An overview of research into the sources of PCB air contamination, exposure routes, and human health risk

Keri Hornbuckle
University of Iowa
Iowa City, Iowa

March 9, 2022

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ISRP
IOWA SUPERFUND
RESEARCH PROGRAM

AIRBORNE PCBS: SOURCES, EXPOSURES, TOXICITIES, REMEDIATION

NIH National Institute of Environmental Health Sciences
Superfund Research Program

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THE UNIVERSITY OF IOWA, IOWA CITY, IOWA

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Biomedical Engineering
Biostatistics
Civil & Environmental Engineering
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Interdisciplinary Graduate Program in Human Toxicology
Internal Medicine
Microbiology and Immunology
Occupational & Environmental Health
Pharmaceutical Sciences and Experimental Therapeutics
Pharmacology
Urban & Regional Planning

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WHAT WE THOUGHT WE KNEW

NEW METHODS WERE NEEDED

WHAT WE KNOW NOW

6

WHAT WE THOUGHT WE KNEW (BUT IS NOT TRUE)

1. PCBs are banned from production
2. PCBs are no longer entering the environment
3. PCBs are non-volatile and the vapor phase is not important
4. Living near a PCB waste site is the worst case for human exposure
5. PCBs do not break down or metabolize
6. Diet, and especially fish, is our route of exposure
7. PCBs that bioaccumulate are the major risk to humans
8. PCBs are possible carcinogens

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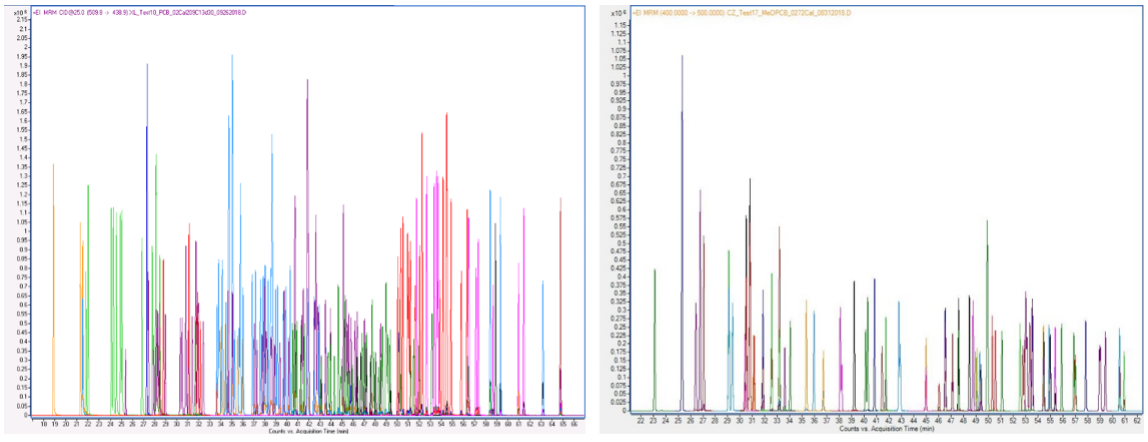

Fig AC-3. Chromatogram of instrument calibration standards for all 209 PCBs, as well as surrogate and internal standards (left) and 72 MeO-PCBs plus surrogate and internal standards (right). Each color represents a different chlorine homolog mass transition and is quantified separately. Separation by triple quadruple mass spectrometry allows discreet identification and quantification of more individual congeners than single quadrupole mass spectrometry can provide.

