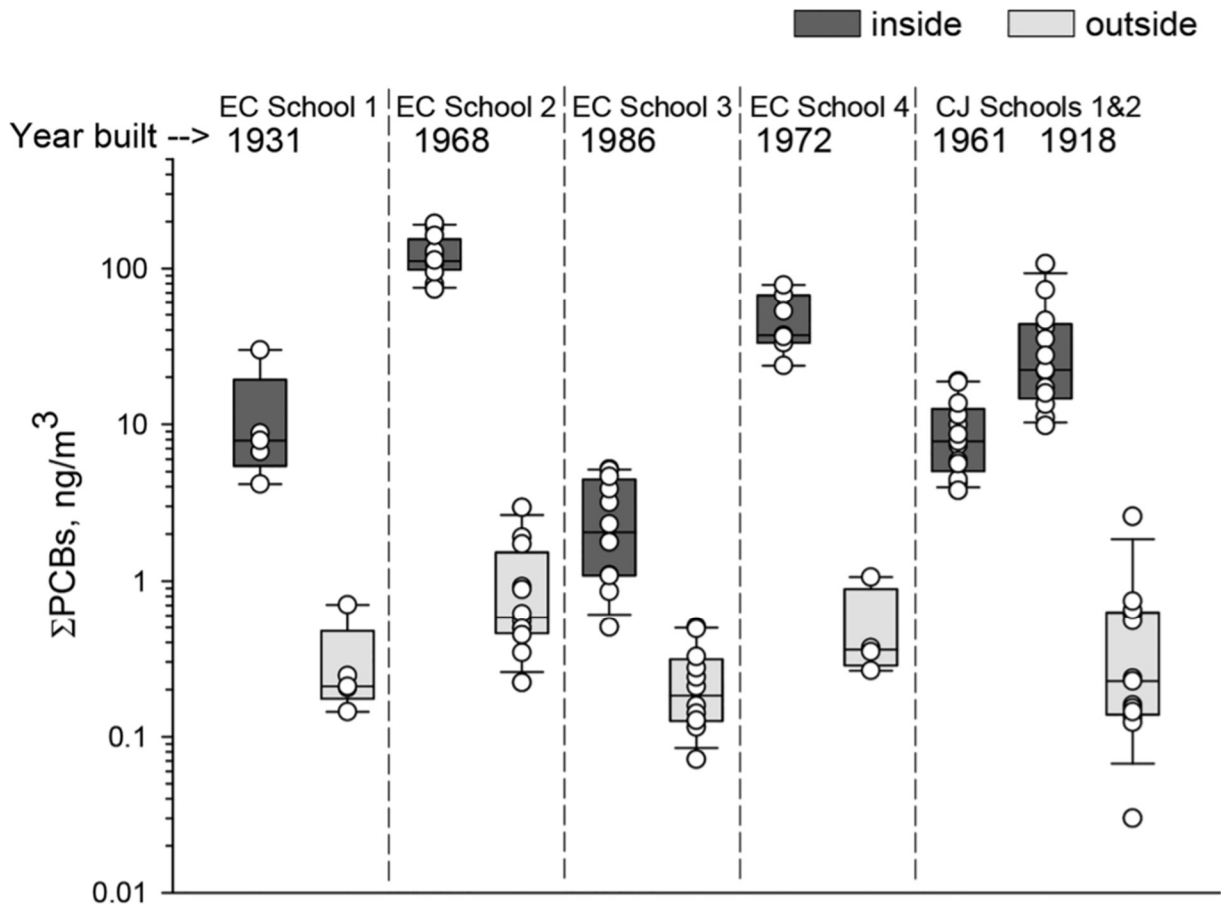


Figure 3 (Marek et al. 2017). This box and whisker plot compares the inside and outside  $\Sigma$ PCB concentrations over the total of 6 schools, which include four schools in East Chicago (EC) and two schools in Columbus Junction (CJ). The box details the 25<sup>th</sup> percentile, the median, and the 75<sup>th</sup> percentile. The whiskers detail the 5<sup>th</sup> and 95<sup>th</sup> percentiles. The open circles represent a concentration measurement according to each detail's percentile. The whiskers showed that the outside  $\Sigma$ PCB concentrations range from 0.03 ng/m<sup>3</sup> to 3 ng/m<sup>3</sup>. As for the indoor  $\Sigma$ PCB concentrations range from approximately 0.5 ng/m<sup>3</sup> to 110 ng/m<sup>3</sup>. This is a difference of 3 orders of magnitude.

Marek et al. (2017) concluded that regardless of the location, the concentration measurements between indoors and outdoors varied greatly and there was no correlation to the geographic location between all 6 schools. Figure 4 shows a box and whisker plot of PCB air

concentration indoors being much higher than that outside, where a lot of circulation may occur while indoor air may have limited ventilation.

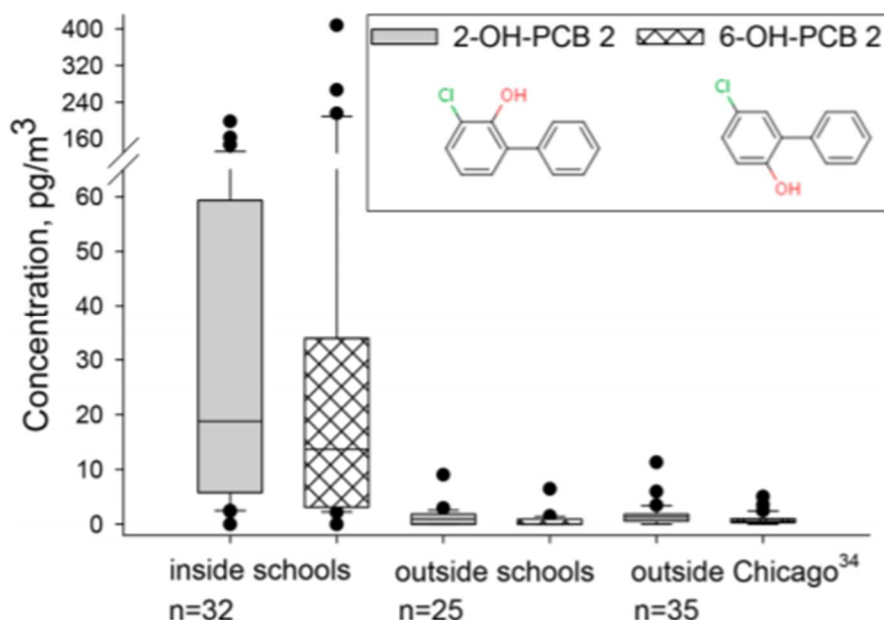


Figure 4 (Marek et al. 2017). This box and whisker plot shows a side by side comparison of air concentration samples collected indoor and outdoor schools and outside of Chicago. Two sets of samples were taken to compare PCB congeners 2-OH-PCB 2 and 6-OH-PCB 2. The concentration of these samples are at  $\text{pg/m}^3$ .

Marek et al. (2017) is an example comparison between indoor and outdoor air concentrations of PCBs at schools. This study indicates that indoor concentrations of PCBs are much higher than that of outdoors. Typically, schools will not consider inspecting their building grounds for PCBs because they would not want to know how extensive the PCB contamination is; otherwise, they would be subject to potential further sampling, then cleanup and disposal, which can be very costly depending on the findings.

Schools are of immediate concern because prolonged exposure leads to PCBs found in blood levels. Gabrio et al. (2000) conducted a study that involved 96 teachers from PCB-contaminated schools and 55 teachers from non-PCB contaminated schools. Teachers were selected because they spend a considerable more amount of time than students at schools. Teachers from the control group had an average of  $0.035 \mu\text{g/L}$  while teachers from PCB-contaminated schools were up to  $0.09 \mu\text{g/L}$ , which is approximately three times the control

average. This study was conducted in Germany with three schools that were known to have indoor air contamination: Don, Wai, Neu, and two control schools, Con. In all four study groups, the age and gender distributions were similar; therefore, correlations may be identified according to age or gender if need be.

Gabrio et al. (2000) identified a pattern that the blood concentrations of PCB- 138, 153, and 180 increased with the teachers' ages while there was no effect on blood concentration levels for PCB-28 and 101. There is a weak correlation in PCB-28 concentration levels in blood with regards to weekly teaching hours. There is less than 10% variability between the control schools and the PCB-contaminated schools (Gabrio et al. 2000). Figure 5 shows the correlation between the weekly teaching hours and PCB-28 in blood measured in  $\mu\text{g/L}$ .

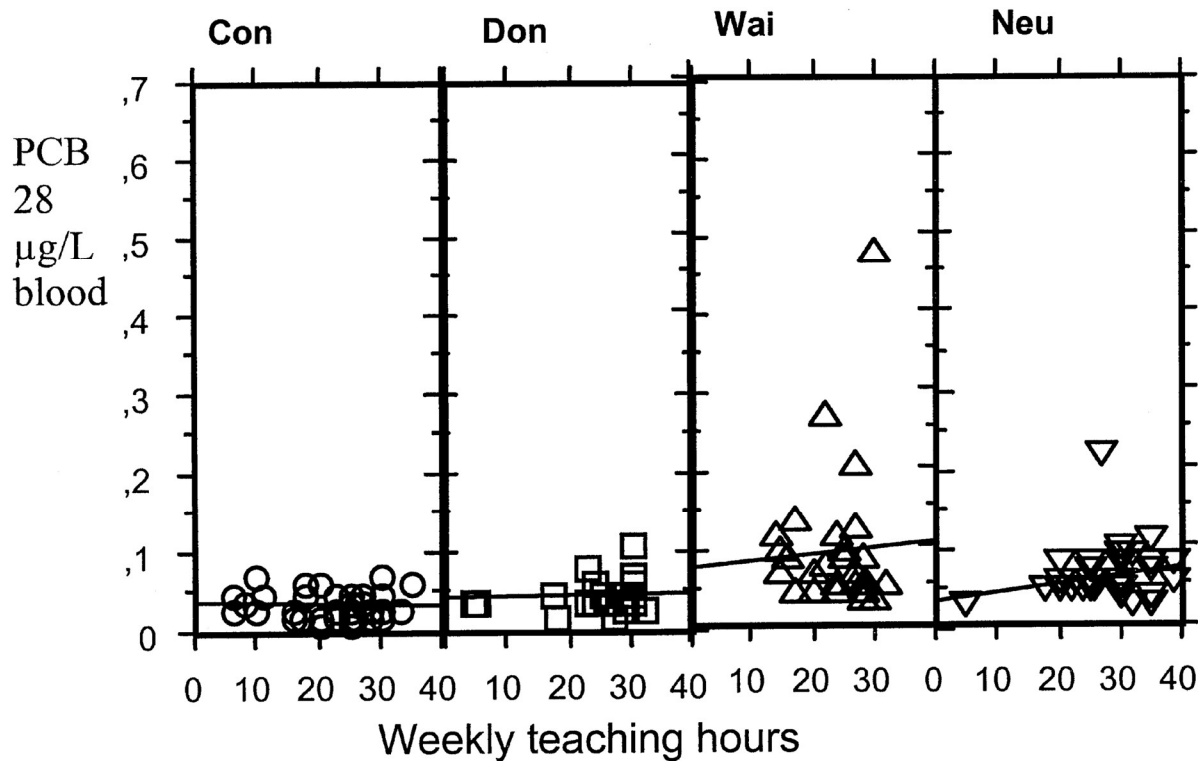


Figure 5 (Gabrio et al. 2000). This figure shows a correlation between PCB-28 concentration in blood and weekly teaching hours for teachers in PCB-contaminated schools. The first portion (Con) is the control while Don, Wai, and Neu are the PCB-contaminated schools in Germany.

While Marek et al. (2017) concluded that there was a higher accumulation of PCBs indoors, Gabrio et al. (2000) acknowledges that prolonged exposure of PCBs results in PCBs

concentrating into teachers' blood. There is a higher accumulation in classrooms because there is not nearly the same amount of air circulation that the outdoors have. Prolonged exposure is difficult to navigate because there may be many different sources and sinks that contribute to the exposure in classrooms.

## VI. Sources and Sinks

The scope of the PCB problem indoors extends from multiple sources and sinks. PCBs are a widespread problem on campuses because they may be present in the air, dust, sediment, and on surfaces within and around the school buildings (Thomas et al. 2012). This leads to multiple exposure routes and minimizing exposure becomes difficult as primary sources transfer into secondary sources. For example, old and failing light ballast capacitors will leak PCB oils. While these light ballast capacitors are replaced as the primary sources, there are leftover PCB oil residues on the light fixtures, which act as secondary sources (Thomas et al. 2012). Scenarios as such are common misconceptions that removing primary sources of contamination will remove the contamination in its entirety.

These secondary sources are considered sinks for primary sources because they are surfaces with large surface areas that absorb PCBs emitted by primary sources. These sinks include furniture, wall paints, dust, masonry, and floor and ceiling tiles (Thomas et al. 2012). Furniture may be replaced and dust is cleaned out of ventilation systems; however, other sinks, such as masonry, wall paints, and floor and ceiling tiles, may not be as financially viable to be replaced and cleaned as they are not a main concern. Secondary sources add to the complexity of PCBs in school.

Figure 6 shows the various sources and sinks of PCBs in a classroom. The top of the classroom displays light ballasts as a primary source. Both the door frame on the right of the figure and the window frame on the left have caulking, a sealant, in place and that is also a major PCB source. As each of these primary PCB sources deteriorate, PCBs begin to vaporize and are absorbed by dust/soil, wall paints, flooring, ceiling, and furniture. These act as primary sinks and secondary PCB sources. Eventually, these PCBs will vaporize and be absorbed by other large surface areas and those become secondary PCB sinks. The ventilation depicted by the blue arrows may show PCB flows depicted by the red and yellow arrows.



