Installation of Liquid Boot®
- a spray-applied membrane -
to reduce vapor intrusion of chlorinated solvents and radon

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Outline:

1. Background (motivation)
2. Membrane characteristics
3. Membrane installation (how to)
4. Project locations (full scale installation)
5. Monitoring & control (results)
6. Conclusions
Systems to reduce vapor intrusion

Gas vapor mitigation systems in use in Denmark

1. Concrete slab construction

2. Concrete slab construction
   + sub slab venting system

3. Concrete slab construction
   + sub slab venting system
   + gas vapor membrane
Installation of Liquid Boot® - a spray applied membrane - to reduce vapor intrusion

Failure from classic sheet applied membranes

Mitigation projects w/ install. of classic sheet applied membranes
Clients: The regions in Denmark (environmental authorities)

1. Post monitoring (indoor air):
   Reduction of contaminant concentrations less than expected

2. Further investigation (tracer gas test):
   Revealed an insufficient containment of soil gas
   Soil gas intrusion observed near:
   • Terminal mechanical strips
   • Utility penetrations

➢ Our motivation to search for alternative solutions
Membrane characteristics (description)

1. Liquid Boot® is a **dual component** membrane
   - bitumen/latex
   - a catalyst

2. Liquid Boot® is a **spray-applied** membrane
   - no seams
   - no overlaps
   - no mechanical fastening (terminal mechanical strips)
   - a tight seal around utility penetrations

3. Liquid Boot® has a **flexible installation procedure**
   - New as well as existing constructions
   - Bonds to most surfaces
Our primary concerns - prior to installation

1. **Diffusion coefficients / permeability**
   (performance)

2. **Long term durability**
   (stability)

3. **Production of off-gas**
   (secondary risk)
### Diffusion coefficients / permeability (chemical properties Liquid Boot®)

<table>
<thead>
<tr>
<th>Chemical property</th>
<th>Test method</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PCE Diffusion Coefficient</strong></td>
<td>Tested at 6,000 mg/m³ (modified ASTM E96)</td>
<td>$2.7 \times 10^{-14}$ m²/sec</td>
</tr>
<tr>
<td><strong>TCE Diffusion Coefficient</strong></td>
<td>Tested at 20,000 mg/m³ (modified ASTM E96)</td>
<td>$8.0 \times 10^{-14}$ m²/sec</td>
</tr>
<tr>
<td><strong>Benzene Diffusion Coefficient</strong></td>
<td>Tested at 43,000 mg/m³ (modified ASTM E96)</td>
<td>$2.9 \times 10^{-11}$ m²/day</td>
</tr>
<tr>
<td><strong>Radon Permeability</strong></td>
<td>Tested by US Dept. of Energy</td>
<td>Zero permeability to Radon (222Rn)</td>
</tr>
<tr>
<td><strong>Methane Permeability</strong></td>
<td>ASTM 1434-82</td>
<td>Passed</td>
</tr>
<tr>
<td><strong>Acid Exposure (10% H₂SO₄ for 90 days)</strong></td>
<td>ASTM D543</td>
<td>Less than 1% weight change</td>
</tr>
<tr>
<td><strong>Chemical resistance: VOC’s, BTEX’s (tested at 20,000 ppm)</strong></td>
<td>ASTM D543</td>
<td>Less than 1% weight change</td>
</tr>
</tbody>
</table>
| **Diesel (1000 mg/l), Ethylbenzene (1000 mg/l), Naphthalene (5000 mg/l) and Acetone (500 mg/l) Exposure for 7 days** | ASTM D543                                      | Less than 1% weight change
| **Oil resistance test. Average weight change, average tensile strength change, average elongation change** | ASTM D543-87                                   | Passed                                      |

- Diffusion coeff. match those of traditional sheet appl. membranes
## Long term durability (physical properties Liquid Boot®)

<table>
<thead>
<tr>
<th>Physical property</th>
<th>Test method</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bonded Seam Strength Tests</td>
<td>ASTM D6392</td>
<td>Passed</td>
</tr>
<tr>
<td>Heat Ageing: Average tensile strength change, average tensile stress change, average elongation change, bonded seams</td>
<td>ASTM D4068-88</td>
<td>Passed</td>
</tr>
<tr>
<td>Dead Load Seam Strength</td>
<td>City of Los Angeles</td>
<td>Passed</td>
</tr>
<tr>
<td>Environmental Stress-Cracking</td>
<td>ASTM D1693-78</td>
<td>Passed</td>
</tr>
<tr>
<td>Soil Burial</td>
<td>ASTM E154-88</td>
<td>Passed</td>
</tr>
<tr>
<td>Elongation</td>
<td>ASTM D412</td>
<td>1,332% - Ø reinforcement, 90% recovery</td>
</tr>
<tr>
<td>Tensile Strength</td>
<td>ASTM D412</td>
<td>58 p.s.i. without reinforcement</td>
</tr>
<tr>
<td>Tensile Bond Strength to Concrete</td>
<td>ASTM D413</td>
<td>2,707 lbs/ft² uplift force</td>
</tr>
<tr>
<td>Water Vapor Permeability</td>
<td>ASTM E96</td>
<td>0.24 perms</td>
</tr>
<tr>
<td>Water Vapor Transmission</td>
<td>ASTM E96</td>
<td>0.10 grains/h-ft²</td>
</tr>
</tbody>
</table>

