Outline/Overview

- PCB sources in buildings
- Indoor air levels and profiles
- Toxicity values and approaches
- Case studies
### PCBs in Indoor Air - Burlington (VT) HS (September 2020)

<table>
<thead>
<tr>
<th>Field Sample No.</th>
<th>Sample Description</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Building F</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F-312-06</td>
<td>Child Care Center – Room F-312</td>
<td>720 ng/m³</td>
</tr>
<tr>
<td>F-312-Dup-07</td>
<td>Child Care Center – Room F-312</td>
<td>640 ng/m³</td>
</tr>
<tr>
<td>F-312-HF-51</td>
<td>Child Care Center – Room F-312</td>
<td>160 ng/m³</td>
</tr>
<tr>
<td>F-304-18</td>
<td>Health Sciences – Room F-304</td>
<td>400 ng/m³</td>
</tr>
<tr>
<td>F-309-26</td>
<td>Criminal Justice – Room F-309</td>
<td>760 ng/m³</td>
</tr>
<tr>
<td>F-205-30</td>
<td>Metals Shop Jewelry – Room F-205</td>
<td>1300 ng/m³</td>
</tr>
<tr>
<td>F-210-28</td>
<td>Welding Shop – Room F-210</td>
<td>5800 ng/m³</td>
</tr>
<tr>
<td>F-214-21</td>
<td>Construction Trades Shop – Room F-214</td>
<td>6300 ng/m³</td>
</tr>
<tr>
<td>F-103-19</td>
<td>Automotive Shop – Rom F-103</td>
<td>1900 ng/m³</td>
</tr>
</tbody>
</table>

**Other Buildings**

A: 1 – 260 ng/m³  
B: 27 – 270 ng/m³  
C: 60 – 130 ng/m³  
D: 11 – 300 ng/m³  
E: 16 – 110 ng/m³

VT DOH (2013)  
Recommended Exposure Level = 15 ng/m³

Data from link at: https://vtdigger.org/2020/09/24/burlington-schools-knew-about-pcbs-in-soil-for-13-months-before-reporting-the-problem/
PCB Properties

- PCBs synthesized in 1929, banned in 1979
- Used in >1,000 products
- 209 congeners, produced as mixtures (e.g., Aroclors)
  - 14 are “co-planar” dioxin-like congeners
- Vapor pressure depends on degree of chlorination

<= Data from Öberg (2001) in units of mm Hg
Commercial Uses of PCBs / Sources in Buildings

- Transformers and capacitors
- Electrical equipment including voltage regulators, switches, re-closers, bushings, and electromagnets
- **Oil used in motors and hydraulic systems**
  - And spills onto floors
- Old electrical devices or appliances containing PCB capacitors
- **Fluorescent light ballasts**
- Cable insulation
- Thermal insulation material including fiberglass, felt, foam; and cork
- Adhesives and tapes
- **Oil-based paint**
- **Caulking**
- Plastics
- Carbonless copy paper
- Floor finish

https://www.epa.gov/pcbs/learn-about-polychlorinated-biphenyls-pcb#commercial
Residual PCB Sources in Building Materials

- Caulk
- Fluorescent light ballasts
- Paint
- Ceiling tiles
- Secondary sources
### PCBs Measured in Caulk

<table>
<thead>
<tr>
<th>Total PCBs in Caulk</th>
<th>Interior Caulks From 5 Schools</th>
<th>Exterior Caulks From 3 Schools</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Samples:</td>
<td>427</td>
<td>73</td>
</tr>
</tbody>
</table>

**Percent of Caulk Samples**

<table>
<thead>
<tr>
<th>Concentration Range</th>
<th>Interior Caulks</th>
<th>Exterior Caulks</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 50 ppm</td>
<td>82.2</td>
<td>37.0</td>
</tr>
<tr>
<td>50 – 999 ppm</td>
<td>7.7</td>
<td>6.8</td>
</tr>
<tr>
<td>1,000 - 99,999 ppm</td>
<td>4.0</td>
<td>21.9</td>
</tr>
<tr>
<td>100,000 – 199,999 ppm</td>
<td>2.3</td>
<td>12.3</td>
</tr>
<tr>
<td>200,000 – 299,999 ppm</td>
<td>3.3</td>
<td>15.1</td>
</tr>
<tr>
<td>300,000 – 399,999 ppm</td>
<td>0.2</td>
<td>6.8</td>
</tr>
<tr>
<td>&gt; 400,000 ppm</td>
<td>0.2</td>
<td>0.0</td>
</tr>
</tbody>
</table>

#### Note:
Multiple samples of the same type of caulks were collected.

100,000 ppm is 10% by weight.