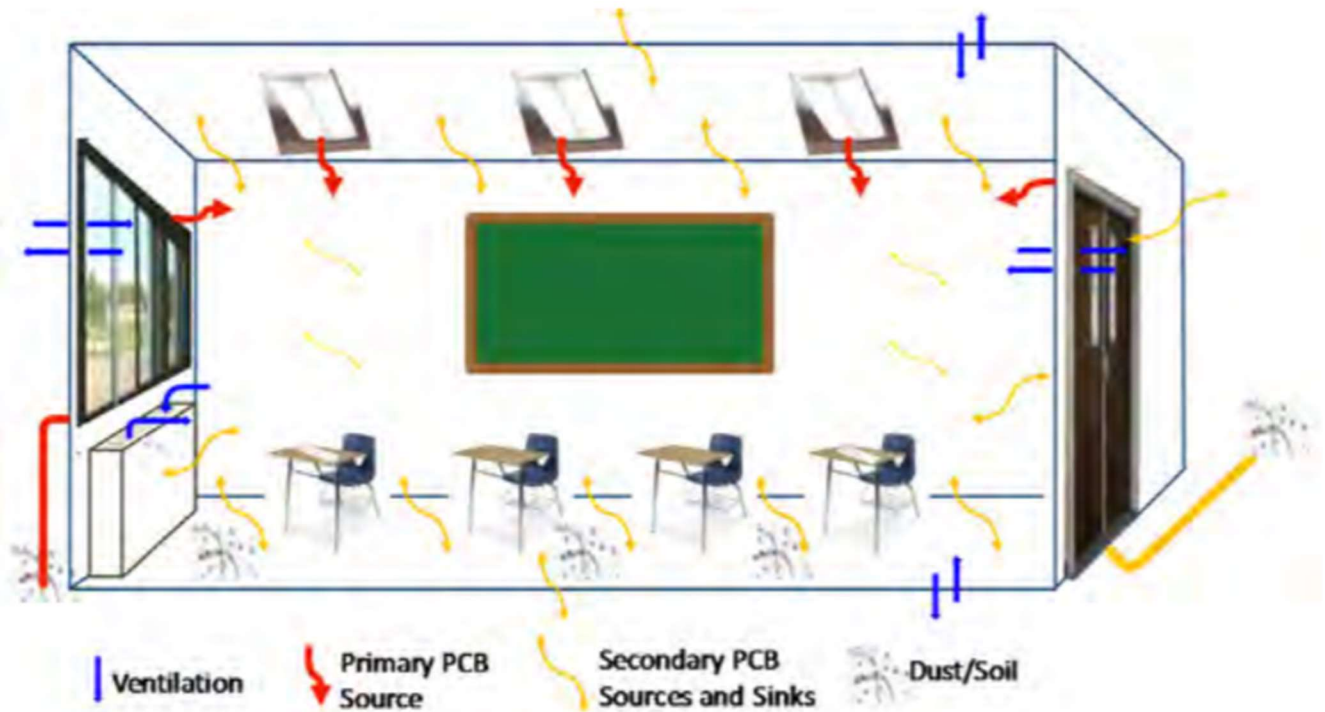


Figure 6 (Thomas et al. 2002). This figure depicts the multiple exposure routes that PCBs may flow in from source to sink from within a classroom. Secondary PCB sources act as sinks to both primary PCB sources and secondary PCB sources. Dust and soil have large surfaces that function as primary sinks and secondary sources and sinks.

Through Figure 6, we can see that inhalation could be a major exposure route in which PCBs enter the human body. Thomas et al. (2002) reveals that inhalation may be behind over 70% of the PCB exposure that students and teachers face in schools. Thomas et al. (2002) recommends cleaning up dust within each building as they may have the largest surface areas that are most commonly present. Dust may settle everywhere within the classroom and the occupants of the classroom will continue to unknowingly inhale PCBs. Not only will classroom occupants inhale the PCB-contaminated dust, but also the dust will settle on clothing and the PCB vapors may be dermally absorbed. Another option is that the dust will settle on food and be ingested.

Having multiple sources and sinks can be difficult to control because classrooms are an interactive space, and depending on the age of the student, there may be increased exposure aside from inhalation and dermal absorption. Younger students, primarily preschoolers and

kindergarteners may be subject to PCB exposure through ingestion because they may put their hands in their mouths after touching the floor or outside soil. Identifying primary and secondary sources allow for proper sanitation and adjustments, such as ventilation filters and window closures, in the classroom.

## VII. Congener Analysis

While we have primary and secondary sources identified, another issue to consider is the proper sampling analysis method in terms of testing for specific PCB congeners or in Aroclors. Testing for Aroclors is the most affordable option, but it may also be the least accurate. In cases where Aroclors have begun to weather, especially in and around old school buildings, the PCB congener makeup may differ from its original Aroclor mixture (Davis and Wade 2003). This is especially a concern because PCBs are tested according to EPA Method 8082A, which tests for a handful of Aroclors and PCBs (EPA 2007). Toxicity criteria have been identified through bioassays for these tested Aroclors and PCB congeners.

Davis and Wade (2003) question the composition of PCB congeners in Aroclors that have been weathered, which could change the congener composition. The unavailability of toxicity criteria for other PCB mixtures becomes an uncertainty for sampling analysis methods because the accuracy of what is being tested has now formed a gap between what is actually present in the sample and what the Aroclor used to be (Davis and Wade 2003). As a result, weathered Aroclors could have a different set of chemical and physical properties. Does the same toxicity criteria still apply or is there uncertainty applying cancer slope factors to changed PCB mixtures?

From the Office of Research and Development at the US EPA, Weitekamp et al. (2021) screened through 3,625 articles to determine PCB exposure at recent background levels through congener analysis. First, Weitekamp et al. (2021) screened through titles and abstracts that were relevant and excluded articles that would not contribute relative information. Next, Weitekamp et al. (2021) reviewed the remaining articles to determine whether or not they met General Applicability Factors. Of the 70 leftover articles, Weitekamp et al. (2021) calculated the average number of congeners measured per exposure pathway and identified the range of congeners that contributed to the average number of congeners. By identifying the range of PCB congeners, researchers may now be able to sort out the overlapping PCB congeners or commonly identified

weathered congeners. Table 2 refers to the exposure pathways with their relative average number of congeners and range of PCB congeners that have been identified through these 70 studies.

Table 2 (Weitekamp et al. 2021). This table lists the exposure pathways that individuals may encounter, whether through background or direct exposure, and their relative average number of congeners and their respective range of congeners. There are a total of 209 PCB congeners.

Exposure Pathway	Average Number of Congeners	Range of PCB Congeners
Dust	110.8	37 to 209
Soil	73.2	25 to 206
Indoor Air	92.7	28 to 209
Outdoor Air	102.8	24 to 209
Dietary Intake	71.5	23 to 205

The US EPA IRIS database has published assessments for only three Aroclors: 1254, 1016, and 1248. Understandably, it would be difficult for the US EPA IRIS database to capture assessments for at least 209 known congeners and thousands of Aroclors without extensive bioassays. As the Office of Research and Development at the US EPA produces assessments for IRIS and has also conducted this extensive review, there may be room for starting bioassay analysis for these overlapping congeners or commonly identified weathered congeners.

Thus, further inhalation studies are needed in various aspects, which include the following: 1) multiple sources and sinks; 2) weathered Aroclors in both outdoor and indoor settings; 3) limited toxicity criteria; and 4) uncertainty in sampling analysis methods. With multiple sources and sinks present within a closed box, there is more PCB exposure available to the occupant. Weathered Aroclors regardless of the environmental setting may account for different toxicological health effects that have yet to be identified due to limited research. Limited toxicity criteria will account for different cancer slope factors and as a result, change the risk and persistence per Aroclor and congener (Davis and Wade 2003). Lastly, the uncertain

informational gap previously mentioned between the initial and weathered Aroclor may be bridged through conducting large bioassays that evaluate or inspect for the known 209 PCB congeners. Bioassays have the potential to provide a more extensive background on the health effects associated with each PCB congener rather than to derive the potential effects from initial to weathered congeners.

## VIII. Estimation of the Number of Detections of PCBs in Los Angeles County Schools

The goal of this section is to predict an estimated range of how many schools in Los Angeles County could potentially have PCB detections. This calculation includes factors such as when the school was built, if the school is still in operation, and uncertainties that can influence whether the school must undergo inspection. In this paper, we are focusing on only institutional, commercial, and industrial buildings, not residential buildings.

### A. Determination of the PCB Detection Application

In Herrick et al. (2015), the researchers summarized 5 studies related to PCB detections in industrial/commercial/institutional buildings; however, I have decided to focus on four of the five studies due to relative estimation of PCB detections. The fifth study done by Klosterhaus et al. (2013) was completed in the San Francisco Bay Area, CA. Its PCB detection percentage is an outlier of 88% because the building selection focused on when the building was constructed and not whether the school was institution/commercial or residential. The criteria of how the buildings were selected would not be an accurate representation of Los Angeles County schools. Therefore, Table 3 will provide a summary of the following 4 studies. The PCB detection range established in Herrick et al. (2015) is 27 to 54%.

Herrick et al. (2004) surveyed 24 buildings in the greater Boston Area that members of the International Union of Bricklayers and Allied Craft workers (BAC) recalled the installation of caulking in the late 1970s. Of these 24 buildings, there were 15 PCB detections found within the caulking. PCB detections ranged from 0.56-36,200 ppm (Herrick et al. 2004).

Kohler et al. (2005) surveyed 1,348 buildings in Switzerland and 646 buildings detected PCBs within the joint sealants. PCB detections ranged from 0.02 g/kg, which was the detection

limit, to 550 g/kg. Kohler et al. (2005) did an extensive comparison in terms of sampling buildings to obtain PCB indoor air concentration in relation to air temperature and PCB mixture.

Robson et al. (2010) surveyed 95 buildings in Toronto, Canada. Of the 80 constructed between 1945 to 1980, 11 buildings had PCB detections. PCB detections ranged from 570 to 82,090 mg/kg. With residences included, the PCB detection percentage was 14%. Because residential exposure can vary considerably from institutional and commercial buildings, a residential-excluded percentage is available, which is 27%. I will apply 27% to the mathematical model for schools in Los Angeles County.

Herrick et al. (2015) reported the results of a previous survey of 87 schools across Denmark, and there were 26 PCB detections. This data was pulled from a national survey completed in Denmark in 2013. The PCB detections ranged from 0.1-5,000 ppm. Of the 26 schools with PCB detections, 11 schools were found to exceed 5,000 ppm.

Table 3 (Herrick et al. 2015). Summary of four studies that conducted surveys directly related to commercial, industrial, and institutional buildings.

Reference	Location	Total Buildings Sampled	Number of PCB Detections	PCB Detection Range (ppm)	Percentage of PCB Detections	What was sampled?
Herrick et al. (2004)	Boston, MA.	24	15	0.56 - 36,200	54%	Caulking
Kohler et al. (2005)	Switzerland	1,348	646	20 - 550,000	48%	Joint Sealant
Robson et al. (2010)	Toronto, Canada	95	11	570-82,090	14% (27% if residential excluded)	Joint sealant (outdoors)
Herrick et al. (2015)	Denmark	87	26	0.1-5,000+	31%	Caulking/ Joint sealant (indoors)

#### B. Execution of the PCB Detection Application to Los Angeles County

Of the 3,719 schools within Los Angeles County, there are currently 2,728 schools that are active, merged, or pending reopening (CDE 2021). Therefore, based on the studies mentioned above, the mathematical estimated model that will be applied to the 2,728 schools built in Los Angeles County will be 27% to 54% between 1950 and 1979 (Herrick et al. 2015). I will not use 14% from Robson et al. (2010) because although it is more inclusive of all types of buildings, it is not residentially-exclusive and the other studies focused on institutional and commercial buildings only. This mathematical model will predict an estimated range of schools with PCB detections within Los Angeles County.

Lewis et al. (2000) stated that the U.S. Department of Education reported that there were 78,300 public schools across the United States in 1999 and 62% were built between 1950 and

1984. Therefore, there would be 48,546 schools constructed and in operation between 1950 to 1984. Of that 48,546 schools, 27 to 54% would range between 13,107 and 26,215 schools with PCB detections (Herrick et al. 2015).

Similarly we may apply this 62% to the 3,719 total schools that were built in Los Angeles County to determine the range of schools built between 1950 to 1984, which is approximately 2,306 schools. Furthermore, we apply the 27 to 54% range to predict the estimated range of PCB detections, which would be approximately 623 to 1245 schools, regardless of the schools' status of active, merged, pending reopening or closed. Therefore, the predicted approximate range of PCB detections for all of the schools built in Los Angeles is 17 to 33%.

Another scenario that we should consider is the 2,728 schools within Los Angeles County that are active, merged, or pending reopening (CDE 2021). Again, we may apply the 62% to the 2,728 schools to determine the range of schools in Los Angeles County that were built between 1950 to 1984, which is approximately 1,691 schools. Then, we may apply the 27 to 54% range to predict the estimated range of PCB detections, which is approximately 457 to 913 schools based on the schools' status of active, merged, or pending reopening. Therefore, the predicted approximate range of PCB detections for the currently active, merged, pending reopening schools built in Los Angeles is 17% to 33%.

Here, an uncertainty is revealed because while the predicted approximate range of PCB detections in schools may stay the same regardless of the schools' statuses, the actual number of schools with PCB detections may vary widely. Unless actual sampling has been collected, there will not be a firm determination of whether or not the schools have actual PCB contamination. Some schools may have already replaced primary and secondary sources of PCB contamination while others may not have had PCB contamination to start with.

Within these two mentioned scenarios, these are predicted ranges of PCB detections for schools within Los Angeles County that were built between 1950 to 1984. The mentioned ranges may not be nearly as accurate if direct data has not been collected and applied from the districts. While Herrick et al. (2015) estimates that 27 to 54% of all commercial/institutional buildings that are built between 1950 to 1984 across the United States have PCB detections, the first two scenarios resulted in 17 to 33%, which is a 6% overlap. Table 4 provides a summary of a predicted range for PCB detections within Los Angeles County.

Table 4. Summary of estimated PCB detections for schools built between 1950 to 1984 within Los Angeles County based on the number of schools built in Los Angeles and the model presented in Herrick et al. (2015). First, I applied 62% to the total number of schools to determine the number of schools built between 1950 to 1984. Next, I applied 27% to 54% to the calculated number of schools built between 1950 to 1984 to identify the estimated range of schools with PCB detections. Lastly, I divided the calculated estimated range of schools with PCB detections by the total number of schools to determine the estimated percentage of total schools with PCB detections.

<b>School Status</b>	<b>Total Number of Schools</b>	<b>Number of Schools Built Between 1950 to 1984</b>	<b>Estimated Range of Schools with PCB Detections</b>	<b>Estimated Percentage of Total Schools with PCB Detections</b>
Active, Merged, Pending Reopening, and Closed	3719	2,306	623 - 1245	17-33
Active, Merged, and Pending Reopening	2728	1691	457 - 913	17-33

An issue to consider is the uncertainty that is revealed in the tested time period of 1950 to 1984 instead of 1950 to 1979. 1979 was when PCBs were banned by the US EPA in the United States. Herrick et al. (2015) selected to end in 1984 because the data presented in Lewis et al. (2000) was the most direct and accurate range available at the time. The uncertainty of stopping at 1984 instead of 1979 may derail the accuracy of this predicted percentage range. 1984 was used instead of 1979 here to keep time consistency from the concluded data in Herrick et al. (2015) to the concluded data within this Master's Project.



## IX. Review of Current US EPA Exposure Tools

As semi-volatile organic carbons, PCBs are able to phase between gas and liquid form (NRC 2001). Semi-volatility causes an issue in being able to control and study the toxicological effects. The EPA and other research institutions have completed risk assessments and many research studies for airborne PCBs and are able to conclude through ingestion studies that PCBs can be very toxic to human health; however, inhalation studies are not well researched and cannot conclusively claim human health effects from inhalation exposure alone (P. Wilson, USEPA, pers. comm. September 14, 2020). Thus, the EPA has been using a route to route extrapolation method to determine the reference dose of PCBs when inhaled (P. Wilson, USEPA, pers. comm. September 14, 2020). This ingestion route to inhalation route extrapolated method has been translated into the EPA-managed Integrated Risk Information System (IRIS), which is then incorporated into an EPA exposure estimation tool. The tools that will be reviewed include the following: 1) IRIS assessments of Aroclors 1254 and 1016; 2) ingestion route to inhalation route extrapolation method; 3) PCB protocol for PCB assessment; and 4) regional cleanup levels.