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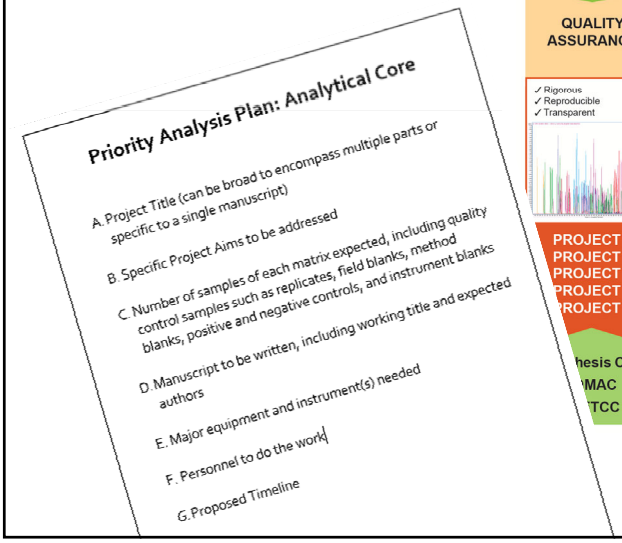
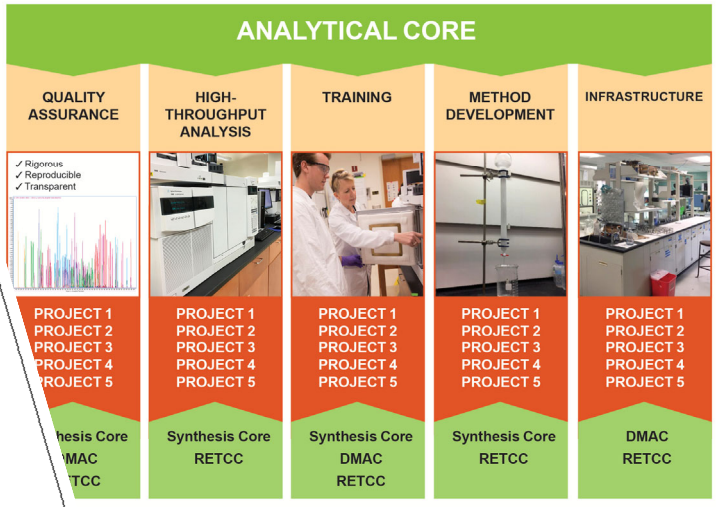
Analytical Core





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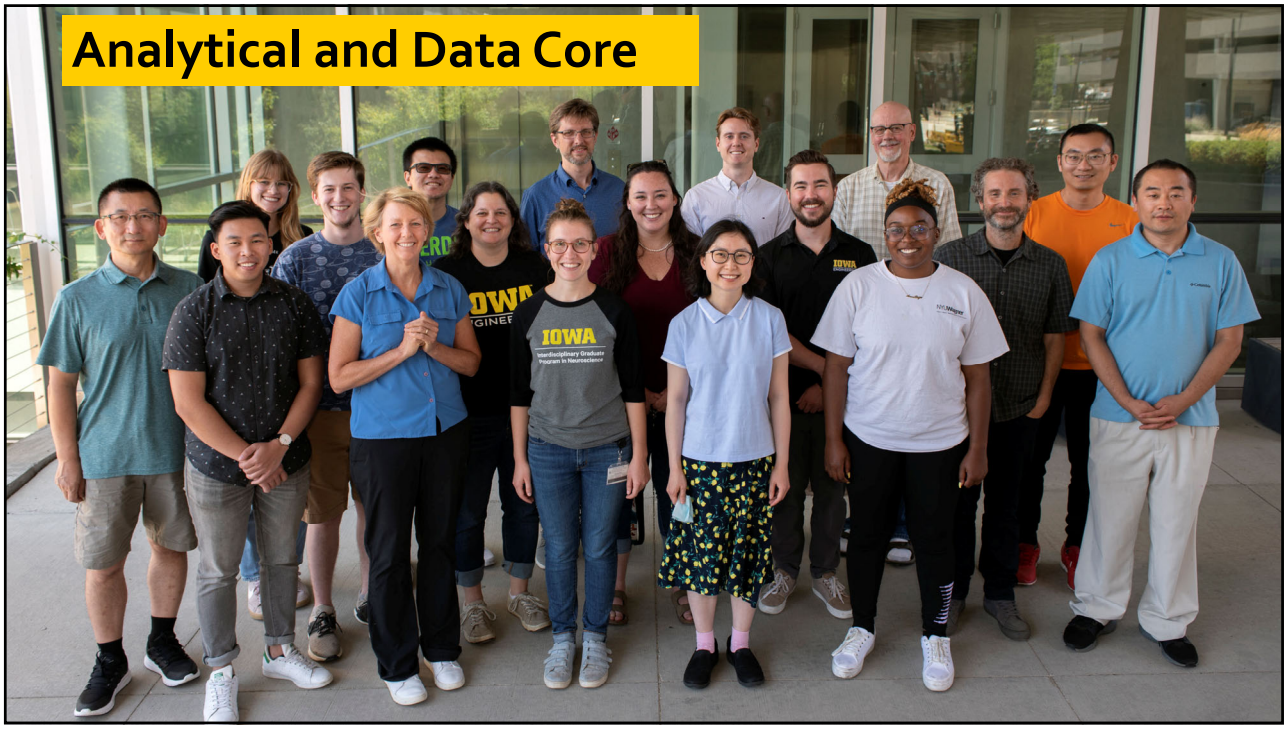

