Lead (Pb): Upcoming Implications for Contaminated Site Soil Quality Guidelines

Remtech 2009
Banff Springs
Calgary, AB

Anthony Knafla, M.Sc., DABT
Jillian Carey, M.Sc.
OVERVIEW

• Background levels (pre- and post-anthropogenic)

• Concentrations at contaminated sites

• Toxicity and toxicokinetics of Pb

• Challenges associated with developing a soil quality guideline for Pb

• Options for data collection to provide site-specific guidelines that are more reflective of site-specific conditions
BACKGROUND LEVELS

- Pb is a highly useful metal apply by humans since pre-Roman and Greek times
- Concentrations in soil prior to human refinement and use of Pb were < 0.1 ppm
- Elevated levels have been found in various rocks

Table 2-7. Naturally Occurring Lead Concentrations in Major Rock Types

<table>
<thead>
<tr>
<th>Lithology</th>
<th>Natural Pb Concentration (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Continental Crust</td>
<td>15.0</td>
</tr>
<tr>
<td>Oceanic Crust</td>
<td>0.9</td>
</tr>
<tr>
<td>Basalts, Gabbros</td>
<td>3.5</td>
</tr>
<tr>
<td>Limestones</td>
<td>5.0</td>
</tr>
<tr>
<td>Granulites</td>
<td>9.8</td>
</tr>
<tr>
<td>Greywackes</td>
<td>14.0</td>
</tr>
<tr>
<td>Gneisses, Mica Schists</td>
<td>22.0</td>
</tr>
<tr>
<td>Shales</td>
<td>22.0</td>
</tr>
<tr>
<td>Granites</td>
<td>32.0</td>
</tr>
</tbody>
</table>

Source: Reuer and Weiss (2002).
ANTHROPOGENIC LEVELS

• Example concentrations at contaminated sites
  – Smelters 1,500 mg/kg; 1 to 5 ug/L water
  – Refinery sites 1,000 mg/kg
  – Mining (acid mine drainage) > 3,000 ug/L

• Historical use of Pb in pipes, paint, pipe solder, and gasoline has lead to widespread increases in Pb soil and water concentrations as well as house dust

• Older urban cities 1,000 mg/kg
• Ottawa – garden soils > 200 mg/kg (95th %ile)
• Ottawa – house dust 1,300 mg/kg

AENV SQG
Agr 70 ppm
Res 140 ppm
Ind 600 ppm
DWG 10 ug/L
CHALLENGES

• Guideline Development
  – typical non-carcinogenic substances involves subtracting background exposure from the threshold reference value
  – What do you do when background exceeds the acceptable limit?
  – Highly published topic – can find 100 new publications per year

• Toxicity
  – Current Pb body burdens maybe in adverse effects range
  – No clear threshold where adverse effects do not occur
  – Evidence for non-linear dose-response steeper at low Pb
  – Body burdens dependent on nutrition, hormone status, socioeconomics, behavior, genetics, age, bioavailability
  – Pb get transferred from the mother to developing embryo in utero and from the mother to infant via breast milk
PEER REVIEWED TOXICITY WORK

- Highly qualified panel
- Physicists from McMaster and Mount Allison University
- Canadian Medical Doctors in areas of Environmental and Occupational Health
- Scientists from Health Canada - Risk Management Bureau, Contaminated Sites Division
- Consultants in Canada and the United States (well published in the field)
- Center for Disease Control & Prevention in the United States
- Federal Biostatisticians
LOW DOSE Pb EFFECTS

- 2.5 µg/dL PbB ~ 0.006 µg/dL plasma ~ 0.003 µg/dL cerebrospinal fluid
- Pb can bind > 1000x more tightly to certain calcium receptors

<table>
<thead>
<tr>
<th>Dose (µg/dL)</th>
<th>Toxicological Endpoint</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00015</td>
<td>effects on vitality and prolif. of human peripheral blood mononuclear cells</td>
<td>Hemdan et al. (2005)</td>
</tr>
<tr>
<td>0.0021</td>
<td>threshold for calmodulin activation (calcium mimicking)</td>
<td>Fergusson et al. (2000)</td>
</tr>
<tr>
<td>0.005</td>
<td>effects on cytokine release</td>
<td>Hemdan et al. (2005)</td>
</tr>
<tr>
<td>0.021</td>
<td>11% decrease in dopaminergic neurite length</td>
<td>Schneider et al. (2003)</td>
</tr>
<tr>
<td>0.21</td>
<td>38% decrease in dopaminergic neurite length</td>
<td>Schneider et al. (2003)</td>
</tr>
<tr>
<td>2.1</td>
<td>44% decrease in dopaminergic neurite length</td>
<td>Schneider et al. (2003)</td>
</tr>
<tr>
<td>2.1</td>
<td>inhibited neurite outgrowth</td>
<td>Kern and Audesirk (2000)</td>
</tr>
</tbody>
</table>
### LOW DOSE EFFECT DATA (< 10 μg/dL)