### A. IRIS Assessments for Aroclor 1254 and 1016

The US EPA Integrated Risk Information System (IRIS) database identifies and characterizes chemicals that may affect environmental and human health. Depending on the amount of research available for the chemical and its various exposure pathways, each IRIS assessment provides the following five toxicity values: 1) reference concentration; 2) reference dose; 3) cancer descriptors; 4) oral slope factor; and 5) inhalation unit risk (IRIS n.d.). The noncancer assessment covers the reference concentration and the reference dose while the cancer assessment reviews the cancer descriptors, oral slope factor, and inhalation unit risk. The reference concentration is an estimated value that reflects how much continuous inhalation exposure that the general public can be exposed to in a lifetime until adverse health symptoms and signs occur (IRIS n.d.). The reference dose is an estimated value that reflects how much daily oral exposure to the general public can be exposed to in a lifetime until adverse health effects occur (IRIS n.d.). Cancer descriptors are included to characterize whether the chemical is carcinogenic to humans through the following categories: 1) carcinogenic to humans; 2) likely to be carcinogenic to humans; 3) suggestive evidence of carcinogenic potential; 4) inadequate information to assess carcinogenic potential; and 5) not likely to be carcinogenic to humans

(IRIS n.d.). The oral slope factor is an estimated value that describes the increased cancer risk from an ingestible dose of 1 mg/kg-day for a lifetime (IRIS n.d.). Lastly, the inhalation unit risk is an estimated value that describes the increased cancer risk from inhalation exposure to a chemical concentration of 1  $\mu\text{g}/\text{m}^3$  for a lifetime (IRIS n.d.).

Because ingestion studies are well researched for PCBs, specifically Aroclors 1254 and 1016, the US EPA was able to conduct assessments and conclude the respective noncancerous reference doses for the two mentioned Aroclors. The noncancerous reference dose for Aroclor 1254 is  $2 \times 10^{-5}$  mg/kg-day while the noncancerous reference dose for Aroclor 1016 is  $7 \times 10^{-5}$  mg/kg-day (EPA 1993; EPA 1994). Unfortunately, there is no extensive peer-reviewed literature available for inhalation exposure; therefore, the US EPA has not assessed and published the reference concentration (EPA 1993; EPA 1994).

The weight of evidence (WOE) characterization of cancer, also known as cancer descriptor, is classified as B2. B2 means that the chemical is a probable human carcinogen based on sufficient evidence of carcinogenicity in animals (PCBs 1989). Brunner et al. (1996) concluded that there were tumor growths on the livers of female rats that were exposed to Aroclors 1260, 1254, 1242, and 1016. Tumor growths that were found on the livers of male rates were exposed to Aroclor 1260 (Brunner et al. 1996). This study falls in line with previous studies conducted that resulted in tumor growths on the livers of rats. The oral slope factor is 2 per mg/kg-day and the extrapolated inhalation unit risk is  $1 \times 10^{-4}$  per  $\mu\text{g}/\text{m}^3$  (PCBs 1989).

#### B. PCB Exposure Estimation Tool

The extrapolation method that the US EPA currently uses is incorporated into an excel sheet that acts as a PCB exposure estimation tool (EPA and PCBs 2009). Part of this estimation tool uses an ingestion route to inhalation route extrapolation method. Table 5 has been summarized to list the specific tabs that will be reviewed.

Table 5 (EPA and PCBs 2009). The ingestion route to inhalation route extrapolation method, also known as the PCB Exposure Estimation Tool, is broken down into the relative tabs needed for analysis.

<b>PCB Exposure Estimation Tool</b>	
Tab	Tab Name
D	Inputs & Assumptions
E	Total Exposure Doses
F	Estimates of Background (Non-school) Doses
G	Estimates of Doses Occurring in Schools

In tab D, the US EPA toxicologist will enter in site-specific values and parameter assumptions for the tool. By filling out this information, the total PCB dose from each exposure pathway will be calculated for background exposure and direct school exposure in accordance to age groups, which is presented in Tab E (EPA and PCBs 2009).

Background exposures include the following: 1) dust ingestion; 2) soil ingestion; 3) indoor air inhalation; 4) outdoor air inhalation; 5) dermal absorption; and 6) diet (EPA and PCBs 2009). Direct school exposure includes the following: 1) dust ingestion; 2) soil ingestion; 3) indoor air inhalation; 4) outdoor air inhalation; and 5) dermal absorption (EPA and PCBs 2009). These PCB doses are adjusted according to age groups including: 1) age 1 to less than 2 years old; 2) age 2 to less than 3 years old; 3) age 3 to less than 6 years old; 4) age 6 to less than 12 years old; 5) age 12 to less than 15 years old; 6) age 15 to less than 19 years old; and 7) adults within the staff (EPA and PCBs 2009).

The total dose is presented in ng/kg-day which is the equivalent to 0.001 ppb/day. The total dose for each exposure pathway is also presented as a percentage of the total PCBs exposed for background exposure and total PCBs exposure for direct school exposure.

Lastly, the total exposure is added between background and exposure and direct school exposure and the toxicologist may compare this with the reference dose for Aroclor 1254 provided by the US EPA IRIS database, which is 20 ng/kg-day or 0.02 ppb (EPA 1994). This

comparison is more stringent than if the total exposure was compared to the reference dose for Aroclor 1016 by 50 ng/kg-day.

Tab F provides a mathematical model for each pathway exposure that was explored in Tab E for background exposure (EPA and PCBs 2009). Tables 6, 7, 8, 9, 10, and 11 list the following models, respectively: dust ingestion, soil ingestion, indoor inhalation, outdoor inhalation, dermal absorption, and dietary ingestion. The dietary ingestion model uses a dietary ingestion constant pulled from an FDA study that administered doses of PCBs at various levels to rats (ASTDR 2000). This FDA study concluded that PCBs accumulated heavily in fat tissues and liver muscles of rats (ASTDR 2000).

Tab G provides a mathematical model for each exposure pathway that was explored in tab E for direct school exposure (EPA and PCBs 2009). Tables 12, 13, 14, 15, and 16 list the following models, respectively: dust ingestion, soil ingestion, indoor inhalation, outdoor inhalation, and dermal absorption.

With Table 16, the dermal absorption formula has been adjusted to include the fraction of the calendar year that is spent in school, whereas with Table 10, the dermal absorption does not include the fraction of the calendar year that is spent in school because this deals with background exposure.

Regardless of the environmental setting, the US EPA specifies the controlling factor for each pathway exposure. Tables 6 and 12 show that the controlling variable for the dust ingestion mathematical model is the dust concentration ( $\mu\text{g/g}$ ). Tables 7 and 13 show that the controlling variable for the soil ingestion mathematical model is the soil concentration ( $\mu\text{g/g}$ ). Tables 8, 9, 14 and 15 show that the controlling variable for both the indoor inhalation mathematical model and outdoor inhalation mathematical model is the air concentration ( $\text{ng/m}^3$ ). Tables 10 and 16 show that the controlling variable for dermal absorption is dust concentration ( $\mu\text{g/g}$ ).

From the US EPA Office of Research and Development, Weitekamp et al. (2021) conducted a review of PCB background exposure and highlighted that ingestion was the main route of PCB exposure. While in ingestive forms, PCBs may accumulate and measure at high concentrations. Over time, as PCBs are metabolized and excreted from species in the food chain, chances of ingesting high concentrations of PCBs will slowly decrease (Weitekamp et al. 2021). On the other hand, inhaling high concentrations of PCBs will gradually increase as PCBs continue to vaporize from paints and caulk (Weitekamp et al. 2021).

### C. PCB Protocol for Preliminary Assessment

The Office of Research and Development at the US EPA released a protocol for noncancer IRIS preliminary assessment for PCBs. This protocol was proposed to further support the development of ingestion and inhalation noncancer toxicity values (EPA 2019). This protocol assessment looked at PCB sources, environmental levels, and exposures (Thomas et al. 2012). The protocol's measurements were taken from six primary and secondary schools in New York and they include the following: 1) primary and secondary source characterization; 2) PCB sampling characterization; 3) exposure model; 4) ranking of exposure routes; and 5) risk management tools for reducing PCB exposure.

The primary sources of PCBs in and around school buildings include caulk, fluorescent light ballasts, and paint. The secondary sources of PCBs may include paint and furnishings that absorb PCBs from primary sources. PCB sampling characterizations were taken from indoor air, dust, soil, and surfaces.

The average total absorbed dose concentrations measured were near Aroclor 1254's reference oral dose and there was an adjustment made for the reference dose for dermal absorption, which was 0.017  $\mu\text{g}/\text{kg}\text{-day}$  (Thomas et al. 2012). The adjustment used for dermal absorption was with a gastrointestinal absorption factor of 85%. (Thomas et al. 2012) As for inhalation exposure, the indoor air concentrations ranged from 70 to 600  $\text{ng}/\text{m}^3$ . Ranking of the exposure routes according to which is the most to least important seemed to be inhalation, dermal absorption, and then ingestion based on exceedance of regulatory guidance levels. Lehmann et al. (2015), from the Office of Research and Development at the US EPA, suggests that inhalation exposure and a dose-response assessment will rely on identifying the congeners in the air, the concentration of those congeners, and the mixtures of congeners associated with their PCB sources.

The two exposure models to consider are the Stochastic Human Exposure and Dose Simulation (SHEDS), which is an extensive exposure model, and a classical pharmacokinetic model, which is an extrapolation model. SHEDS is an exposure model that generates the estimated exposures of PCBs for children in different age groups. SHEDS provided potential doses for all three exposure routes by incorporating PCB concentrations in air, surface wipe, soil, and dust concentrations and combining that with activity levels per age group. Inhalation exposure may occur through the PCB vapors in the air and or PCBs attached to dust. Ingestion

exposure may occur through soil. Dermal absorption of PCBs may occur through surface touch of PCBs sources, such as paint and caulk. A classical pharmacokinetic model is used to evaluate route-to-route extrapolation. A typical model reviews the following: 1) clarity in model purpose, structure, and biological characterization; 2) validity of mathematical descriptors, parameters, and computer implementation; and 3) plausibility of dose metric (EPA 2019). This model will also determine whether or not the route-to-route extrapolation that is currently used must be updated to either more stringent parameters or may be kept.

As for risk management, mitigation measures that could be taken more immediately focused on replacing leaking light ballasts, increasing ventilation if possible, and removal of primary sources if possible. Risk management presented with many limitations due to transferred contamination, poor ventilation if it was an older school, and uncertainty in the exposure model considering these are either vapor or particle-bound contaminants.

#### D. Regional Screening Levels for PCBs

Around the early 1990's, toxicologists at US EPA Region 9 and Region 3 developed a standard set of tables that incorporated toxicity information of EPA-regulated chemicals to determine the risk of exposure at safe concentrations (Wilson, US EPA, per. comm. April 6, 2021). These sets of tables were called preliminary remediation goals (PRGs). All ten USEPA regions used these PRGs for their respective cleanup and permitting programs relative to air, water, and soil. As the technological age grew, access to these PRGs became available online and were used by other regulatory agencies worldwide (Wilson, US EPA, per. comm. April 6, 2021). With the widespread adoption of PRGs, US EPA headquarters took over ownership of updating PRGs and renamed these standardized tables as regional screening levels (RSLs) as they are uniformly used across all ten US EPA regions. Along with renaming PRGs as RSLs, the purpose has been modified as well.

Preliminary remediation goals and regional screening levels are different conceptually. While PRGs determine the extent at which a contaminant may be present at safe levels, regional screening levels function as a screening tool for project managers to confidently determine the level of contamination is above or below a level of concern (Wilson, US EPA, per. comm. April 6, 2021). If the level of contamination is above the level of concern, then the project manager

will divert greater attention and agency resources to the cleanup of this site. The cleanup of the site will depend on its cleanup goals. The term of RSLs is interchangeable with cleanup goals.

The regional screening levels for PCBs depends on if the area is categorized as residential or commercial. The residential cleanup goal is 0.23 ppm while the commercial cleanup goal is 1 ppm (Wilson, US EPA, per. comm. April 6, 2021). The residential cleanup goal is more restrictive than the commercial cleanup goal because an individual may be exposed more frequently and prolonged at home than at an industrial or commercial building. In the case of schools, these school buildings qualify as institutional buildings, which also falls within the realm of industrial and commercial buildings.

## X. Literature Review of the Potential Health Effects

### A. Breakdown of Toxicological Health Effects Associated with PCB Exposure

Adverse health effects as a result of PCB exposure are typically discovered through controlled experiments, incidental acute exposure, or prolonged background or direct exposure. These toxicological health effects may present as carcinogenic or noncarcinogenic. This section is to identify how PCBs impact human health through the following: 1) nervous system; 2) immune system endocrine system; 3) integumentary system; 4) reproductive system; 5) cellular toxicity; and 6) bioaccumulation, metabolism, and excretion.

A pretext of how multiple adverse health effects may occur through exposure is shown in Wang et al. (2020). Wang et al. (2020) conducted a study in which they were able to mimic the subchronic exposure of an environmentally relevant PCB mixture that has resulted in memory impairment, oxidative stress to the liver and lungs, and altered gene expression. These subtle changes were detected in rats at approximately 237 microgram/kilogram\*body weight (ug/kg bw) (Wang et al. 2020). These rats were exposed to either PCBs or lab air through nose-only exposure systems for four days a day for four weeks. The PCB mixture that was created for this experiment was to replicate the common PCB mixture and exposure of that in an older school. An older school may be defined as a school that was constructed between the 1930s to 1970s. By recreating the environment in which children would be subchronically exposed to PCBs everyday, Wang et al. (2020) has been able to establish a more up-to-date assessment of potential toxicological effects. The toxicological health effects resulting in the experiment prepared by Wang et al. (2020) could potentially replicate in students and teachers.

i. Nervous System

PCB exposure may present neurotoxicity through diminished mental capacity and affect motor skills (Jensen 2013). Examples include preschool children, those with Parkinson's disease, and female factory workers with high PCB exposure. Preschool children who may have high PCB exposure through soil ingestion may experience thyroid dysfunction as a result of organochlorine neurotoxicity (Jensen 2013). Individuals with Parkinson's disease may be more susceptible to PCB-153, as has been found in post-mortem human brains of patients who had Parkinson's disease (Jensen 2013). Jensen (2013) also reveals that female factory workers who are exposed to high PCB concentrations for prolonged periods of time may be highly susceptible for Parkinson's disease and dementia.

PCB exposure may also cause dopamine deficiency in brains. Our brains need dopamine to transmit signals to other nerve cells (Ododo and Wabalo 2018). Dopamine deficiency is a result of direct or indirect PCB inhibition of dopamine-producing enzymes, such as tyrosine hydroxylase or L-aromatic amino acid decarboxylase (Ododo and Wabalo 2018). Inhibition of dopamine-producing enzymes leads to a decreased uptake of dopamine into vesicles. Jensen (2013) states that lower-chlorinated PCB congeners may cause changes in dopamine metabolism, inhibit dopamine transport, and produce reactive oxygen species.

Nerve lesions have also been revealed as a result of extremely high exposure to PCBs. In 1982, there was an accidental explosion at a cardboard plant in southeastern Finland, in which 15 electrical capacitors exploded and the workers within the plant and adjacent to the plant were extensively exposed to PCBs (Seppäläinen et al. 1985). Approximately 6 hours after the initial explosion, air samples were taken and the concentrations were measured to range between 8,000 to 16,000 ug/m<sup>3</sup> (Seppäläinen et al. 1985). As a result, there were nerve lesions that symptomized of nausea, headaches, severe perspiration, and decreased amplitudes of sensory action potentials.

ii. Immune System

Jensen (2013) states that PCBs can cause immunosuppression and immune stimulation/inflammation due to respiratory infections, influenza, and a number of other diseases. Immunotoxicity occurs as a result of PCBs binding to the aryl hydrocarbon receptor and a decrease in antibody production (Ododo and Wabalo 2018). This is especially of concern in



individuals with developing immune systems. For example, Dutch and Inuit preschoolers and children of capacitor manufacturing workers encountered PCBs through inhalation, dermal absorption, and soil ingestion (Jensen 2013). As a result, they had compromised immune systems and were susceptible to respiratory infections and chicken pox.