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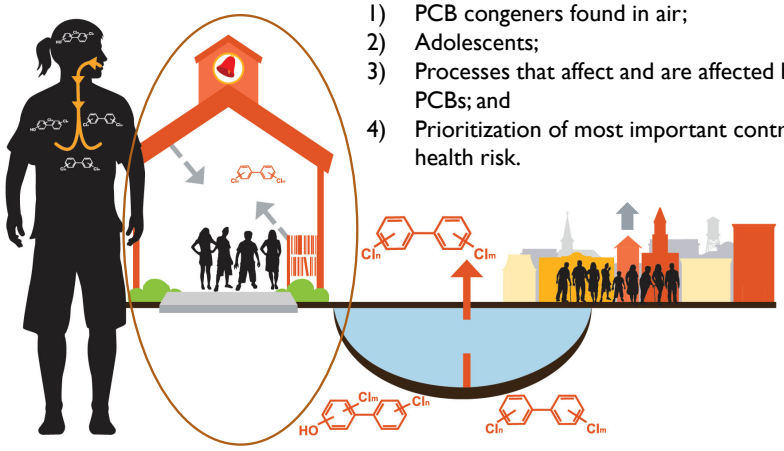
IOWA SUPERFUND RESEARCH PROGRAM



1) PCB congeners found in air;
2) Adolescents;
3) Processes that affect and are affected by the metabolism of PCBs; and
4) Prioritization of most important contributors to human health risk.

Sources, Exposures, Toxicities, and Remediation of Airborne PCBs

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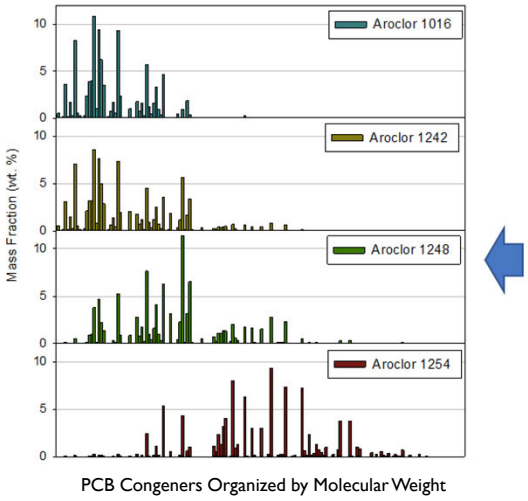
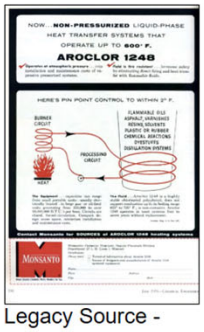
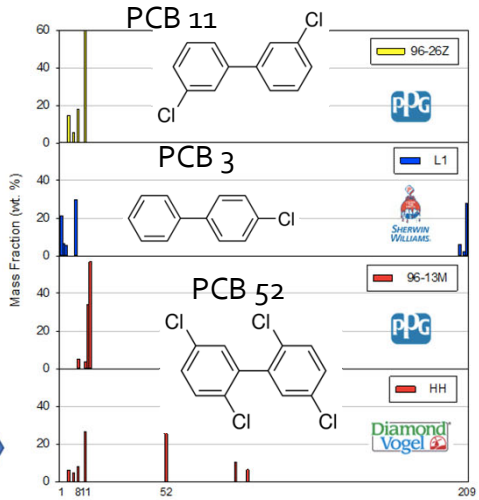


PCB Congeners Organized by Molecular Weight



Legacy Source - Aroclors

Non Legacy Source –



Hu et al, ES&T 2010

PCBs in school air are a combination of Aroclor PCBs, mostly.