<table>
<thead>
<tr>
<th>N</th>
<th>Population</th>
<th>Endpoint</th>
<th>Study</th>
</tr>
</thead>
<tbody>
<tr>
<td>58,518</td>
<td>Adults</td>
<td>increased systolic blood pressure</td>
<td>Nawrot et al. (2002)</td>
</tr>
<tr>
<td>2165</td>
<td>Female adults</td>
<td>Hypertension</td>
<td>Nash et al. (2003)</td>
</tr>
<tr>
<td>30</td>
<td>Females (preg)</td>
<td>altered placental uptake of calcium</td>
<td>LaFond et al. (2004)</td>
</tr>
<tr>
<td>13,946</td>
<td>Adults</td>
<td>Increase cardiovascular disease and mortality</td>
<td>Menke et al. (2006)</td>
</tr>
<tr>
<td>325</td>
<td>Female adults</td>
<td>increased risk of neuropsychological effects, reaction time</td>
<td>Muldoon et al. (1996)</td>
</tr>
<tr>
<td>707</td>
<td>Adults</td>
<td>Kidney effects</td>
<td>Tsaih et al. (2004)</td>
</tr>
<tr>
<td>13,141</td>
<td>Adults</td>
<td>increased risk of kidney disease in hypertensive individuals</td>
<td>Muntner et al. (2003)</td>
</tr>
<tr>
<td>2186</td>
<td>Adolescents</td>
<td>delayed sexual maturity</td>
<td>Selevan et al. (2003)</td>
</tr>
<tr>
<td>138</td>
<td>Infants</td>
<td>decreased birth weight (measured at 1 month)</td>
<td>Sanin et al. (2001)</td>
</tr>
<tr>
<td>290</td>
<td>Children</td>
<td>increased prevalence of dental caries</td>
<td>Gemmel et al. (2002)</td>
</tr>
<tr>
<td>1,333</td>
<td>Children</td>
<td>decrease in IQ</td>
<td>Lanphear et al. (2005); Canfield et al. (2003a)</td>
</tr>
</tbody>
</table>

172
• PbB has dropped since phasing out of lead paint and gasoline
• Levels elevated in Canadian populations well above pre-industrial
• current day in Canada: adults 1 to 4 ug/dL; children < 5 ug/dL

Centre for Disease Control, in the Agency for Toxic Substances and Disease Registry; children aged 1 to 5 years
Flegal and Smith, 1992; Lafond et al., 2004; Wilson et al., 2003; Langlois et al., 1996; Fleming et al., 1999; Hilts, 2002
### FACTORS INFLUENCING BODY BURDENS

<table>
<thead>
<tr>
<th>Age/Gender</th>
<th>Factors Influencing Biokinetics</th>
<th>Percent Increase in PbB</th>
</tr>
</thead>
<tbody>
<tr>
<td>adult females</td>
<td>pregnancy</td>
<td>20 to 33%</td>
</tr>
<tr>
<td>adult females</td>
<td>postpartum</td>
<td>65%</td>
</tr>
<tr>
<td>adult females</td>
<td>menopause</td>
<td>5 to 60%</td>
</tr>
<tr>
<td>adult females</td>
<td>low milk consumption</td>
<td>44%</td>
</tr>
<tr>
<td>adult females</td>
<td>low vitamin C intake</td>
<td>48%</td>
</tr>
<tr>
<td>adult females</td>
<td>low thiamin intake</td>
<td>47%</td>
</tr>
<tr>
<td>adult females</td>
<td>alcohol consumption</td>
<td>55%</td>
</tr>
<tr>
<td>adult males</td>
<td>low iron intake</td>
<td>21%</td>
</tr>
<tr>
<td>adult males</td>
<td>smoking</td>
<td>10%</td>
</tr>
<tr>
<td>Highly exposed children</td>
<td>ALAD 2 carrier</td>
<td>36%</td>
</tr>
<tr>
<td>children</td>
<td>low ferritin</td>
<td>22%</td>
</tr>
<tr>
<td>children 1 to 3</td>
<td>low vitamin D intake</td>
<td>32%</td>
</tr>
</tbody>
</table>
IQ EFFECTS IN CHILDREN