### iii. Endocrine System

The endocrine system uses receptors to carry out different functions. An aryl hydrocarbon (Ah) receptor binds to contaminants, such as dioxins and PCBs, that will ultimately be broken down by cytochrome P-450 enzymes (Ododo and Wabalo 2018). If the P-450 cytochromes are unable to break down the PCB-receptor complex, then enzyme induction occurs. Enzyme induction will continue to produce P-450 enzymes until they are able to break down the PCB-receptor complex.

Enzyme induction is generally a protective mechanism but excessive enzyme activity can cause negative health effects. For example, when PCBs are present in the liver, they cause xenobiotic metabolizing enzymes to form so they may break down PCBs (Ododo and Wabalo 2018). Enzyme induction in the liver is for detoxifying purposes, but if there is a lot of enzyme activity going on, then this could adversely result in increased toxicity (Ododo and Wabalo 2018). Increased toxicity is due to the increased presence of xenobiotic metabolizing enzymes. An increased presence of xenobiotic metabolizing enzymes can result in more toxicity in the liver if such metabolites are not excreted properly. Metabolites may be excreted when they are conjugated with other molecules, such as glucuronic acid and glutathione, to become more hydrophilic for excretion.

PCB exposure can also affect vitamin A production in the liver (Ododo and Wabalo 2018). Vitamin A deficiency occurs as a result of liver toxicity. Vitamin A must be stored and converted into ester in the liver before distribution out to the body. If the PCBs are inhibiting esterifying enzymes, then ester cannot be created, stored, and released. In other words, the liver cannot store Vitamin A and eventually the rest of the human body will suffer from vitamin A deficiency.

Ododo and Wabalo (2018) states that the production of sex hormones and thyroids may be affected by PCBs. PCBs are endocrine disruptors, and so they interrupt hormone production. As a result, thyroid hormone deficiency occurs and prevents proper behavioral, intellectual, and

neurological development. For example, Jensen (2013) reveals that some lower-chlorinated PCB congeners may cause estrogenic effects while some higher-chlorinated PCB congeners exhibit anti-estrogenic effects. This is a result of decreasing thyroxine concentrations in the body, which is necessary for developmental growth.

#### iv. Integumentary System

Ododo and Wabalo (2018) lists chloracne as a result of acute exposure to PCBs due to dermal absorption and ingestion. Chloracne is an inflammatory response to PCB congeners in the sebaceous glands and symptomizes as acne-like rashes and lesions (Ododo and Wabalo 2018). Unfortunately, many times, chloracne does not respond to antibiotics and may last up to tens of years (Ododo and Wabalo 2018). Dermal absorption is most commonly associated with this type of high exposure to heated PCB vapors (Lindell 2012). Although inhalation exposure has not been identified as a means for chloracne, this stands as an example of how the absence of a disease does not mean that there has not been exposure (Ododo and Wabalo 2018).

Scientists have found that those with chloracne have serum PCB levels that are ten to twenty times higher than those with normally minimal exposure in the general population (Lindell 2012). In 1968, Japan experienced the first large-scale PCB ingestion incident in which more than 1,600 individuals ingested rice oil that was contaminated with PCBs. The resulting health effects were called the Yusho disease (NRC 2001). A similar incident occurred in 1979 in Taiwan when 2,000 individuals ingested rice oil that was contaminated with PCBs (NRC 2001). In Chinese, this was called the Yu-cheng disease, which roughly translates to “oil disease” (NRC 2001). The resulting health effects were numerous skin diseases, including chloracne and hyperpigmentation (Lindell 2012). Several years after the Yu-cheng incident, the average serum PCB level of approximately 400 victims was 51  $\mu\text{g/L}$  (Lindell 2012). It is uncertain how long it takes for PCBs to be completely broken down and removed from the body since they also tend to build up in adipose tissue.

#### v. Reproductive System

Jensen (2013) identifies reproductive toxicity in animals as a result of PCB exposure. Specifically, nonhuman primates are more sensitive than rodents based on their Lowest Observed Adverse Effects Levels (LOAEL) for PCB mixtures, which was 0.008 mg/kg/day and 0.25 mg/kg/day, respectively. These LOAELs were reflected in the postnatal effects of rodents

and nonhuman primates. For example, there were fewer offspring, less postnatal survival of the offspring, and impaired function in the offspring (Jensen 2013). These postnatal effects were most commonly associated with PCB mixtures that had more than 41% chlorine weight (Jensen 2013).

vi. Cellular Mutation

Jensen (2013) clarifies that PCB mixtures and congeners are not typically genotoxic, but there are exceptions, such as Aroclor 1221 and 4-chlorobiphenyl. When conducting scientific experiments, scientists typically use higher-chlorinated PCB mixtures to activate liver enzymes (Jensen 2013). Here, continuous enzyme induction for the aryl hydrocarbon receptor may result in the production of CYP1 enzymes, which is part of the P-450 enzyme family (Go et al. 2015). If there is too much production of enzymes in the CYP1-specific family, such as CYP1A1 and CYP1B1, then this could lead to oxidative stress, which is the increased formation of reactive oxygen species (Ododo and Wabalo 2018; Go et al. 2015). Jensen (2013) concludes that PCBs are able to convert non-genotoxic xenobiotics into genotoxic metabolites.

Along with producing reactive oxygen species, lower-chlorinated PCBs can result in intracellular oxidative stress (Robertson and Ludewig 2011). This entails free hydroxyl radicals producing 8-oxodeoxyguanosine, which is a DNA lesion, and attacking fatty acids, such as linoleic acid acid and oleic acid (Robertson and Ludewig 2011). 8-oxodeoxyguanosine causes G nucleic acids to turn into T nucleic acids. When free hydroxyl radicals attack fatty acids, lipid peroxidation-derived enals form and these can alter DNA bases, such as transversing G to T and C to A (Robertson and Ludewig 2011). This is more commonly associated with PCB inhalation exposure.

vii. Bioaccumulation, Metabolism, and Excretion

PCBs can either bioaccumulate or be metabolized and excreted (Ododo and Wabalo 2019). Depending on chlorination position and content, they are more or less likely to metabolize and eventually be excreted. The rule of thumb is that less chlorine atoms means higher chance of metabolization and excretion; however, chlorine positioning can affect the rate of metabolism and the number of chlorines attached to the biphenyls can affect whether the PCBs are excreted in feces or urine (Ododo and Wabalo 2019). If there are more chlorines present, then excretion would be through feces, and if there are less chlorines present, then excretion would be through

urine. Because PCBs are also very lipophilic, they become very attracted to human adipose tissue, which is human tissue with high fat content. For example, breast tissue is considered adipose tissue. Eventually, PCBs bioaccumulate within our bodies and can cause adverse health effects.

Ingestion and bioaccumulation are major concerns between breastfeeding mothers and nursing infants. PCBs can transfer between humans through a mother's breast milk as PCBs bioaccumulate largely in breast tissues and breast milk due to high lipid content (Davis and Wade 2003). Fish consumption is a prime example of PCBs bioaccumulation in living organisms. In bodies of water, fish will consume and bioaccumulate PCBs through the water, silt, and smaller living organisms. When mothers eat the PCB-contaminated fish, the mothers are also bioaccumulating the fish's PCB bioconcentration in both the mother's breast tissue and blood levels (Davis and Wade 2003). Eventually, these PCB concentrations are transferred to nursing infants, which make them very susceptible and sensitive to health effects associated with PCB toxicity. Table 17 shows the PCB concentrations in maternal blood and breast milk.

Table 17 (Davis and Wade 2003). This table shows the total PCB concentrations in maternal blood and breast milk. PCBs accumulate more in breast milk because PCBs bioconcentrate in the mother's breast tissue, which have lipids that contain long fatty acid chains. The units are in ppb.

<b>TOTAL PCBs IN MATERNAL BLOOD AND BREAST MILK</b>			
Population Studied	Maternal Blood (wet basis)	Breast Milk (lipid basis)	Health Effects
Mich nonfish-eaters	4.1 ppb	622 ppb	
Mich fish-eaters	6.1 ppb	866 ppb	Birth weight, head circumference, gestational length, neurobehavior
North Carolina	9.1 ppb	1,800 ppb	Neurobehavior

In Alabama, 458 residents ingested fish with high concentrations of PCBs (ASTDR 2000). The resulting average PCB serum level was 17.2 ug/L. This is almost twice the concentration for the fish-eaters in North Carolina that had 9.1 ppb in this maternal blood. If the health effects associated with fish-eaters in North Carolina have neurobehavioral deficits, what would be the health effects with twice the average PCB serum levels?

Overall, the adverse health effects associated with PCBs are not limited to the mentioned above. Because PCBs are emerging and legacy contaminants, there is still much to expose in terms of how PCBs are reflected in the environment and how humans are subjected to PCBs.

These toxicological effects may not all occur in students and teachers simultaneously, but stating the correlations between PCBs and human exposure provides awareness among researchers, regardless of the environmental setting.

## XI. International Health Risk Assessments

Jensen (2013) conducted a health risk assessment in Denmark and concluded that if an individual is exposed to 300-3,000 ng PCB/m<sup>3</sup> indoors and inhales 20 m<sup>3</sup> air daily, then the PCB inhalation will be approximately 6,000-60,000 ng PCB per day. In 2009, the Danish Health and Medicine Authority recommended two action levels for PCBs in indoor, which include the following: 1) levels about 3,000 ng/m<sup>3</sup> must be remediated or removed; and 2) levels between 300 and 3,000 ng/m<sup>3</sup> could cause potentially serious health risks and remedial plan must be considered (Jensen 2013). Compared to the United States, Denmark's required actions are not as stringent as that of the United States' because the United States' long-term average exposure is 300 ng/m<sup>3</sup> and requires remedial/removal action at 50 ng PCB/m<sup>3</sup>. (Jensen 2013).

In addition to the United States and Denmark, Switzerland has established maximum tolerable average values for indoor exposure. Switzerland's tolerable indoor exposure in schools is 2 µg/m<sup>3</sup> in school and 6 µg/m<sup>3</sup> in other institutional buildings (Waeber and Brüscheiler 2002). Of the three countries, Switzerland is more conservative than the United States and Denmark. Table 18 provides a comparison between Denmark, Switzerland, and the United States.

Table 18. This table compares the allowable indoor air exposure between Denmark, Switzerland, and the United States. Switzerland is 3 orders of magnitude less than Denmark and the United States. The action levels set are determined for remedial, mitigative, or removal work. This information has been collected from Jensen (2013).

Unit	Allowable Indoor Air Exposure (ng/m <sup>3</sup> )	Action Levels (ng/m <sup>3</sup> )	Reference
Denmark	300	300 - 3000	Jensen (2013)
Switzerland	0.002 in home 0.006 in other institutional buildings	--	Waeber and Brüscheiler (2002)
United States	300	50	Sullivan et al. (2008)

While Switzerland’s allowable indoor air exposure is 3 orders of magnitude less than that of Denmark and the United States, the United States’ action level is approximately a tenth of Denmark’s lowest action level of 300 ng/m<sup>3</sup>. Actually, it is important to note that the allowable indoor air exposure for the United States may vary depending on age. Table 19 depicts the varying school indoor air exposure levels based on age.

Table 19 (Jensen 2013). This table shows that as age increases, the allowable indoor air exposure before health risks are of concern will increase as well. These values take into account the amount of time individuals spend within the school building. The units are in ng/m<sup>3</sup>.

Age 1-<2 yr	Age 2-<3 yr	Age 3-<6 yr	Age 6-<12 yr Elementary School	Age 12-<15 yr Middle School	Age 15-<19 yr High School	Age 19+ yr Adult
70	70	100	300	450	600	450

Ivanescu (2015) takes a different approach for a human health risk assessment for PCB exposure in Bucharest, Romania. GIUDITTA software has incorporated the Standard Guide for Risk-Based Corrective Action, or ASTM standard E2081-00, and includes several toxicant-based databases from the US EPA, Cal EPA, TOXNET. and This study uses GIUDITTA software to determine the calculated risk and the hazard index to quantify carcinogenicity. Ivanescu (2015)

sampled 44 outdoor spots throughout the Bucharest area and has concluded that human health risks are mainly associated with PCB exposure through soil ingestion and dermal absorption. If the samples had been taken indoors, then would inhalation and dietary ingestion be the main routes of PCB exposure? Because PCBs are a relatively new field, using GIUDITTA software could potentially further the research available for PCB exposure indoors.

Another difference between the health risk assessments presented by Ivanescu (2015) and Jensen (2013) is that they have different end goals but utilize the same overarching objective, which is looking for methods to counteract PCB exposure. Ivanescu's model has the potential to be used as a redevelopment or remedial tool for sites. Jensen (2013) focused on setting action levels for remediation or excavation.

#### A. Uncertainty in Health Risk Assessments

Generally, health risk assessments are bound to have uncertainties due to the unpredictable nature of contaminants and the variability of the environment (NAP 2013). While the US EPA uses health risk assessments and risk-management models to identify and to approximate the immensity of chemicals, these tools can only go so far if data is not available (NAP 2013). For example, uncertainties present in cancer risk assessments associated with trichloroethylene (TCE) may be present in estimating cancer potency derived from rodent testing could vary by over 500-fold (NAP 2013, EPA 2009). Variation in potency is explained by extrapolations made up of different models.

Specifically, health risk assessments associated with PCBs may hold some uncertainty due to the many extrapolations made for assumptions that make up for the lack of data available (Cogliano 2016). This is especially common for toxicants that are not extensively researched. The more research available, the smaller the uncertainty may be when creating an extrapolation for an assumption. Especially for the case of PCBs, there is not a lot of inhalation studies available to conclusively quantify the risk associated with inhalation exposure. With these circumstances, the US EPA has created an ingestion route to inhalation route extrapolation method, as mentioned earlier, to estimate the exposure for occupants in schools.

Many times, the studies incorporated as evidence for conclusions related to PCBs are from experiments tested on animals. Cogliano (2016) identifies that the slope factors that the EPA uses may not be entirely accurate because these toxicity values were developed from

studies done on rats that developed tumors. Humans may not react 100% the same and these studies do not predict or confirm an accuracy percentage that says these rat-based studies apply to humans. In order to address this gapped uncertainty, with each study, new studies incorporate such circumstances to duplicate the results and even further the explanation behind why these circumstances matter.

Earlier, Davis and Wade (2003) identified that sampling analysis methods do not test for all PCB congeners and this may derail the accuracy of the toxicity related to weathered Aroclors. Cogliano (2016) identifies this as an uncertainty because PCB-11 is a common congener used in many Aroclor mixtures, but is not necessarily tested for when testing for Aroclor 1016. Aroclor 1016 is composed mainly of lower-chlorinated PCB congeners (Cogliano 2016). This is an example of a data gap as a result of sampling analysis methods holding a lot of room for uncertainty.

Data gaps are also prevalent in health risk assessments because of the lack of inhalation studies available (Cogliano 2016). There is no reference concentration provided by the US EPA for PCB assessments. The US EPA uses extrapolation measures, which will be later addressed, to bridge this data gap for PCB exposure in schools.