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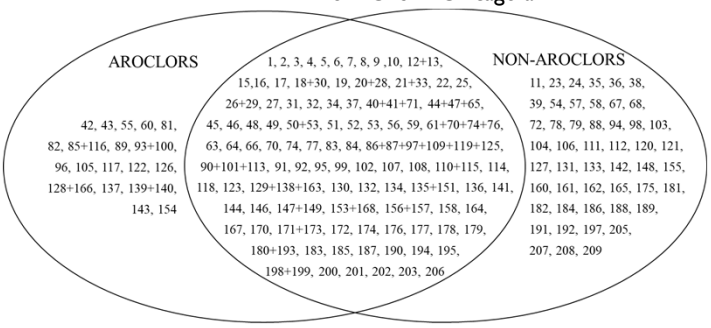
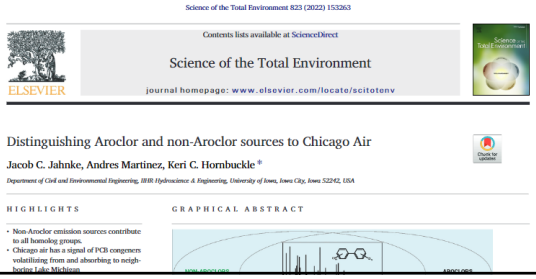
Many of the PCBs in Aroclor are also byproducts of chemical manufacturing

Non-Aroclor sources explain ~15% of PCBs in Chicago air





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ELSEVIER

Distinguishing Aroclor and non-Aroclor sources to Chicago Air

Jacob C. Jahnke, Andres Martinez, Keri C. Hornbuckle *

Department of Civil and Environmental Engineering, IIHR Hydroscience & Engineering, University of Iowa, Iowa City, Iowa 52242, USA

HIGHLIGHTS

- Non-Aroclor emission sources contribute to all homolog groups.
- Chicago air has a signal of PCB congeners volatilizing from and absorbing to neighboring Lake Michigan

GRAPHICAL ABSTRACT

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WHAT WE THOUGHT WE KNEW (BUT IS NOT TRUE)

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8. ~~PCBs are possible carcinogens~~

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ENVIRONMENTAL Science & Technology

Article

pubs.acs.org/est

PCBs and OH-PCBs in Serum from Children and Mothers in Urban and Rural U.S. Communities

Rachel F. Marek,[†,‡] Peter S. Thorne,[†,§,*] Kai Wang,[∥] Jeanne DeWall,[§] and Keri C. Hornbuckle[†,‡,§,*]

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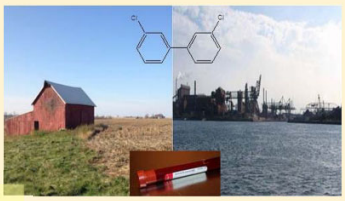
Supporting Information

ABSTRACT: East Chicago, Indiana is a heavily industrialized community bisected by the Indiana Harbor and Ship Canal, which volatilizes ~7.5 kg/yr polychlorinated biphenyls (PCBs). In contrast, the rural Columbus Junction, Iowa area has no known current or past PCB industrial sources. Blood from children and their mothers from these communities were collected April 2008 to January 2009 (n = 177). Sera were analyzed for all 209 PCBs and 4 hydroxylated PCBs (OH-PCBs). Sum PCBs ranged from nondetect to 658 ng/g lw (median = 33.5 ng/g lw). Sum OH-PCBs ranged from nondetect to 1.2 ng/g fw (median = 0.07 ng/g fw). These concentrations are similar to those reported in other populations without high dietary PCB intake. Differences between the two communities were subtle. PCBs were detected in more East Chicago mothers and children than Columbus Junction mothers and children, and children from East Chicago were enriched in lower-molecular weight PCBs. East Chicago and Columbus Junction residents had similar levels of total and individual PCBs and OH-PCBs in their blood. Concentrations of parent PCBs correlated with concentrations of OH-PCBs. This is the first temporally and methodologically consistent study to evaluate all 209 PCBs and major metabolites in two generations of people living in urban and rural areas of the United States.



Environ. Sci. Technol. 2013

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ENVIRONMENTAL Science & Technology

Article

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Airborne PCBs and OH-PCBs Inside and Outside Urban and Rural U.S. Schools

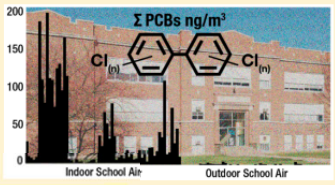
Rachel F. Marek,*[,†] Peter S. Thorne,*[,‡] Nicholas J. Herkert,[†,§] Andrew M. Awad,[†] and Keri C. Hornbuckle*[,†,§]

[†]IIHR-Hydroscience and Engineering and [§]Department of Civil & Environmental Engineering, The University of Iowa, 103 South Capitol Street, 4105 SC, Iowa City, Iowa 52242, United States

