

## Vapor Intrusion through Sewer Systems: Migration Pathways of Chlorinated Solvents from Groundwater to Indoor Air

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The presentation will focus on gas phase migration by advection and diffusion of chlorinated solvents into houses through the sewer system. The findings indicate that migration through the sewer system can be a very significant and maybe overlooked pathway for vapor intrusion. If overlooked the result may be unnoticed indoor air problems in houses located outside areas with soil and groundwater contamination.

In Skuldelev, Denmark, a plume of chlorinated ethenes (300 m in length) has been detected and delineated in a shallow aquifer. Chlorinated ethenes (primarily PCE) have been detected in the indoor air in 29 houses through repeated monitoring over a 5-year period. The affected houses are located both above the plume and outside the periphery of the plume. The PCE concentrations in soil gas, soil and groundwater have been investigated in detail at the locations of all the affected houses. Comprehensive investigations have been undertaken to map the migration pathways of the contaminants to the indoor air. The following methods have been applied for this purpose: Perfluorcarbon gas tracer test, Formier gas tracer test, thermography, continuous radon measurements, continuous differential pressure measurements, video inspection of sewer line, water and air sampling in sewer catch pits, and repeated sampling from vertical soil gas nests.

Results of a video inspection of the public sewer system running through and adjacent to the groundwater plume show a considerable influx of groundwater into the sewer at minimum eight locations along the 500 m section inspected. Analyses of water and air samples collected in the catch pits along the inspected section show that PCE concentrations are increasing in the sewer line with increasing distance from the source area. Maximum PCE concentrations in both the sewage water and the catch pit air are detected down gradient the section of the sewer line with the highest influx of contaminated groundwater.

At several houses along the inspected sewer line high concentrations of PCE have been detected in the indoor air. Differential pressure measurements between the sub-slab and the indoor air show a constant negative pressure in one of the affected houses. This results in a net advective contaminant transport into the house. Continuous measurements of radon concentrations in the house and in the sub-slab show a net attenuation factor of 250 across the floor of the house. This corresponds poorly to the measured PCE concentrations in the indoor air vs. in the sub-slab, indicating clearly that there is another source to the detected vapor intrusion than the soil gas. Tracer gas testing using two Perfluorcarbon tracers has verified this. One tracer (PMCP) was added in the outside catch pit. Results show a linear correlation ( $R^2 = 0.76$ ) between PCE and PMCP concentrations at the 15 data collection points representing all rooms in the house and that the concentrations of both compounds are decreasing with distance from the indoor sewer line entrance point.

Temporary sealing of the sewer line into the house has resulted in decreasing concentrations (2-10 times) in the indoor air. In order to mitigate the problem, a vapor barrier has been installed in the sewer catch pit at the site.