## XII. Management Recommendations

### A. Recommendation 1: Addressing Uncertainties For Schools in Los Angeles/California

The California Department of Education has published a live database of all the schools in California with their current statuses, such as opening and closing dates, contact information, and districts the schools belong to (CDE 2021). Unfortunately, this database does not have a complete picture of every school listed. When going through the open and close dates for Los Angeles County, I noticed that most of the open dates were listed as July 1, 1980. Therefore, I contacted the support desk that manages this database, and it was revealed that July 1, 1980 is a placeholder date for missing information (CDE 2021). Upon further review of the whole database, this placeholder date accounted for over half of the schools.

Another uncertainty to consider are the building materials that may or may not have contained PCBs. Although PCBs were widely used for caulking and light ballasts, there is still a possibility that not all construction companies used such PCB-containing materials. This is another reason to define which schools were built within the time period of 1959 and 1980.



The solution to this incomplete database and its related issues is a simple email from each school district. Within each district office, there is a coordinator who has the opened and closed dates of their respective schools on file. I recommend that the California Department of Education release an issue brief that explains how correcting the placeholder dates for each school could potentially help identify which schools may be contaminated with PCBs. By doing so, this could help identify which schools would need to undergo inspections instead of requiring every school to complete inspection. Minimizing the number of schools that would need inspections would also minimize the amount of financial resources that would need to go into paying for these inspections. The inspection includes costs for sampling, laboratory testing, and potentially remedial and excavation.

After the schools that were built between 1959 and 1980 have been identified, these schools will be listed as the responsible parties that would need to pay for cleanup and disposal costs. Just as though at hazardous waste sites, it is the responsible party's responsibility to prove that the PCB spill occurred prior to 1979 to avoid a potentially lengthy process. Similarly, the schools, as the responsible party, would need to prove that their school was built before 1950 or after 1980. Another option I would recommend as a loophole would be that it is the schools' responsibility to prove that known articles of PCB contamination have already undergone remodeling, removal, or replacement. By doing so, this could avoid an extensive amount of financial resources spent on sampling, excavation, land deed restrictions, remediation, and disposal. Not to mention, all these actions could cause restricted occupancy on school grounds to reduce exposure.

Another uncertainty to consider is if the building at which the school has been operating at may have already been built before 1950. It is not unheard of in which schools move to buildings or campuses that are bigger because it may be cheaper to move instead of expanding the original location. Along with asking the districts to submit the corrected open dates, provided that information is available, the districts would also include within the submission of the dates at which these buildings were actually constructed.

#### B. Recommendation 2: Mitigative Actions to Remove PCBs From Secondary Sources

As seen in Figure 6, PCBs travel between primary sources to primary sinks, which function as secondary sources and eventually to secondary sinks. Mitigative actions are typically

done for primary sources to minimize financial expenditures. For example, there are leftover PCB residues from leaking light ballast capacitors remaining in fixtures. To minimize remedial costs, only light ballast capacitors will be removed as they are seen as the primary source; however, what about the secondary sources? What about the fixtures?

I recommend that secondary sources be required to be cleaned up if primary sources have been deemed a risk. Meaning, if there are immediate concerns where tested PCB samples show that there is a high risk and is in violation of reference doses for students and teachers within the building, then after primary resources have been removed, secondary sources will either undergo similar remediation or implement Best Management Practices (BPMs).

Currently, the US EPA does not require PCB inspections in schools; however, the US EPA does provide BPMS that can be applied to both primary and secondary sources of PCB. These BPMs include the following: 1) ventilation systems that are accordance to ANSI/ASHRAE/ACCA Standard 1012; 2) wipe surfaces with a wet or damp cloth; 3) vacuum floors with high efficiency particulate air filters; and 4) do not use dry cloths or brooms for dusting (EPA 2015). The main point of these specific practices is to prevent the further spread and exposure of PCBs.

If PCB removal and remediation does not quite fit into the budget and is not deemed an immediate concern, then another recommendation is to annually wipe down the classrooms' known PCB primary and secondary sources. This continues to mitigate the PCB exposure as they transfer from source to sink. Assuming caulk is not chipping and light ballasts are not leaking, PCBs are accumulating at ppbs or less over time.

Because schools are not required to conduct PCB inspections at all, I would recommend setting an inspection requirement every 10 years, assuming an immediate and urgent concern has not been unveiled. Inspections are not normally routine required for many air contaminants, and so I would recommend that this PCB inspection would be grouped with both air and soil contaminants, such as SVOCs and lead. This is at the least implementing a time frame component that may need to become enforced through a health- or risk-based regulation. Figure 7 shows a flow diagram of how to manage PCBs in school building materials.

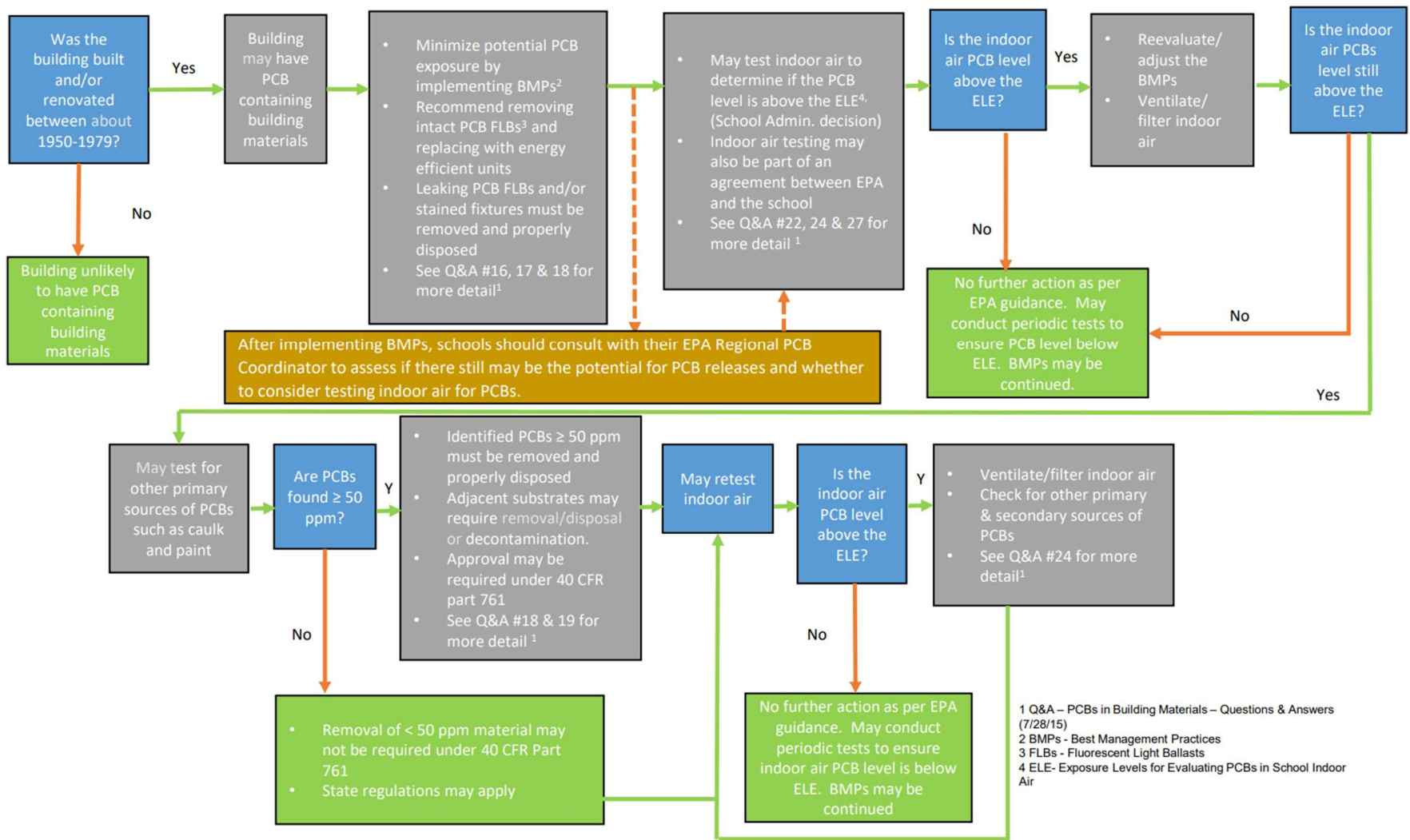


Figure 7 (EPA 2018). This flow diagram describes the process of how to manage PCB-contaminated materials within school buildings. This guide shows the options that may be taken depending on the extent of PCB contamination and exposure.

### C. Recommendation 3: Next Steps for EPA's IRIS PCB Assessment

I would recommend that the US EPA's Office of Research and Development consider adding specific sections correlating the toxicological health effects associated with each PCB exposure route (inhalation, ingestion, dermal absorption). This correlation may be done by weighing the likelihood of obtaining these toxicological health effects. By identifying such risks associated with each PCB exposure route, this could potentially help schools prioritize mitigative actions to reduce exposure through inhalation and ingestion.

I would also recommend a section dedicated to research into PCBs in schools. This section could outline previous studies conducted, future plans to implement inspections, and risk calculation surrounding building deteriorating and PCB concentrations. Providing a background on previous studies conducted will allow for the general public to have a better understanding as to what was sampled, what the concentrations were, and what next steps were taken. Creating a section on implementing inspections could also be taken in a direction as to why PCB inspections are not mandatory just yet. Risk calculation could provide a foundational basis as to why inspections are or not urgent.

### D. Recommendation 4: Data Gap for IRIS Toxicity Values

As mentioned earlier, bioassays have the potential to expand the knowledge of associated health effects for PCB exposure. It is very unlikely for researchers to conduct experiments for every single congener. I recommend first identifying the top ten overlapping congeners among all exposure pathways or identify the PCB congeners that are known to weather from one congener to the next.

Second, I would now recommend conducting individual PCB congener experiments with different exposure pathways as the variable. For example, for PCB-125, variables would be different exposure pathways in either background exposure or direct exposure. PCB-125 may weather into another congener and an experiment may be conducted with the same variables. This would allow researchers to see the potential adverse health effects that would result in PCB congeners weathering within Aroclor mixtures.

#### E. Recommendation 5: Data Gap For Weathered Aroclors

Over the course of 40 to 60 years, PCB congeners and mixtures may undergo deterioration and weathering into other PCB congeners and mixtures. As a result, semi-volatilization and exposure may either be better with improved ventilation or worse with older buildings. In my interview with Geniece Lehmann from the US EPA's Office of Research and Development on September 14, 2020, Lehmann mentioned that the US EPA published IRIS toxicity values that were representative of the conditions 40 years ago; however, today's environmental setting, both indoors and outdoors, may not accurately reflect the toxicity values that were developed based on the information available 40 years ago. Because PCBs are emerging and legacy contaminants, there is a whole lot of information that has been established within the last five years. In fact, more buildings are deteriorating today and PCBs are semi-volatilizing; therefore, PCBs themselves may have weathered as well.

In my interview with Patrick Wilson, who is a US EPA Region 9 toxicologist, on September 14, 2020, Wilson mentioned that even if there are more inhalation and ingestion studies published, the exposure tools at the EPA may not actually change. Wilson feels as though these tools would present with less uncertainty and at a higher level of confidence in its predictions. This is another perspective, but with the same goal for increased accuracy for these exposure tools.

Here, we have two expert toxicologists from the US EPA with different conservative views. I recommend that the US EPA move forward with publishing an extrapolated reference concentration considering they have already pushed an extrapolated inhalation unit risk. This extrapolated reference concentration may be later revisited every 15 to 20 years as more inhalation studies are published. By publishing this toxicity value, research groups will be able to take that reference concentration and apply it to a given population, measure PCB concentrations in that environment, and produce exposure concentrations (Lehmann, US EPA, per. comm.).

#### F. Recommendation 6: Cleanup Grant

With the lack of case studies available, it may be suggested that a cleanup grant be used to fund a pilot study or a project equivalently scaled. This cleanup grant could initially function for funding pilot studies and eventually be adjusted for large-scaled projects within a district.

These pilot studies could potentially function as case studies that would supplement inhalation studies for PCBs in schools.

Asking districts to consider PCB inspections is difficult due to no regulatory requirement. I recommend that the US EPA creates a cleanup grant that is specifically related to public schools. By doing so, parents that attend Parent Teacher Association meetings may discuss among themselves and with the district their concerns for their children's health and safety.

Many of these parents may not even be aware of these PCBs in their child's schools, and so this may be resolved with info sessions and fact sheets. There is a possibility that districts may not want to even consider sampling characterization because they are worried about being subjected to costly sampling, removal, and remediation. I would recommend that this cleanup grant would be set at a specific amount and would be overseen by RCRA project managers that specialize in PCB-contaminated sites. The main costs that the schools would need to finance themselves would be the maintenance and annual inspections associated with a deed restriction or land use covenant.

To apply for the grant, the district or school would need to qualify as to why they are unable to finance the whole project. As with other US EPA cleanup grants, there are qualification requirements, informational webinars, pre-application assistants (US EPA 2015b). By providing this grant, it will somewhat bridge the regulatory gap in optional inspections and unregulated PCB exposure.

### XIII. Conclusion

To reiterate, the purpose of this Master's Project is to address the uncertainties associated with PCBs in schools. My first research objective was to predict the potential range of PCB detections in schools within Los Angeles County. My second research objective was to extensively outline the exposure tools produced by the US EPA that are used to bridge uncertainty gaps and to identify PCB-associated toxicological health effects.

Marek et al. (2017) and Weitekamp et al. (2021) have identified that indoor concentrations of PCBs in schools is much higher than that of outdoor concentrations. Through my calculations in Los Angeles County, there is a possibility that this may be the case for approximately 17 to 33% of the 2,728, which is 457 to 913, public and in operation schools in the county. Due to the California Department of Education's limited data available for all

schools in California, the open and closed dates are not completely accurate. I have recommended that there be a generated memo or issue brief that identifies why these dates are necessary. This project is not extensive because one email from each district would be sufficient and there would not need to be a revisit until a school has closed.

While PCBs may be considered stable in the context of soil migration, they are unforeseeable in the context of air travel. Primary sources of PCBs can easily cause multiple secondary sources, which makes controlling PCBs more difficult in terms of time and cost. Teachers experience prolonged inhalation exposure every day while children are more vulnerable to ingestive exposure. I have recommended that mitigative measures be taken for secondary sources to limit the prolonged inhalation, ingestion, and dermal absorption exposure of PCBs in the classroom.

Of these 457 to 913 operational schools in Los Angeles County, the US EPA has particularly created the exposure estimation tool to determine the exposure through inhalation, ingestion, and dermal absorption. This exposure estimation incorporates other exposure measures that the US EPA has created. The IRIS assessments of Aroclors 1254 and 1016 were selected for their largely common presence in everyday PCB exposure and to provide a foundational understanding of their toxicity values. The PCB exposure estimation tool highlights the direct and background exposure for multiple age groups in schools and has identified that ingestion is the main route of exposure due to the bioaccumulation. The PCB protocol for the preliminary assessment addresses PCB exposure through case studies, exposure models, and potential risk management strategies. Lastly, although the regional screening levels are not regulatory standards, they have been standardized and enforced by all ten US EPA regions for remediation and cleanups to a safe concentration. Upon reviewing the US EPA exposure tools, I have recommended that the US EPA publish an extrapolated reference concentration that may be updated every 15 to 20 years. This application will allow for the production of exposure concentrations that could potentially provide a more precise and accurate toxicity value. I also recommended that the US EPA publish an uncertainties section in their upcoming IRIS PCB assessment and to descriptively quantify as to how these current exposure tools properly supplement for the missing reference concentration.