### Fluorescent Light Ballasts

<table>
<thead>
<tr>
<th></th>
<th>School 1</th>
<th>School 2</th>
<th>School 3</th>
<th>School 4</th>
<th>School 5</th>
<th>School 6**</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Examined</td>
<td>727</td>
<td>487</td>
<td>619</td>
<td>927</td>
<td>--</td>
<td>33</td>
</tr>
<tr>
<td>Likely PCB-Containing</td>
<td>417</td>
<td>373</td>
<td>275</td>
<td>879</td>
<td>--</td>
<td>8</td>
</tr>
<tr>
<td>% Ballasts Likely w PCBs</td>
<td>57%</td>
<td>77%</td>
<td>44%</td>
<td>95%</td>
<td>--</td>
<td>24%</td>
</tr>
</tbody>
</table>

** Only a small subset of ballasts in the school were surveyed

## Secondary Sources

<table>
<thead>
<tr>
<th>Material</th>
<th>Concentration (ppm by mass)</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Median</td>
<td>Maximum</td>
<td></td>
</tr>
<tr>
<td>Paint</td>
<td>39</td>
<td>750</td>
<td></td>
</tr>
<tr>
<td>Fiberboard</td>
<td>31</td>
<td>55</td>
<td></td>
</tr>
<tr>
<td>Dust</td>
<td>22</td>
<td>87</td>
<td></td>
</tr>
<tr>
<td>Varnish</td>
<td>11</td>
<td>62</td>
<td></td>
</tr>
<tr>
<td>Ceiling tile</td>
<td>7.6</td>
<td>14</td>
<td></td>
</tr>
<tr>
<td>Laminate</td>
<td>5.4</td>
<td>200</td>
<td></td>
</tr>
<tr>
<td>Floor tile</td>
<td>4.4</td>
<td>57</td>
<td></td>
</tr>
</tbody>
</table>

Emissions and Source Potential

- Emissions – Assuming:
  - 100 ng/m³ of PCBs in indoor air
  - In a 5 m by 10 m by 10 m room
  - With 2 changes of air per hour
  - Translates to a mass flux of 0.1 mg/hour ≈ 2 g/year

- Source Potential – Assuming:
  - A 2 ft by 4 ft window with a ¼ in triangular bead of caulk
  - Caulk density 1.5 g/cm³ and 10% PCBs (by mass)
  - Equates to 354 g PCBs

- Conclusion: There can easily be enough PCBs present in building materials to sustain PCBs at levels of concern in indoor air
### PCB Concentrations Measured in Indoor Air

<table>
<thead>
<tr>
<th>Location</th>
<th>Date</th>
<th>Concentrations (in ng/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Housing Complex, CA</td>
<td>2002</td>
<td>96 – 234</td>
</tr>
<tr>
<td>Estabrook School, Lexington, MA</td>
<td>2010</td>
<td>300 – 1,800</td>
</tr>
<tr>
<td>New York City Schools</td>
<td></td>
<td></td>
</tr>
<tr>
<td>P.S. 199M</td>
<td>2010</td>
<td>410 – 1,500</td>
</tr>
<tr>
<td>P.S. 309K</td>
<td></td>
<td>540 – 5,000</td>
</tr>
<tr>
<td>Burke School, Peabody, MA</td>
<td>2011</td>
<td>260 – 740</td>
</tr>
<tr>
<td>Child Care Center, Boston, MA</td>
<td>2012</td>
<td>120 – 200</td>
</tr>
<tr>
<td>Public Buildings, Germany</td>
<td>2002</td>
<td>720 – 4,200</td>
</tr>
<tr>
<td>Apartment Complex, Denmark</td>
<td>2012</td>
<td>170 – 3,800</td>
</tr>
</tbody>
</table>

- **Residential Screening Level**: 4.9 ng/m³
- **Industrial Screening Level**: 21 ng/m³
- **Public School Levels**: 100 – 600 ng/m³

Estimated 13,000 to 26,000 U.S. schools impacted (Herrick et al., 2016)
Toxicological Values for Risk Assessment

- **Carcinogenic Potencies (kg-day/mg) (EPA IRIS, 1996)**
  - High risk/persistence: 1 to 2
  - Low risk/persistence: 0.3 to 0.4
  - Lowest risk/persistence: 0.04 to 0.07
  - 2,3,7,8-TCDD: 130,000 (TEQ/co-planar)

- **“Non-cancer” Reference Doses (ng/kg-day) (EPA IRIS, 1994 for Aroclors)**
  - Aroclor 1254: 20 higher risk
  - Aroclor 1016: 70 lower risk
  - 2,3,7,8-TCDD: 0.0007 TEQ/co-planar

- **Neurological Equivalents Reference Doses (ng/kg-day) (Simon, 2007)**
  - Aroclor 1254: 8 higher risk
  - Aroclor 1016: 70 lower risk
Effective Dioxin-Like Potencies and RfDs