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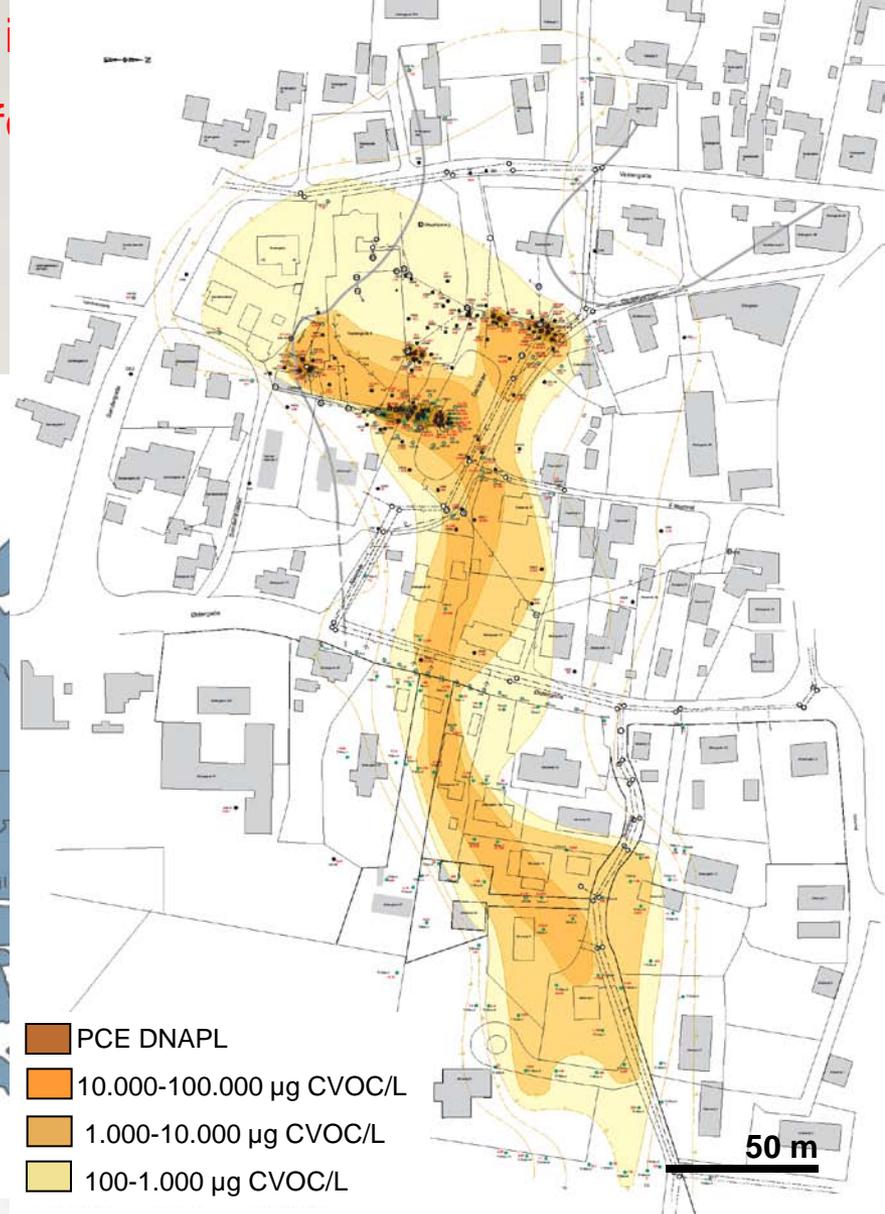
**Monterey, May 24 2010**