The associated adverse health effects of PCBs have not been established with regards to exposure routes; however, understanding the potential toxicological effects is still important in

the environmental realm of exposure to both humans and animals. Health risk assessments are useful but limited with regards to uncertainties unveiled by animal testing, sampling methods, and the lack of inhalation studies available. I have recommended bridging the data gap for associated health effects between animals and humans by conducting more bioassays. This would supplement for Aroclors that have weathered over the years; therefore, the PCB congeners and mixtures may not be consistent when the Aroclors were originally produced.

With the semi-volatility of PCBs, the recommendation that is most plausible to implement first would either be completing the California Department of Education's school database or begin mitigating actions of secondary sources. Completing the database would not only help with quantifying the potential range of PCB detections in schools, but also provide other needs of school districts' administration. As for completing mitigating actions of secondary sources of PCBs, this would essentially be implemented in either janitorial cleaning or maintenance upkeep.

Although PCBs are emerging and legacy contaminants, the potentially increasing exposure has yet to show drastic adverse health effects in residential homes and at schools. For some, not knowing may be comforting because of the potential disruption it may cause. For others, this potential disruption should be prioritized to avoid unnecessary PCB exposure. Based on my research, addressing PCBs in schools is not immediate and urgent; however, creating short term goals through the mentioned recommendations will ultimately contribute to long term health.



#### XIV. References

Aroclor 1016 (EPA)(1993).

[https://cfpub.epa.gov/ncea/iris2/chemicalLanding.cfm?substance\\_nmbr=462](https://cfpub.epa.gov/ncea/iris2/chemicalLanding.cfm?substance_nmbr=462). Accessed February 19, 2021.

Aroclor 1254 (EPA)(1994).

[https://cfpub.epa.gov/ncea/iris2/chemicalLanding.cfm?substance\\_nmbr=389](https://cfpub.epa.gov/ncea/iris2/chemicalLanding.cfm?substance_nmbr=389). Accessed February 19, 2021.

Agency for Toxic Substances and Disease Registry (ASTDR) (2000). Toxicological Profile for Polychlorinated Biphenyls.

Basic Information about the Integrated Risk Information System (IRIS) (n.d.).

<https://www.epa.gov/iris/basic-information-about-integrated-risk-information-system>. Accessed February 19, 2021.

Brunner, M.J., Sullivan, T.M., Singer, A.W., et al. 1996. An Assessment of the Chronic Toxicity and Oncogenicity of Aroclor-1016, Aroclor-1242, Aroclor-1254, and Aroclor-1260 Administered in Diets to Rats. Study No. SC920192. Chronic Toxicity and Oncogenicity Report. Battelle, Columbus, OH.

California Department of Education (CDE) (2021). Public Schools and Districts Files.

<https://www.cde.ca.gov/ds/si/ds/pubschls.asp>. Accessed February 28, 2021.

Cogliano, V. (2016). Lack of Data Drives Uncertainty in PCB Health Risk Assessments.

Environmental Science and Pollution Research International, 23(3), 2212-2219, doi: 10.1007/s11356-015-5157-4.

Committee on Decision Making Under Uncertainty; Board on Population Health and Public Health Practice; Institute of Medicine (NAP) (2013). Environmental Decisions in the Face of Uncertainty. 2, Risk Assessment and Uncertainty.

<https://www.ncbi.nlm.nih.gov/books/NBK200844/>

Davis, B. & Wade, M. (2003). Risk Assessment of Polychlorinated Biphenyls at Hazardous Waste Sites.

- Envirostor (DTSC) (2021). Malibu High School Project (19820092).  
[https://www.envirostor.dtsc.ca.gov/public/profile\\_report?global\\_id=19820092](https://www.envirostor.dtsc.ca.gov/public/profile_report?global_id=19820092). Accessed April 27, 2021.
- EPA (2007). Method 8082A Polychlorinated Biphenyls (PCBs) By Gas Chromatography.  
Accessed March 19, 2021.
- EPA (2009). Toxicological Review of Trichloroethylene: In Support of Summary Information on the Integrated Risk Information System (IRIS) [External Review Draft].  
[https://cfpub.epa.gov/si/si\\_public\\_record\\_report.cfm?Lab=NCEA&dirEntryID=215006](https://cfpub.epa.gov/si/si_public_record_report.cfm?Lab=NCEA&dirEntryID=215006). Accessed May 15, 2021.
- EPA (2015). Practice Actions for Reducing Exposure to PCBs in Schools and Other Buildings.  
Accessed March 23, 2021.
- EPA (2018). An Example of How to Manage Polychlorinated Biphenyl (PCB)-Containing Materials in School Buildings. Accessed March 23, 2021.
- EPA (2019). Systematic Review Protocol For the PCBs Noncancer IRIS Assessment. Accessed February 17, 2021.
- EPA and PCBs (2009). <https://www.pcbinschools.org/epa-and-pcbs>. Accessed September 30, 2020.
- Gabrio, T., Piechotowski, I., Wallenhorst, T., Klett, M., Cott, L., Friebel, P., Link, B., & Schwenk, M. (2000). PCB-Blood Levels in Teachers, Working in PCB-Contaminated Schools. *Chemosphere*, 40(9), 1055-1062, doi: 10.1016/S0045-6535(99)00353-7.
- Go, R., Hwang, K., & Choi, K. (2015). Cytochrome P450 1 family and cancers. *The Journal of steroid biochemistry and molecular biology*, 147, 24-30, doi: <https://doi.org/10.1016/j.jsbmb.2014.11.003>.
- Herrick, R. F., Stewart, J. H., & Allen, J. G. (2015). Review of PCBs in US Schools: A Brief History, an Estimate of the Number of Impacted Schools, and an Approach for Evaluating Indoor Air Samples. *Environmental Science and Pollution Research International*, 23(3), 1975-1985, doi: 10.1007/s11356-015-4574-8.

- Herrick, R. F., McClean, M. D., Meeker, J. D., Baxter, L. K., & Weymouth, G. A. (2004). An Unrecognized Source of PCB Contamination in Schools and Other Buildings, 112(10), 1051-1053, doi: 10.1289/ehp.6912.
- Ivanescu, V. (2015). Human Health risk Assessment Posed By PCB Exposure in Bucharest Area. *Agriculture and Agricultural Science Procedia*, 6, 453-458, doi: 10.1016/j.aaspro.2015.08.118.
- Jensen, A. A., Hansen, H. L., Keiding, L. (2013). Health Risks of PCB in the Indoor Climate in Denmark -Background For Setting Recommended Action Levels Environmental Assessment of PVC and Selected Alternative Materials View Project.
- Klosterhaus, S., McKee, L. J., Yee, D., Kass, J. M., Wong, A. (2014) Polychlorinated Biphenyls in the Exterior Caulk of San Francisco Bay Area Buildings, California, USA. *Environ Int.*; 66:38–43. [PubMed: 24518434]
- Kohler, M., Tremp, J., Zennegg, M., Seiler, C., Minder-Kohler, S., Beck, M., Lienemann, P., Wegmann, L., & Schmid, P. (2005). Joint Sealants: An Overlooked Diffuse Source of Polychlorinated Biphenyls in Buildings. *Environmental Science & Technology*, 39(7), 1967-1973, doi: 10.1021/es048632z.
- Legal Information Institute (LII) (n.d.). 40 CFR § 761.61 - PCB remediation waste. <https://www.law.cornell.edu/cfr/text/40/761.61>. Accessed May 15, 2021.
- Lehmann, G., (2020). U.S. Environmental Protection Agency, Toxicologist, Center for Public Health and Environmental Assessment, Research Triangle Park, NC Personal Communication.
- Lehmann, G. M., Christensen, K., Maddaloni, M., & Phillips, L. J. (2015). Evaluating Health Risks From Inhaled Polychlorinated Biphenyls: Research Needs For Addressing Uncertainty. *Environmental Health Perspectives*, 123(2), 109-113.
- Lewis, L., Snow, K., Farris, E., Smerdon, B., Cronen, S., Kaplan, J. (2000). Condition of America's Public School Facilities: 1999 U.S. Department of Education. Washington, DC: National Center for Education Statistics, NCES 2000-032.

- Lindell, B., (2012). The Nordic Expert Group For Criteria Documentation of Health Risks From Chemicals 146. Polychlorinated Biphenyls (PCBs).
- Marek, R. F., Thorne, P. S., Herkert, N. J., Awad, A. M., & Hornbuckle, K. C. (2017). Airborne PCBs and OH-PCBs inside and outside urban and rural U.S. schools. *Environmental Science & Technology*, 51(14), 7853-7860, doi: 10.1021/acs.est.7b01910.
- Markowitz, G. (2018). From Industrial Toxins To Worldwide Pollutants. *Public Health Reports* (1974), 133(6), 721-725, doi: 10.1177/0033354918801578.
- National Research Council (NRC)(2001). A Risk-Management Strategy for PCBContaminated Sediments: National Academy Price, 23-52.
- Ododo, M. M. , & Wabalo, B. K. (2019). Polychlorinated Biphenyls (PCBs) and Their Impacts on Human Health: A Review. *Journal of Environment Pollution and Human Health*, 7, doi: 10.12691/jephh-7-2-3.
- Office of Legacy Management Environmental Justice History (OLM)(n.d).  
<https://www.energy.gov/lm/services/environmental-justice/environmental-justice-history>. Accessed Apr 30, 2021.
- Patel, S. (2018). School District Given Five More Years to Clean Up PCBs.  
[http://www.malibutimes.com/news/article\\_ba5dc3e0-0a0d-11e9-addf-431c295539ef.html](http://www.malibutimes.com/news/article_ba5dc3e0-0a0d-11e9-addf-431c295539ef.html). Accessed Apr 28, 2021.
- PEER (2018). Malibu Schools Want 5 Year Delay in Toxic PCB Cleanup.  
<https://www.peer.org/malibu-schools-want-5-year-delay-in-toxic-pcb-cleanup/>. Accessed May 15, 2021.
- Polychlorinated biphenyls (PCBs)(1989); CASRN 1336-36-3 I. Chronic Health Hazard Assessments For Noncarcinogenic Effects I.A. Reference Dose For Chronic Oral Exposure (RfD) Substance Name -Polychlorinated Biphenyls (PCBs)(b). Accessed February 17, 2021

- Robertson, L. W., & Ludewig, G. (2011). Polychlorinated Biphenyl (PCB) Carcinogenicity With Special Emphasis on Airborne PCBs. *Gefahrstoffe, Reinhaltung der Luft = Air Quality Control*, 71(1-2), 25-32.
- Robson, M., Melymuk, L., Csiszar, S. A., Giang, A., Diamond, M. L., & Helm, P. A. (2010). Continuing Sources of PCBs: The Significance of Building Sealants. *Environment International*, 36(6), 506-513, doi: 10.1016/j.envint.2010.03.009.
- Seppäläinen, A.M., Vuojolahti, P., Elo, O. (1985). Reversible Nerve Lesions After Accidental Polychlorinated Biphenyl Exposure. *Scandinavian Journal of Work, Environment & Health*, 11(2), 91-95, doi: 10.5271/sjweh.2248.
- Skelton, R., Miller, V. (2016). The Environmental Justice Movement. <https://www.nrdc.org/stories/environmental-justice-movement>. Accessed Apr 28, 2021.
- SMMCTA (2015). US EPA Conditional Approval SMMUSD. [http://www.smmcta.com/uploads/4/0/6/2/40622543/epa\\_approval\\_nov\\_2.pdf](http://www.smmcta.com/uploads/4/0/6/2/40622543/epa_approval_nov_2.pdf). Accessed April 27, 2021.
- SMMUSD (2018). Facility Improvement Projects. 21st-Century Schools. <https://www.smmusd.org/domain/4170#:~:text=Measure%20M%3A%20Malibu%2C%20%24195%20million,improving%20Malibu%20pathway%20school%20facilities>. Accessed May 15, 2021.
- SMMUSD (2019). Malibu High School PCB Chart. <http://fip.smmusd.org/reports/Malibu/PCBBldgMaterialsoverTSCALevel.pdf>. Accessed April 27, 2021
- Sullivan, D. M. , Hunt, G.T., Alfonse, S. (2008). Polychlorinated Biphenyls (PCBs) and Indoor air: Source Investigation and Remedial Approach For a Public School Building in New Bedford, Massachusetts, USA. *Organohalogen Compounds*; 70: 850-854
- Thomas, K., Xue, J., Williams, R., Jones, P., & Whitaker, D. (2012). Polychlorinated Biphenyls (PCBs) in School Buildings: Sources, Environmental Levels, and Exposures.

- US EPA (2013). Multimedia Fate and Transport Modeling - Overview.  
<https://www.epa.gov/fera/multimedia-fate-and-transport-modeling-overview>. Accessed Apr 23, 2021.
- US EPA (2014). Environmental Justice. <https://www.epa.gov/environmentaljustice>. Accessed Apr 27, 2021.
- US EPA (2015a). Dioxin and Dioxin-Like Compounds Toxic Equivalency Information.  
<https://www.epa.gov/toxics-release-inventory-tri-program/dioxin-and-dioxin-compounds-toxic-equivalency-information>. Accessed Apr 17, 2021.
- US EPA (2015b). Environmental Justice Grants, Funding and Technical Assistance.  
<https://www.epa.gov/environmentaljustice/environmental-justice-grants-funding-and-technical-assistance>. Accessed Apr 29, 2021.
- Waeber, R., & Brüsweiler, B. (2002). Richtwert für PCB in der innenraumluft.  
[https://www.bag.admin.ch/dam/bag/de/dokumente/chem/themen-a-z/pcb-richtwert-innenraeume.pdf.download.pdf/20070919\\_PCB\\_Richtwert%20f%C3%BCr%20Innenr%C3%A4ume\\_DE.pdf](https://www.bag.admin.ch/dam/bag/de/dokumente/chem/themen-a-z/pcb-richtwert-innenraeume.pdf.download.pdf/20070919_PCB_Richtwert%20f%C3%BCr%20Innenr%C3%A4ume_DE.pdf). Accessed April 17, 2021.
- Wang, H., Adamcakova-Dodd, A., Flor, S., Gosse, L., Klenov, V. E., Stolwijk, J. M., Lehmler, H., Hornbuckle, K. C., Ludewig, G., Robertson, L. W., & Thorne, P. S. (2020). Comprehensive Subchronic Inhalation Toxicity Assessment of an Indoor School Air Mixture of PCBs. *Environmental Science & Technology*, 54(24), 15976-15985, doi: 10.1021/acs.est.0c04470.
- Weitekamp, C. A., Phillips, L. J., Carlson, L. M., DeLuca, N. M., Cohen Hubal, E. A., & Lehmann, G. M. (2021). A State-of-the-Science Review of Polychlorinated Biphenyl Exposures at Background Levels: Relative Contributions of Exposure Routes. *Science of The Total Environment*, 776, 145912, doi: <https://doi.org/10.1016/j.scitotenv.2021.145912>.
- Wilson, P., (2020). U.S. Environmental Protection Agency, Toxicologist, Land, Chemicals and Redevelopment Division, San Francisco, CA Personal Communication.