[‡]Department of Occupational and Environmental Health, The University of Iowa, 100 CPHB, S341A, 145 N. Riverside Dr., Iowa City, Iowa 52242, United States

Supporting Information

ABSTRACT: PCBs appear in school air because many school buildings were built when PCBs were still intentionally added to building materials and because PCBs are also present through inadvertent production in modern pigment. This is of concern because children are especially vulnerable to the toxic effects of PCBs. Here we report indoor and outdoor air concentrations of PCBs and OH-PCBs from two rural schools and four urban schools, the latter near a PCB-contaminated waterway of Lake Michigan in the United States. Samples (n = 108) were collected as in/out pairs using polyurethane foam passive air samplers (PUF-PAS) from January 2012 to November 2015. Samples were analyzed using GC/MS-MS for all 209 PCBs and 72 OH-PCBs. Concentrations inside schools were 1−2 orders of magnitude higher than outdoors and ranged from 0.5 to 194 ng/m^3 (PCBs) and from 4 to 665 pg/m^3 (OH-PCBs). Congener profiles were similar within each sampling location across season but different between schools and indicated the sources as Aroclors from building materials and individual PCBs associated with modern pigment. This study is the first cohort-specific analysis to show that some children's PCB inhalation exposure may be equal to or higher than their exposure through diet.



INTRODUCTION

been measured in people around the world including children.[2,26−29] Although OH-PCBs are recognized as

Environ. Sci. Technol. 2017

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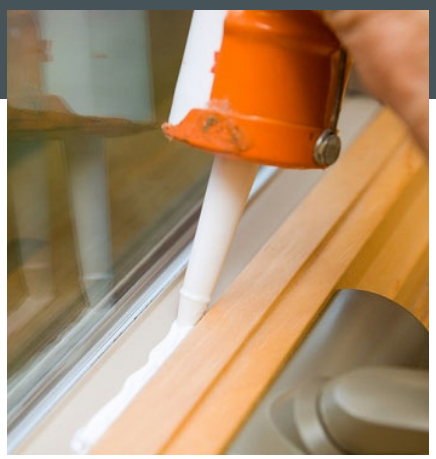
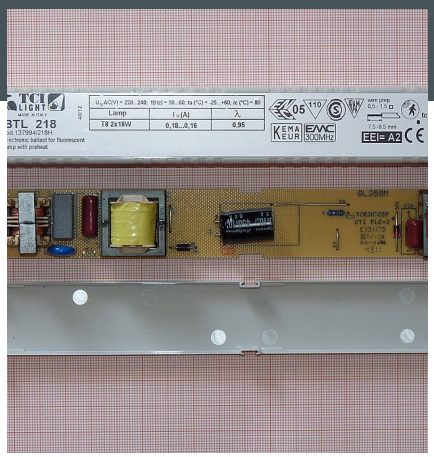


Window Caulking



Light ballast

Aroclor sales directly coincide with the rise of public-school construction from 1950-1980 (55,000 schools).

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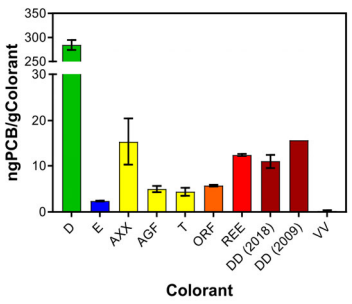
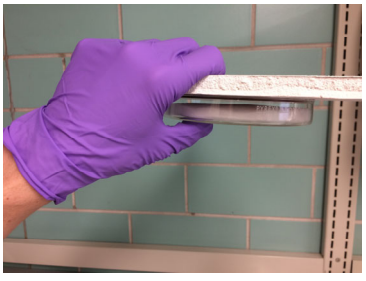
Modern PCBs are unintentionally produced through the production of colorants and cabinet varnishing.





ENVIRONMENTAL Science & Technology

Article

Cite This: Environ. Sci. Technol. 2019, 53, 5187−5194

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PCB Emissions from Paint Colorants

Jacob C. Jahnke and Keri C. Hornbuckle*

Department of Civil & Environmental Engineering, IIHR-Hydroscience and Engineering, The University of Iowa, Iowa City, Iowa 52242, United States

ENVIRONMENTAL Science & Technology

Article

Cite This: Environ. Sci. Technol. 2018, 52, 5154−5160

pubs.acs.org/est

Emissions of Tetrachlorobiphenyls (PCBs 47, 51, and 68) from Polymer Resin on Kitchen Cabinets as a Non-Aroclor Source to Residential Air

Nicholas J. Herkert, Jacob C. Jahnke, and Keri C. Hornbuckle*

Department of Civil and Environmental Engineering, IIHR-Hydroscience and Engineering, The University of Iowa, Iowa City, Iowa 52242, United States

Supporting Information

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The EPA currently does not have a centralized, school-specific plan for airborne PCB remediation. But Vermont does.