<table>
<thead>
<tr>
<th>Aroclor mixture</th>
<th>Cancer Potency (d-kg/mg)</th>
<th>Non-Cancer Reference Dose (ng/kg-d)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>High Risk: 1 to 2</td>
<td>Low Risk: 0.3 to 0.4</td>
</tr>
<tr>
<td></td>
<td>Low Risk: 0.04 to 0.07</td>
<td>Low Risk: 70</td>
</tr>
<tr>
<td></td>
<td></td>
<td>High Risk: 20</td>
</tr>
<tr>
<td>1242</td>
<td>0.09</td>
<td>996</td>
</tr>
<tr>
<td>1248 (v1)</td>
<td>0.22</td>
<td>415</td>
</tr>
<tr>
<td>1248 (v2)</td>
<td>0.23</td>
<td>390</td>
</tr>
<tr>
<td>1254</td>
<td>3.55</td>
<td>26</td>
</tr>
<tr>
<td>1254 Late</td>
<td>0.47</td>
<td>193</td>
</tr>
<tr>
<td>1260</td>
<td>0.06</td>
<td>1525</td>
</tr>
</tbody>
</table>

Based on:
- Potency of 130,000 mg/kg-d and RfD of 0.0007 ng/kg-d (EPA RSLs)
- EPA-recommended TEFs for 14 co-planar PCBs
- ATSDR (2000) PCB Toxicity Profile for Aroclor mixture compositions
### Indoor Air Screening Levels

EPA’s Exposure Levels for Evaluating Polychlorinated Biphenyls (PCBs) in Indoor School Air (ng/m³)
(https://www.epa.gov/pcbs/exposure‐levels‐evaluating‐polychlorinated‐biphenyls‐pcbs‐indoor‐school‐air)

<table>
<thead>
<tr>
<th>Age 1-&lt;2</th>
<th>Age 2-&lt;3</th>
<th>Age 3-&lt;6</th>
<th>Age 6-&lt;12</th>
<th>Age 12-&lt;15</th>
<th>Age 15-&lt;19</th>
<th>Age 19+</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>100</td>
<td>200</td>
<td>300</td>
<td>500</td>
<td>600</td>
<td>500</td>
</tr>
</tbody>
</table>

EPA’s Regional Screening Levels (ng/m³)
(https://www.epa.gov/risk/regional‐screening‐levels‐rsls‐generic‐tables, TR=1E-06)

<table>
<thead>
<tr>
<th></th>
<th>High Risk (dust)</th>
<th>Low Risk (evaporated)</th>
<th>Lowest Risk (99.5% &lt;4 Cl)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential</td>
<td>4.9</td>
<td>28</td>
<td>140</td>
</tr>
<tr>
<td>Industrial</td>
<td>21</td>
<td>120</td>
<td>610</td>
</tr>
</tbody>
</table>
Composition data from ATSDR (2000) Toxicity Profile for PCBs
Aroclor 1254

Co-Planar (Dioxin-Like)  Ortho (non-Dioxin Like)

Composition data from ATSDR (2000) Toxicity Profile for PCBs
PCBs in Denmark Homes
Danish Health Protection Agency, 2012

- 83 PCB-contaminated apartments
- 27 congeners in caulking, indoor air, & serum
- Plotted against Aroclor 1254 composition

* indicates dioxin-like (co-planar) congener
- Patterns shift to lower chlorinated congeners
- Child care center an exception
PCB Homologue Groups & Congeners in Air Sampling

- Outdoor air contains 0.04 – 0.5 ng/m³ PCBs
- Davis et al (2002) vapor intrusion investigation
- Soils contain up to 160,000 mg/kg PCBs
- PCBs up to 220 ng/m³, >97% mono PCBs
Title: Case Study #1: “Brownfield” Redevelopment

- Mill building conversion to condominiums
  - PCB-impregnated floors
  - Renovation workers at risk?

- Exposure estimate
  - Assume 3.3 mg/m³ of dust (high level)
  - 5.8 mg/kg PCB in dust
  - Yields exposure to 20 ng/m³ of PCBs

- Acceptable/safe levels
  - OSHA PEL: 500,000 μg/m³
  - More recent studies: 10,000 μg/m³
Case Study #2: Child Care Center

- PCB concentrations measured in indoor air
  - 110 – 200 ng/m³ at time of study
  - > 300 ng/m³ previously
  - Exceed EPA guideline of 100 ng/m³ for 1-2 and 2-3 yr-olds

- Questions
  - Should center be closed?
  - What about < 1 yr-olds?

- Issues and perspectives
  - Homologue profile resembles Aroclor 1254
  - EPA guidelines derive from toxicity study in monkeys
    - Safety factor of 250 applied
    - Humans may be less sensitive to PCBs than monkeys
  - Nursing infants receive ~ 20 times more exposure than EPA’s Reference Dose
Case Study #3: “Brownfield” Redevelopment

- Industrial building conversion to luxury apartments
  - PCB-impregnated concrete floors to remain in place
  - Future residents at risk?