Test results document high strength and elongation, and supports an expectancy for a long term durability.

- Heat ageing, chemical exposure tests (acid exposure & oil component exposure) and accelerated weather test
Membrane installation (how to)
Membrane installation (how to)
Membrane installation (utility penetrations)

Installation of Liquid Boot® - a spray applied membrane - to reduce vapor intrusion
Project locations (full scale installation)

1. **Residential site (I-III), Copenhagen**
   - Radon, residential use
   - Exist. concrete slab construction

2. **Dry cleaning site (IV), Aabenraa**
   - PCE, residential use
   - Add on to former mitigation sys.
   - Exist. concrete slab construction

3. **Dry cleaning site (V), Holstebro**
   - PCE, residential use (partly)
   - Exist. wood construction
Monitoring & control (procedure)

Procedure on project locations:

1. Visual and destructive control

2. Performance of tracer gas test
   (leakage search procedure)

3. Measurement of indoor air concentrations
   (monitoring)

4. Measurement of off-gasses, membrane material
   (monitoring)
Control of membrane installation

• Visual and destructive control

• Tracer gas test (leakage search procedure)

For all 6 projects:
• Visual and destructive control (thickness, bond, overlap - OK)
• Tracer gas test (no intrusion of tracer gas)
✓ Properly installed & well functioning membrane
Monitoring of indoor air concentrations

1. Measurement of indoor air concentrations (radon)

<table>
<thead>
<tr>
<th>Location</th>
<th>Indoor air radon-conc. Before Liquid Boot® [Bq/m³]</th>
<th>Indoor air radon-conc. After Liquid Boot® [Bq/m³]</th>
<th>Reduction [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential site (I),</td>
<td>&lt;30, &gt;250</td>
<td>&lt;30</td>
<td>Up to 88</td>
</tr>
<tr>
<td>Copenhagen</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Indoor air radon concentration < detection level
- Sufficient soil gas containment

2. Measurement of indoor air concentrations (PCE)

<table>
<thead>
<tr>
<th>Location</th>
<th>Indoor air PCE-conc. Before Liquid Boot® [µg/m³]</th>
<th>Indoor air PCE-conc. After Liquid Boot® [µg/m³]</th>
<th>Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry cleaning site (IV),</td>
<td>8, 51</td>
<td>3, 96</td>
<td>82</td>
</tr>
<tr>
<td>Aabenraa</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dry cleaning site (V),</td>
<td>12, 23</td>
<td>4, 67</td>
<td>75</td>
</tr>
<tr>
<td>Holstebro</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Indoor air PCE concentration equivalent to Danish MCL
- Sufficient soil gas containment

- Sinks may be reason (partly) for limited reduction (PCE-sites)
Off-gasses from membrane material

1. **Measurement of off-gasses** (TVOC’s) in indoor air **1 hr after installation** (active sampling, 2 hrs)
   - 200 µg/m³ (cure time appx. 24 hrs)

2. **Measurement of off-gasses** (TVOC’s) in indoor air **2-6 months after installation** (passive sampling, 2 weeks)
   - 600-1,400 µg/m³ (due to other sources)

3. **Measurement of off-gasses** (VOC’s) **Laboratory test** performed by CETCO, USA
   - No VOC’s detected (ASTM D6886)

✓ **OUR EVALUATION**...........no significant off-gas
Conclusions

1. **Spray application** implies installation advantages (time & tightness)

2. **Tracer gas tests** document a membrane install. w/ no leakages (well functioning membrane)

3. Monitoring data have shown **reduced contaminant concentrations in indoor air** after the membrane installation (reduction of vapor intrusion)

4. Monitoring data have identified **no significant unique off-gas** from the membrane material (no secondary risk)

✓ **Preferred alternative to traditional sheet applied membranes**
Installation of Liquid Boot® - a spray applied membrane - to reduce vapor intrusion

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Acknowledge co-authors

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- Jim Olsta, CETCO, USA
Thanks for your attention!

Questions?

Outdoor installation to new slab construction

Indoor installation to existing slab construction