Exposure Levels for Evaluating PCBs in School Indoor Air (ng/m3)*

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
100	100	200	300	500	600	500

US. EPA

In 2021, the Vermont legislature required that by 2024 all schools built or renovated prior to 1980 be tested for polychlorinated biphenyls (PCBs) in the indoor air. The Vermont Department of Health (Health) developed school action levels (SALs) to prioritize action when PCBs are found in school indoor air. PCB levels in the indoor air of schools should be kept as low as possible.

The school action levels are:

- 30 ng/m^3 (nanograms per cubic meter) for pre-kindergarten
- 60 ng/m^3 for kindergarten through 6th grade
- 100 ng/m^3 for 7th through 12th grades

State of Vermont, Feb, 2022

26

We used polyurethane foam passive air samplers to measure airborne PCBs in nine classrooms in one school









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ENVIRONMENTAL Science & Technology

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Article

Room-to-Room Variability of Airborne Polychlorinated Biphenyls in Schools and the Application of Air Sampling for Targeted Source Evaluation

Moala K. Bannavti,[†] Jacob C. Jahnke,[†] Rachel F. Marek, Craig L. Just, and Keri C. Hornbuckle*

Cite This: *Environ. Sci. Technol.* 2021, 55, 9460−9468

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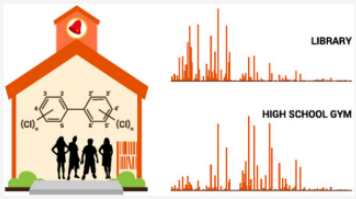
ABSTRACT: Airborne polychlorinated biphenyl (PCB) concentrations are higher indoors than outdoors due to their historical use in building materials and their presence in modern paints and surface treatments. For some populations, including school children, PCB levels indoors result in inhalation exposures that may be greater than or equivalent to exposure through diet. In a school, PCB exposure may come from multiple sources. We hypothesized that there are both Aroclor and non-Aroclor sources within a single school and that PCB concentration and congener profiles differ among rooms within a single building. To evaluate this hypothesis and to identify potential localized sources, we measured airborne PCBs in nine rooms in a school. We found that schoolroom concentrations exceed outdoor air concentrations. Schoolroom concentrations and congener profiles also varied from one room to another. The concentrations were highest in the math room (35.75 ng m^{-3} ± 8.08) and lowest in the practice gym (1.54 ng m^{-3} ± 0.35). Rooms in the oldest wing of the building, originally constructed between 1920 and 1970, had the highest concentrations. The congener distribution patterns indicate historic use of Aroclor 1254 as well as modern sources of non-Aroclor congeners associated with paint pigments and surface coatings. Our findings suggest this noninvasive source identification method presents an opportunity for targeted source testing for more cost-



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ENVIRONMENTAL Science & Technology LETTERS

Letter

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Release of Airborne Polychlorinated Biphenyls from New Bedford Harbor Results in Elevated Concentrations in the Surrounding Air

Andres Martinez,*[,†] Bailey N. Hadnott,[†] Andrew M. Awad,[†] Nicholas J. Herkert,[†] Kathryn Tomsho,[‡] Komal Basra,[‡] Madeleine K. Scammell,[‡] Wendy Heiger-Bernays,[‡] and Keri C. Hornbuckle*[,†]

[†]Department of Civil & Environmental Engineering, IIHR-Hydroscience and Engineering, 4105 Seamans Center for the Engineering Arts and Sciences, The University of Iowa, Iowa City, Iowa 52242, United States

[‡]Department of Environmental Health, Boston University School of Public Health, 715 Albany Street, T4W, Boston, Massachusetts 02118, United States