Wilson, P., (2021). U.S. Environmental Protection Agency, Toxicologist, Land, Chemicals and Redevelopment Division, San Francisco, CA Personal Communication.

## XV. Appendix

1. Interview with Geniece Lehmann 9-14-2020 (Lehmann, US EPA, per. comm.)

### PCB Transcript with Geniece Lehmann 9-14-2020

- Affiliation and title: United States Environmental Protection Agency Office of Research and Development Toxicologist
- Contact information: lehmann.geniece@epa.gov
- Disclaimer: This interview has been condensed for clarity.

### Geniece Lehmann:

1. PCB regulations were established in 1979. At the time of establishment, there was not really any health data and health risks available and so the EPA used a very low conservative screening value.
2. Today, people argue that the EPA published value is not a health-based value and will cost a lot of money to take samples, remove materials, replace functions, or rebuild, etc.
  - a. There isn't any demonstration of PCBs in the caulk, etc. is causing health effects and it isn't clear how those health levels are translated to PCB air levels, which are proximal measures for whether it will cause health effects. Thus, making it difficult to enforce the regulations. This is a disincentive to get screening completed.
3. As buildings age and materials deteriorate, more PCBs are released into the air. The current EPA PCB regulations may not accurately reflect what screening levels could be today. Exposure conditions were different 40 years ago. It's not until deterioration, like leaking light ballasts, occurs that people are now worried and want to clean that up and screen for PCB levels. There is also a push back from those same groups of people that screenings/inspections may not even need to be completed because there doesn't seem to be any health effects being displayed in the current cohorts.
4. Even if you have the same levels of total PCBs at 2 different schools, it doesn't mean that the health risks are the same because the congeners that are present may be different. This makes it hard for EPA to regulate PCBs.
5. The current levels listed in EPA regulations are set at the limit of detection based on the best available assay at the time – therefore, with the analytical equipment they have available at the time, the standard limit was based on the detection limit so if we can't detect it below this limit, then there's no point in setting the standard below that detection limit.
6. Tools used to bridge the gaps between regulation standards set by the EPA 40 years ago until today's updated research: regional screening levels, exposure estimation tool (ways that the agency has attempted in the absence of better information).
  - a. Cancerous and noncancerous tools
  - b. Assessment developed in December 2019
  - c. Currently in progress assessment with IRIS
  - d. Values for cancerous and noncancerous
7. If EPA develops a reference value for PCBs (slope factor or reference dose), another group will take that value and apply it to a given population, so they will do all the measuring of PCBs in the environment and figuring out what the exposures are. The only thing they will say about the reference value is that they used this slope factor or reference dose. They won't say what went into developing that or what the health effects or different experiments or what the reference dose



was characterized. They will just say reference dose use and the paper will end up being about PCB measurements, what the populations' habits are and their exposures, and then the exposures compared to the reference value, but not the background because they just reference it and you'd have to look at the IRIS assessment or toxicological profile.

8. In Ethiopia or other countries, they do not have a centralized procedure usually. Most countries will use WHO's developed values.
9. EPA does have reference values for PCBs, but they are not what the regulation is based on.
  - a. Why are we still regulating at x ppb of PCBs for building materials when we do have reference values that came out 20-30 years after the regulation was established?
10. People are criticizing that EPA regulations for PCBs in schools have not been applied evenly across the US because they are managed regionally.

2. Interview with Patrick Wilson 9-14-2020 (Wilson, US EPA, per. comm. September 14, 2020)

#### Q&A Formal Interview with Patrick Wilson 9-15-2020

- Affiliation and title: United States Environmental Protection Agency Region 9 Toxicologist
  - Contact information: Wilson.patrick@epa.gov
  - Disclaimer: This interview has been condensed for clarity.
1. What is IRIS and how does it work?
    - a. IRIS stands for the Integrated Risk Information System. It is considered EPA's gold standard peer-reviewed source of toxicity information for chemicals, chemical hazards, toxic chemicals. It is the primary database that the EPA uses to understand potency and toxicity of different chemicals, and the health effects or adverse health impacts that those chemicals cause when they're exposed to humans, via different routes. It is a public database, but it is maintained by the EPA.
  2. How do you incorporate the exposure estimation tool into determining a human health risk?
    - a. The toxicity criteria or toxicity information that its in our IRIS database for PCBs is incorporated into the exposure estimation tool. The exposure estimation tool is a tool that allows and helps us to estimate the degree or level of PCB exposure in various settings. In order to understand the health risk of that exposure, we need that toxicity information from the IRIS database. In combination, the IRIS database and the exposure estimation allows individuals to come up with an estimate of PCB exposure in a particular setting and what would be the risk or the likelihood of PCB developing diseases from that kind of exposure.
  3. Could you describe the scientific connection of ingestion route to inhalation route extrapolation?
    - a. As a general proposition, EPA does not encourage route to route extrapolation, which means if we have toxicity data or information from one route of exposure, then we generally don't recommend extrapolating that type of detail for another route of exposure. The major routes of exposure for humans and toxic chemicals, and that's ingestion (oral exposure), inhalation of chemicals into lungs, or direct dermal contact. If we have toxicity information for a particular chemical that was obtained using one route,

as a general proposition, EPA does not recommend extrapolating that information for another route.

- b. Under certain circumstances when there is a high priority need, EPA does allow that route to route extrapolation to occur under certain conditions. There has to be a lack of toxicity information available. Those conditions include the following. The first being does the chemical or toxic agent have a portal of entry effect? A portal of entry effect is like when an acid is in the air and you directly inhale it and it burns your lungs because the lungs are the portal to the entry of the body. By inhaling that acid as a gas, you would directly damage your lungs. If you ingest that acid, it would have a different impact. It could burn your stomach or GI tract. The chemical has a direct impact on the portal of entry. If we have a chemical that does that, then EPA does not recommend using route to route extrapolation. PCBs do not behave that way and so they do not have a portal of entry effect. Therefore, it allows us to think about conducting a route to route extrapolation.
  - c. The second condition asks are the chemicals expected to have two different toxicities by the two different routes? The toxicity of PCBs is not really expected to vary based on the route of entry. Why do we think that? PCBs are well absorbed when they are inhaled, ingested via the stomach, and they absorb decently across the skin barrier as well. The fact that they are absorbed uniformly well and distributed systemically(very effectively) in the blood circulation leads us to believe that the toxicity does not differ remarkably based on the different routes of exposure.
  - d. The third condition is a first passed effect. When we ingest anything, whether it's a chemical, drug, or food, our liver metabolizes or changes that substance in an effort to make it more water soluble. Our body does that because it is an effort to facilitate excretion of the chemical, of the substance, of the toxin, or of the food. For some substances like PCBs, when you ingest them and they are subject to metabolism by the liver, we call that a first passed effect because the liver changes the PCBs when it metabolizes them into different forms/constituents within the body. If that occurs when you ingest PCBs, but does not occur when you inhale PCBs, then you have a problem because there is a difference between how PCBs are managed by the body during your liver metabolizing the ingested PCBs. With PCBs, it seems that whether they are ingested or inhaled by oral exposures, there is a similar metabolic pathway for each exposure route. So there are no first pass effects with PCBs from ingestion and that allows us more confidence in doing a route to route extrapolation from ingestion to inhalation.
  - e. This does not apply to other surrogate SVOCs that behave similarly so that there may be more information upon.
4. What do inspectors do when they go to a site for a risk assessment and which reference values do they use?
- a. EPA does not send inspectors out to sites to do risk assessments. In our section (referencing the work we do in our specific RCRA LCRD section – Corrective Action), typically what happens is that in the risk-based approvals, there will be some sort of risk analysis within the approval to come up with the cleanup level. The cleanup level would be protective of residential scenario, commercial worker scenario, recreational scenario, or something with how the land will be used in the future. This is all part of the PCB

cleanup application and the application should include some sort of risk analysis. The staff will review the risk assessment to make sure it's conducted in a way that is consistent with EPA's recommended methods of procedures and practices. If the EPA project manager (PM) and the toxicologist agree upon the number in the risk assessment, like the PCB should be cleaned down till 1 ppm, then the EPA PM will approve of the application. At some point, the work at the site will actually be done and the responsible party (RP) will dig up all of the contaminated soil/building material and remove it until the agreed upon cleanup value in the application. When the work has been completed, the work must be submitted to the EPA in the form of a completion report. The completion report should detail all of the actions that were taken and how the RP verified that the cleanup achieved the cleanup goals. That cleanup verification report is also consistent with the tenancy of the risk assessment. Then, the cleanup verification report is evaluated by the EPA PM, toxicologist, and anyone else necessary. Once everyone is okay with the cleanup verification report, then the RP receives an approval.

- b. The EPA relies on the RP and the RP has to certify under penalties of perjury and penalties of TSCA that they have conducted the work consistent with the application. Once they have sent the completion report to the EPA PM and the PM has approved it, then we believe the site has achieved the remedial goals.
5. What challenges did you face with Malibu High School?
    - a. EPA's most significant challenge had to do with the lack of toxicity information of PCBs when they are inhaled. The principal exposure to PCBs is via inhalation. In the absence of good inhalation data, that was a significant challenge. Another challenge within buildings is PCB contaminated dust on nonporous surfaces. That dust came from PCB building materials within the structure, such as caulk and paint that has chipped off in the window of time and has settled as dust on a horizontal surface. In addition to not having inhalation data to understand how toxic or potent PCBs are when they are inhaled, the EPA did not have solid risk-based criteria for evaluating PCBs as dust on surfaces. How much dust is too much if you have a child sitting and working at that desk and is exposed to that PCB contaminated dust throughout the school day? Is it 1 ug, 20 ug? How much PCBs in the dust is too much in a scenario like that? So EPA had to figure that out and there is a number in the regulations for PCB contaminated dust, but that number is not considered to be health-based. It is considered to be a regulatory number. It is 10 ug of PCBs per 100cm<sup>3</sup>. So EPA had to establish a PCB workgroup in the agency to come up with a health-based number for dust in schools and on surfaces.
    - b. The numbers that we have for school air was developed and peer reviewed by that science workgroup, and the numbers that were developed for dust were also developed by the workgroup, but are still undergoing peer review.
  6. If Congress were to rebudget and EPA decided that we wanted to address airborne PCBs within buildings as a top concern, where do you think EPA would start first?
    - a. Patrick believes that EPA would probably start first in schools because schools have a number of sensitive individuals that is children. A number of schools were built before the PCB regulations took place (late 1970s) and the schools would provide the EPA to go after a relatively defined universe. This is more specific than going after commercial buildings built before the late 1977-78, then which are more likely to have PCB-

containing building materials. That would be a pretty significant challenge so it would probably be a little easier for the EPA to get their arms around schools because of their discrete nature, and the fact that schools have children on a routine and typical basis whereas commercial structures may or may not.

7. Do you think it would ever be realistic for EPA to send contractors out to test schools for PCB detections?
  - a. Senior management at the EPA may try to staff those inspections with federal workers or federal contract workers, but there is technically or scientifically to prevent contractors that we at EPA would be able to do in that setting.
  - b. School districts don't have environmental professionals, such toxicologists and PMs, on staff that are familiar with cleanup of toxic materials. They prioritize other things and this beyond their reach. Like Santa Monica's Malibu High School did, school district would contract out to an environmental consulting group. These groups would represent the school district's interests back to EPA, conduct the work (cleanup, remedial, sampling, and analysis) on behalf of the school district, and provide all of that information back to EPA under the cover for the school district. Hiring these consultants are expensive and would result in resource implications like if EPA were to do something like that, for example, 50 FTE (full time employees) to do that.
8. If there were more inhalation studies available, how do you think the tools we have today would change, aside from adjusting estimations?
  - a. The tools may not change, but the EPA's confidence in the results or the findings from the tools would have less uncertainty and more confidence in the predictions that the EPA tools are providing. Personally, Patrick feels that these numbers in the tools may not be stricter because PCBs are more toxic when ingested versus inhaled. He feels that way but doesn't have the toxicology studies to support that.
9. How do we tell the difference between a PCB site addressed by DTSC vs EPA Region 9?
  - a. PCBs are one of the few chemicals that are regulated under the Toxic Substances Control Act that is not delegated down towards the states. The other laws that Patrick and I implement in our division, such as the Resource, Conservation, and Recovery Act, the state of California, Nevada, and Arizona are delegated by EPA to also implement RCRA. Therefore, there is federal implementation of RCRA and state implementation of RCRA. For TSCA, the one that governs PCBs, for one reason or another, that law has not been delegated down towards the states and EPA retains authority to implement that law. Since PCBs are regulated under TSCA, that means EPA regulates PCBs.
  - b. However, that doesn't prevent a state from regulating PCBs because the state of California considers PCBs a hazardous waste. EPA only considers PCBs to be a hazardous waste if they are above 50 ppm. The states can also regulate them usually under a different statute. California regulates PCBs as a hazardous waste under RCRA and California cleans PCBs up with RCRA authorities, but since the federal government retains the authority for TSCA, EPA has to have a say.
  - c. DTSC's role in this come from other constituents/toxic chemicals being released at the same site PCBs have been released as well. It is very rare that one our PCB sites is only PCBs. They usually also include chrome, lead, TCE, another solvent, or something like that. Many sites that we at EPA will come in contact with include other toxic chemicals

that DTSC will be cleaning up under RCRA or CERCLA. We, federal EPA, will be cleaning up PCBs under TSCA. This is us working in conjunction with states.

10. Have you had to personally work with DTSC in managing PCB sites?
  - a. Yes, Patrick has. In fact, DTSC has produced a HERO note. DTSC has a whole office of toxicologists, called the Human and Ecological Risk Office, and they produce these guidance documents that are called HERO notes. In the notes for PCBs, you will see that DTSC thanks both Patrick Wilson and Carmen Santos for helping DTSC come up with their strategies for approaching PCBs, including which analytical methods to use, congeners versus Aroclors, what are the appropriate cleanup levels, residential RSLs (regional screening levels) versus industrial RSLs. Thus, EPA does help DTSC with guidance on best practices and approaches. This also applies with Arizona's ADEQ, Nevada's NDEP, and Hawaii's HDOH.
3. Follow-up interview with Patrick Wilson 4-6-2021 (Wilson, US EPA, per. comm. April 6, 2021)

#### Follow-Up Interview with Patrick Wilson 4-6-2021

- Affiliation and title: United States Environmental Protection Agency Region 9 Toxicologist
  - Contact information: Wilson.patrick@epa.gov
  - Disclaimer: This interview has been condensed for clarity.
1. How were these regional screening levels developed for Region 9?
    - a. The regional screening levels, as they are known now, were preceded by a similar group of tables called the preliminary remediation goals or PRGs. When I say preceded, what I mean by that is that back in the early 90's, around 1992-93, two regional offices, specifically Region 9 and Region 3, came up or derived a standard set of tables that use the toxicity information for all the chemicals that EPA regulates to arrive at concentrations for these chemicals that were safe in soil, air or water. These tables were called PRGs, and those tables look like our regional screening levels tables today. Those PRG tables remained in existence until approximately the mid-2000's. They were updated once a year by toxicologists at Region 9 and Region 3. By 1995, the toxicologist at Region 3 retired and the toxicologist at Region 9 took on responsibility for updating the PRGs on an annual basis. These PRGs were used by all 10 regional offices to help people understand the concentrations were safe in air, water, and soil for the chemical that we regulate.
    - b. At some point, EPA headquarters called these tables preliminary remediation goals. Not only are all 10 EPA regions are using them for cleanup, to support the cleanup and permitting programs, but we were also getting calls from different countries. With the internet available, these other countries were using these tables as cleanup guidelines for air, water, and soil. Because these tables now had widespread use, internationally, EPA headquarters felt that we should rename these PRGs as regional screening levels. EPA headquarters decided to take ownership from Region 9 and be responsible for updating the regional screening levels tables twice a year rather than once a year. Now, different EPAs throughout the world uses them.
  2. Why are these tables called Regional Screening Levels?