- Canfield et al. IQ of children (n=220), urban area with elevated Pb
- low population IQ & SES; significant decrease in child IQ
- An increase in soil Pb from 250 to 500 mg/kg could be associated with an IQ decrease of 6 points (PbB increase of 3 ug/dL)

\[ y = -2.013x + 103.1 \]

\[ R^2 = 0.150 \]

- Canfield et al. (2003)
IQ EFFECTS IN CHILDREN

- Recent study confirmed effects with several cohorts
- No threshold identified, although other papers suggest a threshold

- Lanphear et al., 2005
IQ EFFECTS IN CHILDREN

• Supported by animal data

• Monkeys exposed to Pb during infancy (Rice, 1985)
  • ‘lowish’ PbB (11 or 13 µg/dL)
  • impairment in non-spatial discrimination reversal tasks & susceptibility to being distracted by irrelevant clues
  • Similar results when same monkeys tested at 9 to 10 years

• Exposure of pregnant monkeys and offspring to Pb
  • impairment of IQ at age 6 to 7
  • maternal transfer plus childhood exposure may be cumulative
    – Rice 1990; Rice and Gilbert 1990; Rice and Karpinski, 1988; Rice and Gilbert, 1985
IQ EFFECTS IN CHILDREN - CONTEXT

- Guidelines based on a 1 point population mean IQ drop
- How does this compare to other factors?
- Interpret data below cautiously – correlates, not necessarily cause and effect

<table>
<thead>
<tr>
<th>Environmental Correlates of Children's IQ</th>
<th>Magnitude of Potential Effect on IQ (IQ Points)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Socioeconomic Status (SES)</td>
<td>+ 12</td>
</tr>
<tr>
<td>Parent's Education</td>
<td>+ 15</td>
</tr>
<tr>
<td>Family Size and child's position in family</td>
<td>+ 8</td>
</tr>
<tr>
<td>Enriched Pre-school</td>
<td>+ 15</td>
</tr>
</tbody>
</table>
SOME SUGGEST NON-LINEAR SLOPE

- Based on mathematical function slope fitting

- If true, an increase in soil Pb from 5 to 30 ppm could be associated with unacceptable health risks in terms of child IQ

Graph showing non-linear dose response at low dose.
Elevated SBP and Hypertension is a key factor that contributes to risk
- Canadians have low SBP compared to other populations
- USA has lowest SBP particularly in older individuals – disease treatment

Can impose the increase in SBP cause by Pb onto baseline levels
‘Unexposed’ versus ‘Contaminated Site Exposed’ populations

Pb-RELATED SBP EFFECTS

- Again, no threshold; logarithmic & linear functions
- Suggested guideline based on a 1% increase in mean SBP
- equivalent to a PbB increase of approximately 1.5 ug/dL

![Graph showing the relationship between Blood Lead (PbB) and Systolic Blood Pressure (SBP) Increase. The graph includes data from various studies as follows:
- Nawrot et al. (2002) M&F-V (95th)
- Den Hond et al. (2002) M&F C (M)
- Nawrot et al. (2002) M&F-V (M)
- Glenn et al. (2002) M-NS & Vupp (M)
- Nash et al. (2003) F-C (M)
- Rothenberg et al. (2002) F(preg)-LA (M)
- Vupputuri et al. (2003) F-AA (95th)
HYPERTENSION RISK

- What does a change in SBP really mean?
- Extra risk of Pre-hypertension, Stage 1, and Stage 2 hypertension prevalence (SBP >120, > 140, > 160 mmHg)
  - Limit of a 1 point increase in mean population SBP
  - Example shown below for males – age bracket 65 to 74 years
  - increase of 4%, 3%, and 2% of the population above hypertension thresholds

![Graph showing the difference in the number of additional hypertension cases with systolic blood pressure.](image-url)
HEART DISEASE MORTALITY

- Baseline IHD Mortality Rate, impose Pb-related effects on mortality
  - 1% increase in SBP
  - Increased incidence calculated per gender & decade age bracket
    Summed for adult (34 to 75) lifetime risk
  - shift between stages of hypertension is associated with increase
    risk of heart disease mortality
  - compare with carcinogen risks of 1 in 100,000