Supporting Information

ABSTRACT: Qualitatively and quantitatively, we have demonstrated that airborne polychlorinated biphenyl (PCB) concentrations in the air surrounding New Bedford Harbor (NBH) are caused by its water PCB emissions. We measured airborne PCBs at 18 homes and businesses near NBH in 2015, with values ranging from 0.4 to 38 ng m^{-3}, with a very strong Aroclor 1242/1016 signal that is most pronounced closest to the harbor and reproducible over three sampling rounds. Using U.S. Environmental Protection Agency (U.S. EPA) water PCB data from 2015 and local meteorology, we predicted gas-phase fluxes of PCBs from 160 to 1200 μg m^{-2} day^{-1}. Fluxes were used as emissions for AERMOD, a widely applied U.S. EPA atmospheric dispersion model, to predict airborne PCB concentrations. The AERMOD predictions were within a factor of 2 of the field measurements. PCB emission from NBH (110 kg $year^{-1}$, average 2015) is the largest reported source of airborne PCBs from natural waters in North America, and the source of high ambient air PCB concentrations in locations close to NBH. It is likely that NBH has been an important source of airborne PCBs since it was contaminated with Aroclors more than 60 years ago.

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WHAT WE KNOW NOW

- ~~PCBs are banned from production~~
- ~~PCBs are no longer entering the environment~~
- ~~PCBs are non-volatile~~
- ~~Living near a PCB waste site is the worst case for human exposure~~ → School air is a major exposure route
- ~~PCBs do not break down or metabolize~~
- ~~Diet, and especially fish, is our route of exposure~~ → PCB exposure through inhalation is equally important
- ~~PCBs that bioaccumulate are the major risk to humans~~
- ~~PCBs are possible carcinogens~~ → PCBs are hormone disruptors, neurotoxicants, associated with metabolic disease, and are known human carcinogens

30

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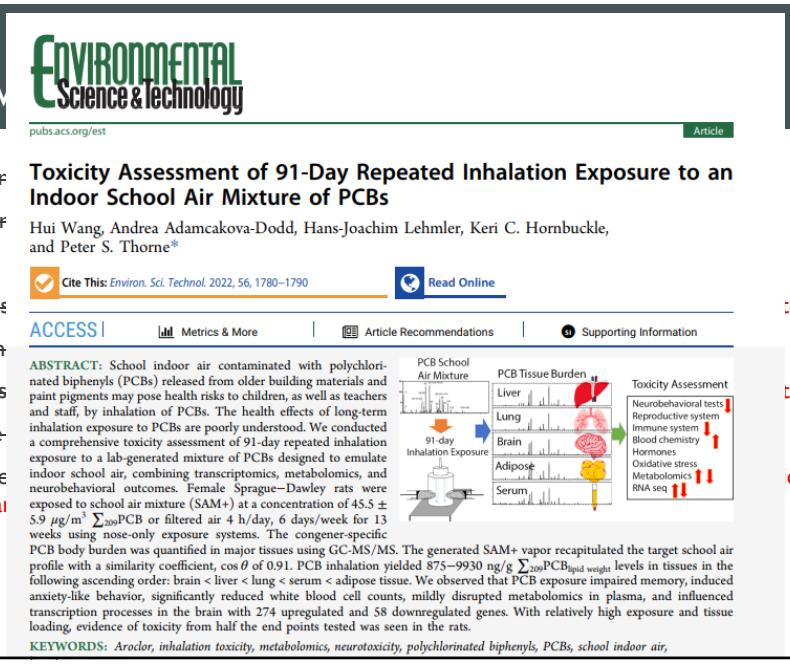

ENVIRONMENTAL Science & Technology

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Toxicity Assessment of 91-Day Repeated Inhalation Exposure to an Indoor School Air Mixture of PCBs

Hui Wang, Andrea Adamcakova-Dodd, Hans-Joachim Lehmler, Keri C. Hornbuckle, and Peter S. Thorne*