- a. Let's go back to preliminary remediation goals. Where did this name come from? EPA derived these tables in such a way that if you achieve this concentration for that particular contaminant in soil, air or water, then we knew it was so little of a contaminant that it was likely to be safe. When I say likely I mean likely with a fair amount of significance. When we clean up soils in a residential setting to the PRG, those soils may not be safe to grow food in and eat for the rest of your life, but those soils are safe from that particular contaminant for the typical uses of residential soil. Most residential soils are not used to grow food.
  - b. These same PRG tables are used by all ten regional offices in their cleanup programs. When I say cleanup programs, I mean like our PCB cleanup program RCRA Corrective Action cleanup program, and Superfund program. All the project managers in these cleanup programs use the information that is provided in those tables to come up with a level that's clean, a cleanup level. The project managers would tell the responsible party to remove in one shape or another, all the contamination at your site in order to meet these preliminary remediation goals or the numbers within those tables.
  - c. If you want to hire a toxicologist and do a more site-specific analysis, to come up with a different number that may be different than the number in the PRG tables, then you can do that. We allow you to do that in the cleanup programs. If you are not willing to do that and you just need to know how clean is clean, then the EPA has these PRG tables that provide all that information for what level is considered clean. These tables are used by all 10 regional offices.
  - d. Today, we call these tables regional screening levels. A screening level is a little bit different in concept to a remediation goal or cleanup goal. An EPA project manager may have up to forty sites that they may be responsible for at one time, with respect to cleanup or permitting. All of those sites have a different mix of chemical contamination. A project manager like that, in the cleanup programs, needs a table where they can quickly look up a number for a specific chemical and find out if that chemical is present at high, medium, or low level. A low level would be so low that it is safe and we shouldn't even worry about it or prioritize agency resources to do something about it. These RSL tables provide that level of detail. The concept behind this idea of a regional screening level is that these numbers are now considered to be so safe, that if or when you evaluate your site, if the concentrations are below these levels, then the project managers in cleanup programs don't have to pay attention to those sites, or that portion of the site, because the level of contamination is below a level of concern. The level of concern can be found in the regional screening level. This allows project managers to screen out a whole bunch of sites for additional work, consideration, or priority. This allows you as a project manager to focus your attention and the agency's resources on the sites that have the greatest amount of health risk or vulnerability.
3. Why isn't there a more universal value that all regulatory agencies apply to? Why do some organizations have a more conservative value?
    - a. The EPA strongly believes in the process that it uses to derive these values. That process is predicated on EPA understanding the toxicity or the potency of the vast number of chemicals that are found or contained in these tables.

- b. So how do we arrive as an agency at that understanding of how toxic chemical X or chemical Y is? Well, it's pretty elaborate. It takes several years and it involves several scientists in different parts of the agency. EPA has a separate Office of Research and Development, or ORD, and a portion of this office dedicates its efforts entirely to understanding the hazards associated with toxic chemicals. EPA has an elaborate peer review process, where other scientists with expertise in this scientific chemical are invited and included in the review of the material that EPA produces. EPA's process frequently involves going before an independent science advisory board with these types of analyses. The science advisory board is composed of scientists and people from the academic community from different universities and organizations throughout the country that can take a look at this work and provide peer review. The EPA is then responsible for commenting and replying to the peer review.
- c. The take home message from our side of the house is that EPA is confident in its process that is used to arrive at decisions regarding the toxicity of these chemicals. That process also includes a round of not only interagency review, but also an external peer review, in which the research is sent to the Center for Disease Control, the Agency for Toxic Substances and Disease Registry, the Occupational Safety and Health Administration, or our scientific colleagues at the National Institutes of Health. Therefore, there is a level of federal and state government that is sometimes or frequently incorporated into our process.

4. Tables 6-16

Table 6 (EPA and PCBs 2009). Dust ingestion mathematical model to calculate the average daily dose of dust ingestion according to each age group.  $C_{dust}$  ( $\mu\text{g/g}$ ) is the only variable that can be altered whereas all other variables are constants.

<b>Dust Ingestion: <math>ADD_{dust} = (C_{dust} \times IngR_{dust} \times Fians \times CF \times ABS_{dust-soil}) / BW</math></b>	
<b>Variable (units)</b>	<b>Variable Description</b>
$ADD_{dust}$ ( $\mu\text{g/kg-day}$ )	Average daily dose
$C_{dust}$ ( $\mu\text{g/g}$ )	Dust concentration
$IngR_{dust}$ (mg/day)	Dust ingestion rate
Fians (unitless)	Fraction of indoor awake time (over a year) not spent at school
CF (g/1,000 mg)	Conversion Factor

ABS <sub>dust-soil</sub> (fraction)	Relative absorption factor
BW (kg)	Body weight

Table 7 (EPA and PCBs 2009). Soil ingestion mathematical model to calculate the average daily dose of soil ingestion according to each age group. C<sub>soil</sub> (µg/g) is the only variable that can be altered whereas all other variables are constants.

<b>Dust Ingestion: <math>ADD_{soil} = (C_{soil} \times IngR_{soil} \times Fotns \times CF \times ABS_{dust-soil}) / BW</math></b>	
<b>Variable (units)</b>	<b>Variable Description</b>
ADD <sub>soil</sub> (µg/kg-day)	Average daily dose
C <sub>soil</sub> (µg/g)	Soil concentration
IngR <sub>soil</sub> (mg/day)	Soil ingestion rate
Fotns (unitless)	Fraction of outdoor time (over a year) not spent at school
CF (g/1,000 mg)	Conversion Factor
ABS <sub>dust-soil</sub> (fraction)	Relative absorption factor
BW (kg)	Body weight

Table 8 (EPA and PCBs 2009). Indoor inhalation mathematical model to calculate the average daily dose of PCB inhalation of indoor air according to each age group. C<sub>air-indoor</sub> (ng/m<sup>3</sup>) is the only variable that can be altered whereas all other variables are constants.

<b>Outdoor Inhalation: <math>ADD_{inhalation-indoor} = (C_{air-indoor} \times IR \times Ftins \times CF_1 \times ABS_{air}) / BW</math></b>	
<b>Variable (units)</b>	<b>Variable Description</b>
ADD <sub>inhalation-indoor</sub> (µg/kg-day)	Average daily dose



$C_{\text{air-indoor}}$ (ng/m <sup>3</sup> )	Air concentration
IR (m <sup>3</sup> /day)	Inhalation rate
F <sub>tins</sub> (unitless)	Fraction of total time (over a year) spent indoors not at school
CF <sub>1</sub> (μg/1,000 ng)	Conversion Factor 1
ABS <sub>air</sub> (fraction)	Relative absorption factor
BW (kg)	Body weight

Table 9 (EPA and PCBs 2009). Outdoor inhalation mathematical model to calculate the average daily dose of PCB inhalation of outdoor air according to each age group.  $C_{\text{air-outdoor}}$  (ng/m<sup>3</sup>) is the only variable that can be altered whereas all other variables are constants.

<b>Outdoor Inhalation: <math>ADD_{\text{inhalation-outdoor}} = (C_{\text{air-outdoor}} \times IR \times F_{\text{ttons}} \times CF_1 \times ABS_{\text{air}}) / BW</math></b>	
<b>Variable (units)</b>	<b>Variable Description</b>
$ADD_{\text{inhalation-outdoor}}$ (μg/kg-day)	Average daily dose
$C_{\text{air-outdoor}}$ (ng/m <sup>3</sup> )	Air concentration
IR (m <sup>3</sup> /day)	Inhalation rate
F <sub>ttons</sub> (unitless)	Fraction of total time (over a year), spent outdoors not at school
CF <sub>1</sub> (μg/1,000 ng)	Conversion Factor 1
ABS <sub>airl</sub> (fraction)	Relative absorption factor
BW (kg)	Body weight

Table 10 (EPA and PCBs 2009). Dermal absorption mathematical model to calculate the average daily dose of PCB dermal absorption from indoor dust contact in background exposure according to each age group.  $C_{\text{dust}}$  ( $\mu\text{g/g}$ ) is the only variable that can be altered whereas all other variables are constants.

<b>Dermal Absorption: <math>\text{ADD}_{\text{dermal}} = (C_{\text{dust}} \times \text{Ad} \times \text{SA} \times \text{CF} \times \text{ABS}_{\text{dermal}}) / \text{BW}</math></b>	
<b>Variable (units)</b>	<b>Variable Description</b>
$\text{ADD}_{\text{dermal}}$ ( $\mu\text{g/kg-day}$ )	Average daily dose
$C_{\text{dust}}$ ( $\mu\text{g/g}$ )	Dust concentration
Ad ( $\text{mg/cm}^2\text{-day}$ )	Dust to skin adherence
SA ( $\text{cm}^2$ )	Skin contact area
CF ( $\text{g}/1,000 \text{ mg}$ )	Conversion Factor
$\text{ABS}_{\text{dermal}}$ (fraction)	Relative absorption factor
BW (kg)	Body weight

Table 11 (EPA and PCBs 2009). Dietary ingestion is a constant that in background exposure and is adjusted according to each age group.  $C_{\text{dust}}$  ( $\mu\text{g/g}$ ) is the only variable that can be altered whereas all other variables are constants.

<b>Dietary Ingestion: <math>\text{ADD}_{\text{food}}</math></b>	
<b>Variable (units)</b>	<b>Variable Description</b>
$\text{ADD}_{\text{food}}$ ( $\mu\text{g/kg-day}$ )	Average daily dose

Table 12 (EPA and PCBs 2009). Dust ingestion mathematical model to calculate the average daily dose of dust ingestion according to each age group.  $C_{\text{dust}}$  ( $\mu\text{g/g}$ ) is the only variable that can be altered whereas all other variables are constants.

<b>Dust Ingestion: <math>ADD_{dust} = (C_{dust} \times IngR_{dust} \times Fias \times CF \times ABS_{dust-soil}) / BW</math></b>	
<b>Variable (units)</b>	<b>Variable Description</b>
$ADD_{dust}$ ( $\mu\text{g}/\text{kg}\text{-day}$ )	Average daily dose
$C_{dust}$ ( $\mu\text{g}/\text{g}$ )	Dust concentration
$IngR_{dust}$ ( $\text{mg}/\text{day}$ )	Dust ingestion rate
Fias (unitless)	Fraction of indoor awake time (over a year) spent at school
CF ( $\text{g}/1,000 \text{ mg}$ )	Conversion Factor
$ABS_{dust-soil}$ (fraction)	Relative absorption factor
BW (kg)	Body weight

Table 13 (EPA and PCBs 2009). Soil ingestion mathematical model to calculate the average daily dose of soil ingestion according to each age group.  $C_{soil}$  ( $\mu\text{g}/\text{g}$ ) is the only variable that can be altered whereas all other variables are constants.

<b>Dust Ingestion: <math>ADD_{soil} = (C_{soil} \times IngR_{soil} \times Fots \times CF \times ABS_{dust-soil}) / BW</math></b>	
<b>Variable (units)</b>	<b>Variable Description</b>
$ADD_{soil}$ ( $\mu\text{g}/\text{kg}\text{-day}$ )	Average daily dose
$C_{soil}$ ( $\mu\text{g}/\text{g}$ )	Soil concentration
$IngR_{soil}$ ( $\text{mg}/\text{day}$ )	Soil ingestion rate
Fots (unitless)	Fraction of outdoor time (over a year) spent at school
CF ( $\text{g}/1,000 \text{ mg}$ )	Conversion Factor

ABS <sub>dust-soil</sub> (fraction)	Relative absorption factor
BW (kg)	Body weight

Table 14 (EPA and PCBs 2009). Indoor inhalation mathematical model to calculate the average daily dose of PCB inhalation of indoor air according to each age group. C<sub>air-indoor</sub> (ng/m<sup>3</sup>) is the only variable that can be altered whereas all other variables are constants.

<b>Outdoor Inhalation: <math>ADD_{\text{inhalation-indoor}} = (C_{\text{air-indoor}} \times IR \times F_{\text{ttis}} \times CF_1 \times ABS_{\text{air}}) / BW</math></b>	
<b>Variable (units)</b>	<b>Variable Description</b>
ADD <sub>inhalation-indoor</sub> (µg/kg-day)	Average daily dose
C <sub>air-indoor</sub> (ng/m <sup>3</sup> )	Air concentration
IR (m <sup>3</sup> /day)	Inhalation rate
F <sub>ttis</sub> (unitless)	Fraction of total time (over a year) spent indoor at school
CF <sub>1</sub> (µg/1,000 ng)	Conversion Factor 1
ABS <sub>air</sub> (fraction)	Relative absorption factor
BW (kg)	Body weight

Table 15 (EPA and PCBs 2009). Outdoor inhalation mathematical model to calculate the average daily dose of PCB inhalation of outdoor air according to each age group. C<sub>air-outdoor</sub> (ng/m<sup>3</sup>) is the only variable that can be altered whereas all other variables are constants.

<b>Outdoor Inhalation: <math>ADD_{\text{inhalation-outdoor}} = (C_{\text{air-outdoor}} \times IR \times F_{\text{ttos}} \times CF_1 \times ABS_{\text{air}}) / BW</math></b>	
<b>Variable (units)</b>	<b>Variable Description</b>
ADD <sub>inhalation-outdoor</sub> (µg/kg-day)	Average daily dose

$C_{\text{air-outdoor}}$ (ng/m <sup>3</sup> )	Air concentration
IR (m <sup>3</sup> /day)	Inhalation rate
F <sub>ttos</sub> (unitless)	Fraction of total time (over a year) spent outdoor at school
CF <sub>1</sub> (μg/1,000 ng)	Conversion Factor 1
ABS <sub>airl</sub> (fraction)	Relative absorption factor
BW (kg)	Body weight

Table 16 (EPA and PCBs 2009). Dermal absorption mathematical model to calculate the average daily dose of PCB dermal absorption from indoor dust contact in direct school exposure according to each age group.  $C_{\text{dust}}$  (μg/g) is the only variable that can be altered whereas all other variables are constants.

<b>Dermal Absorption: <math>ADD_{\text{dermal}} = (C_{\text{dust}} \times Ad \times SA \times CF \times Fs \times ABS_{\text{dermal}}) / BW</math></b>	
<b>Variable (units)</b>	<b>Variable Description</b>
$ADD_{\text{dermal}}$ (μg/kg-day)	Average daily dose
$C_{\text{dust}}$ (μg/g)	Dust concentration
Ad (mg/cm <sup>2</sup> -day)	Dust to skin adherence
SA (cm <sup>2</sup> )	Skin contact area
CF (g/1,000 mg)	Conversion Factor
F <sub>s</sub> (unitless)	Fraction of year in school
ABS <sub>dermal</sub> (fraction)	Relative absorption factor
BW (kg)	Body weight