<table>
<thead>
<tr>
<th>CV Disease</th>
<th>35-44</th>
<th>45-54</th>
<th>55-64</th>
<th>65-74</th>
<th>75-84</th>
<th>85+</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>19</td>
<td>78</td>
<td>267</td>
<td>702</td>
<td>1825</td>
<td>4020</td>
<td>6911</td>
</tr>
<tr>
<td>1% inc. in SBP</td>
<td>1.2</td>
<td>5.5</td>
<td>6.9</td>
<td>16.9</td>
<td>n.c.</td>
<td></td>
<td>31</td>
</tr>
</tbody>
</table>
• Economic costs of CVD on Canadian health (1998)
  – Total approx. $18.5 billion (11.6% of total of illnesses cost)
    • Direct – approx. 6.8 billion (treatment, care and rehabilitation, etc)
    • Indirect – approx. 11.7 billion (economic output lost due to illness, injury-related work, or premature death)
• IHD (including AMI) mortality - the single largest source of economic cost associated with CVD (27%)

<table>
<thead>
<tr>
<th>Endpoint</th>
<th>Baseline Annual Incidence (age 35 - 84)</th>
<th>Est. Cost/Case</th>
<th>Additional Cases (Increased Incidence) at same PbB Increase</th>
<th>Additional Cost per Endpoint</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hypertension</td>
<td>170631</td>
<td>$5,157</td>
<td>172</td>
<td>$887,060</td>
</tr>
<tr>
<td>IHD (Hyp-Related)</td>
<td>11662</td>
<td>$202,024</td>
<td>10</td>
<td>$2,020,237</td>
</tr>
<tr>
<td>IHD Mortality</td>
<td>2892</td>
<td>$1,675,773</td>
<td>1</td>
<td>$1,675,773</td>
</tr>
</tbody>
</table>

Costs for IHD (Hyp-Related) excludes mortality cost and includes hospital care, drugs, and long-term disability
EXAMPLE EXPOSURE LIMITS

• Population Mean effects, not individuals – very important

• M ADULTS PbB – SBP increase of 1% - 4.9 µg/dL
  6,200 in 100,000 additional Stage 1 Hypertension cases
  increased incidence of 31 in 100,000 for CHD mortality

• F ADULTS PbB – SBP increase of 1% - 2.4 µg/dL
  6,000 in 100,000 additional Stage 1 Hypertension cases
  increased incidence of 12 in 100,000 for CHD mortality

• CHILDREN PbB – IQ decrease of 1% - Both genders – 1.4 µg/dL
  extra risk of 400 in 100,000 with mild mental retardation

• These absolute limits are very difficult to apply given current day body burdens

• As a result, Equilibrium recommended that the government consider an incremental risk approach, similar to carcinogens, although for a non-carcinogenic substance – deviates from convention

• Results in risk evaluations and guidelines for contaminated sites that
Bioavailability is highly variable for Pb in the environment.

Consider using a P-BET approach – Physiologically Based Extraction Test.

What can be done on a site-specific basis? Bioavailability is Key...

- Blake et al., 1976; Casteel et al. (2006); swine data
• Groundwater related risks to Pb may be relatively low
• Absorption of Pb is considerably reduced in mineralized water
• Differences between fasted and non-fasted states – can’t be applied site-specific

Blake et al., 1976; Casteel et al. (2006); swine data
EXAMPLE OF BIOAVAILABILITY EFFECT ON GUIDELINES

- Child PbB limit of 1.4 µg/dL (1% IQ, 400 additional cases of MMR)
- Equivalent to a Tolerable daily uptake of 0.08 ug/kg-day
- Exposure to AENV residential soil quality guideline (140 mg/kg)
- Default CCME parameters for body weight and ingestion rate

- Risk depends on bioavailability

- At 100% bioavailability, 140 mg/kg exceeds the guideline by 10-fold
- At 30% bioavailability, 140 mg/kg exceeds the guideline by 3-fold
- At 10% bioavailability, 140 mg/kg is equivalent to the guideline

- A relative-risk approach would allow for increases in these concentrations above background levels

- It is likely that risk management may be applied for some populations where background levels are high

- The question is – how should Canadian’s money be spent?
  - Lower guideline for contaminated sites?
  - Improved child education?
  - Improved nutrition?
REGARDLESS OF THE LIMIT

- REGARDLESS OF THE LIMIT DEVELOPED,

- THERE ARE LIKELY TO BE PEOPLE IN CANADA THAT WILL HAVE PbB CONCENTRATIONS ABOVE THE LIMIT AS A CONSEQUENCE OF HISTORICAL EXPOSURES

- POSES CHALLENGES FOR RISK COMMUNICATION