- Exposure estimate
  - Measured volatilization rate
  - Indoor air model 44 ng/m³
  - Homologue pattern indicates low-risk PCBs

- Acceptable/safe level 98 ng/m³ based on EPA school methodology

- Mitigation through encapsulation (concrete layer plus epoxy)

- Confirmatory indoor air samples:
  - 1st round: All ND
  - 2nd round: 2 of 5 low detects (0.5 ng/m³ and 1.2 ng/m³)

Developed in conjunction with Paul Muniz, Environmental Partners, LLC
Acceptable Concentration (Case Study #3)

Public Health Level exposure methodology (EPA 2009 Exposure Estimation Tool):

Allowable incremental + Background ≤ Safe level

\[ C_{\text{Indoor}} = \frac{B_w}{I_r} (R_{fD} - e_{\text{diet}}) - C_{\text{outdoor}} \]

- \( C_{\text{Indoor}} \): Allowable PCB concentration in indoor air (ng/m³)
- \( B_w \): Body weight = 11.4 kg (small child)
- \( I_r \): Inhalation rate = 8 m³/d
- \( R_{fD} \): Reference dose (ng/kg-d) – 20 ng/kg-d (high risk) or 70 ng/kg-d (low risk)
- \( e_{\text{diet}} \): Background exposure = 1.2 ng/kg-d (Total Diet Study) – EPA default 8 ng/kg-d
- \( C_{\text{outdoor}} \): Background PCBs in outdoor air = 0.5 ng/m³

Developed in conjunction with Paul Muniz, Environmental Partners, LLC
Acceptable Concentration (Case Study #3)

\[ C_{\text{Indoor}} = \frac{B_w}{I_r} (R_{FD} - e_{\text{diet}}) - C_{\text{outdoor}} \]

- Application of formula yields:
  - \( C_{\text{Indoor}} = 98 \text{ ng/m}^3 \) if \( R_{FD} = 70 \text{ ng/kg-d} \) – EPA RSL = 28 \text{ ng/m}^3
  - \( C_{\text{Indoor}} = 26 \text{ ng/m}^3 \) if \( R_{FD} = 20 \text{ ng/kg-d} \) – EPA RSL = 4.9 \text{ ng/m}^3

- Compare to building estimates:
  - 44 \text{ ng/m}^3 flux chamber model
  - 4.5 \text{ ng/m}^3 static test
  - ND for encapsulant test

Developed in conjunction with Paul Muniz, Environmental Partners, LLC
Encapsulation / Risk Mitigation (Case Study #3)

- Diffusion model to predict effectiveness of epoxy and concrete encapsulants
  - 1” concrete layer delays PCB volatilization over practical lifetime of building (100s of years)
  - Epoxy effective for over 60 years

Diffusion model through porous medium

PCB concentration distribution in the concrete layer:

\[
c(x, t) = c_0 \frac{\delta - x}{\delta} + c_0 \sum_{n=1}^{\infty} \frac{(-1)^n}{n\pi} \sin \left( \frac{n\pi \delta - x}{\delta} \right) \exp \left( -\frac{n^2 \pi^2Dt}{\delta^2} \right)
\]

PCB Flux from concrete:

\[
D \frac{c_0}{\delta} \left( 1 + 2 \sum_{n=1}^{\infty} (-1)^n \exp \left( -\frac{n^2 \pi^2Dt}{\delta^2} \right) \right)
\]

Developed in conjunction with Paul Muniz, Environmental Partners, LLC
Aroclor 1254
Distribution in Red
Limited Shift Toward Low-Cl Congeners
Concentrations < 80 ng/m³
Aroclor 1254 Distribution in Red
Considerable Shift Toward Low-Cl Congeners
Carcinogenic Unit Risk Factors for PCB Mixtures

Burlington (VT) Indoor Air Sampling Results (September 2020)

- **High Risk Mixtures**
- **Low Risk Mixtures**
- **Lowest Risk Mixtures**

Sample-specific unit risk factors estimated from weighting congener distributions and dioxin-like PCBs

Green Lines at Unit Risk Factors for PCB Mixtures per EPA RSL Tables
Summary

- Levels of PCBs measured in indoor air due to building material sources have been near or greater than recommended exposure levels.
- PCBs found in many (but not all) indoor air emphasize the less chlorinated, and generally less toxic, congeners of the parent mixtures.
- Actual risks to health may be substantially overestimated (or conversely, exposure guidelines are highly protective).
- PCB-containing building materials remain a source of PCBs to indoor air for many years.
- PCB risk assessment methods are uncertain, could be improved, and will likely evolve.
References


Thank you!

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