Cite This: *Environ. Sci. Technol.* 2022, 56, 1780−1790 Read Online

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ABSTRACT: School indoor air contaminated with polychlorinated biphenyls (PCBs) released from older building materials and paint pigments may pose health risks to children, as well as teachers and staff, by inhalation of PCBs. The health effects of long-term inhalation exposure to PCBs are poorly understood. We conducted a comprehensive toxicity assessment of 91-day repeated inhalation exposure to a lab-generated mixture of PCBs designed to emulate indoor school air, combining transcriptomics, metabolomics, and neurobehavioral outcomes. Female Sprague−Dawley rats were exposed to school air mixture (SAM+) at a concentration of 45.5 ± 5.9 $\mu g/m^3$ $\sum_{209}$PCB or filtered air 4 h/day, 6 days/week for 13 weeks using nose-only exposure systems. The congener-specific PCB body burden was quantified in major tissues using GC-MS/MS. The generated SAM+ vapor recapitulated the target school air profile with a similarity coefficient, cos θ of 0.91. PCB inhalation yielded 875−9930 ng/g $\sum_{209}PCB_{lipid\ weight}$ levels in tissues in the following ascending order: brain < liver < lung < serum < adipose tissue. We observed that PCB exposure impaired memory, induced anxiety-like behavior, significantly reduced white blood cell counts, mildly disrupted metabolomics in plasma, and influenced transcription processes in the brain with 274 upregulated and 58 downregulated genes. With relatively high exposure and tissue loading, evidence of toxicity from half the end points tested was seen in the rats.

KEYWORDS: *Aroclor, inhalation toxicity, metabolomics, neurotoxicity, polychlorinated biphenyls, PCBs, school indoor air,*

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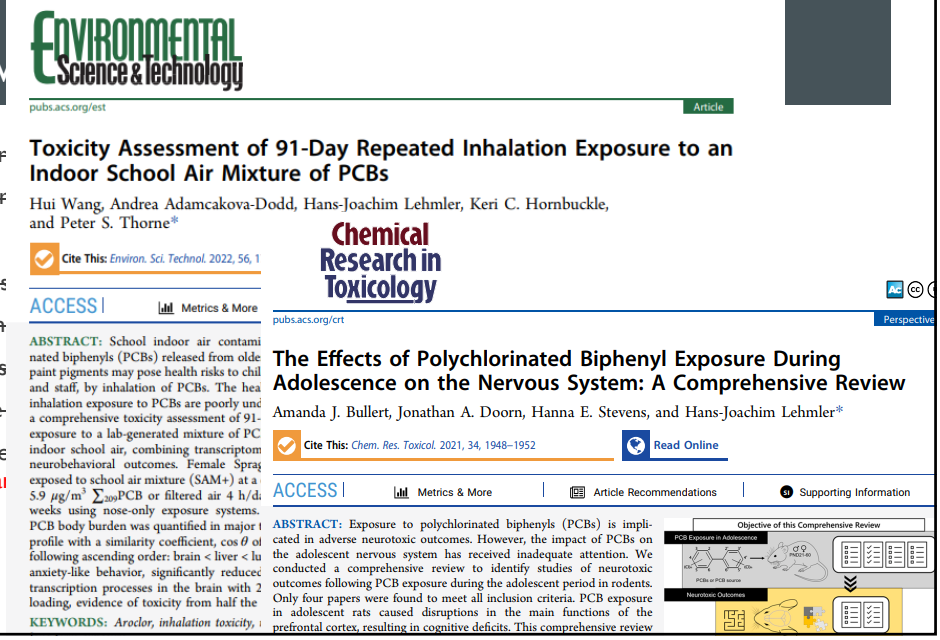

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Article

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Cite This: *Environ. Sci. Technol.* 2022, 56, 1

ACCESS | Metrics & More

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KEYWORDS: *Aroclor, inhalation toxicity,*

Chemical Research in Toxicology

pubs.acs.org/crt

Perspective

The Effects of Polychlorinated Biphenyl Exposure During Adolescence on the Nervous System: A Comprehensive Review

Amanda J. Bullert, Jonathan A. Doorn, Hanna E. Stevens, and Hans-Joachim Lehmler*

Cite This: *Chem. Res. Toxicol.* 2021, 34, 1948−1952

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ABSTRACT: Exposure to polychlorinated biphenyls (PCBs) is impli-
cated in adverse neurotoxic outcomes. However, the impact of PCBs on
the adolescent nervous system has received inadequate attention. We
conducted a comprehensive review to identify studies of neurotoxic
outcomes following PCB exposure during the adolescent period in rodents.
Only four papers were found to meet all inclusion criteria. PCB exposure
in adolescent rats caused disruptions in the main functions of the
prefrontal cortex, resulting in cognitive deficits. This comprehensive review

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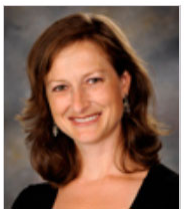

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NIH National Institute of Environmental Health Sciences
Superfund Research Program

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- Iowa Superfund Research Program https://iowasuperfund.uiowa.edu/
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