# Site description – Skuldelev, Denmark

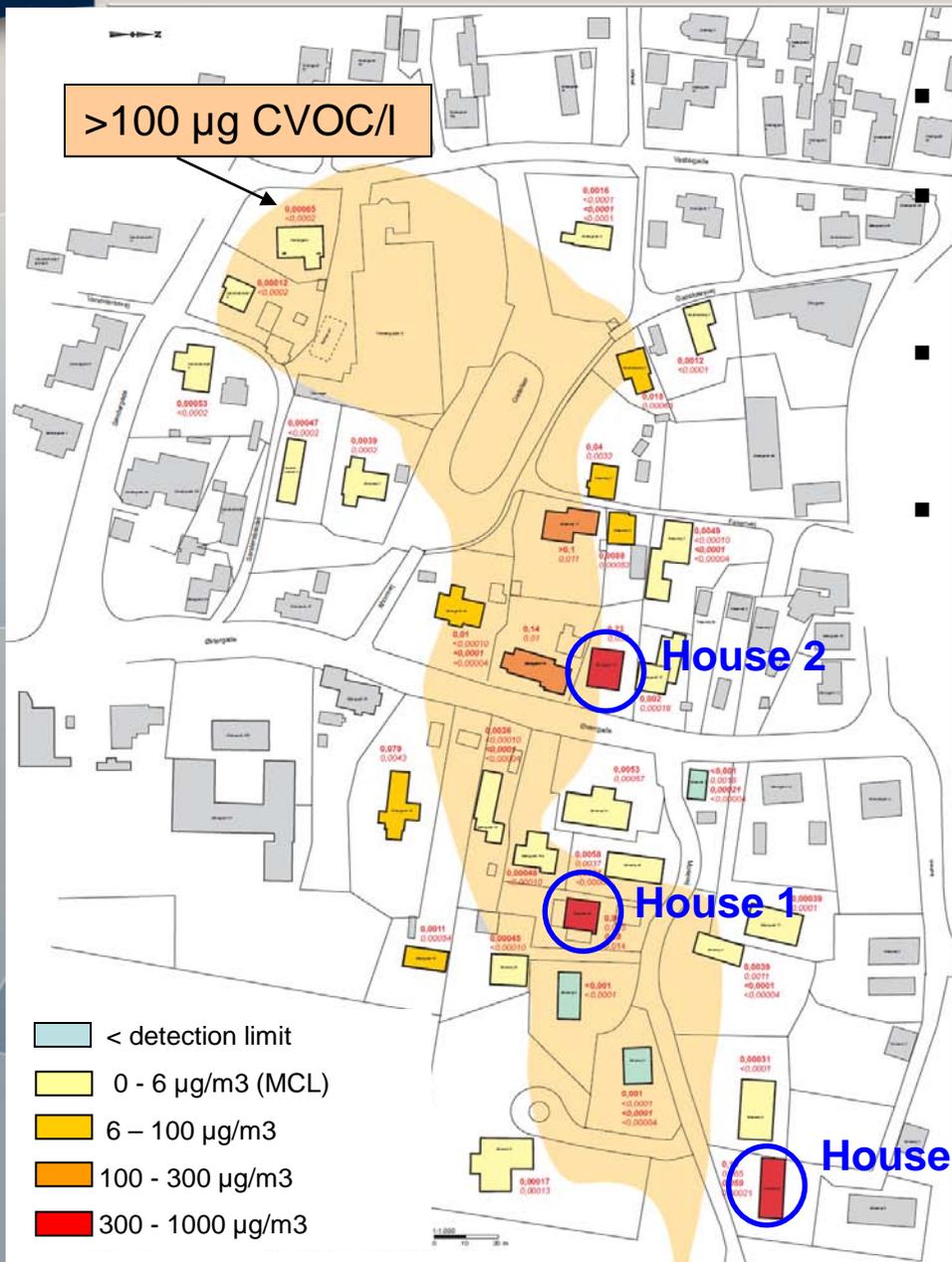


1969-1983  
PCE used for

- 7 PCE DNAPL hot spots
- 300 m long plume in sand layer 2-6 m bgl
- Variable geology above sand layer: Clay till – sandy fill
- Potential vapor intrusion problem in many houses above plume



# Indoor air measurements



- Measurements in 32 houses

- Semi-annual monitoring in 15 houses

- PCE and degradation products detected in indoor air

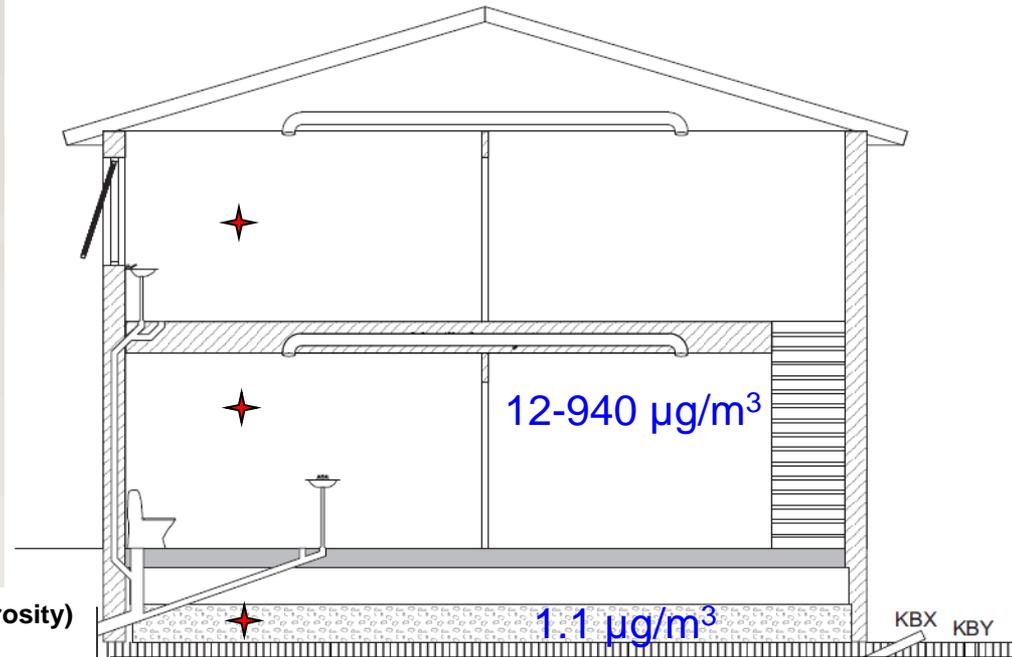
- No clear correlation between plume extent and locations of houses with vapor intrusion problems

Results from investigations in 3 houses with significant VI problems

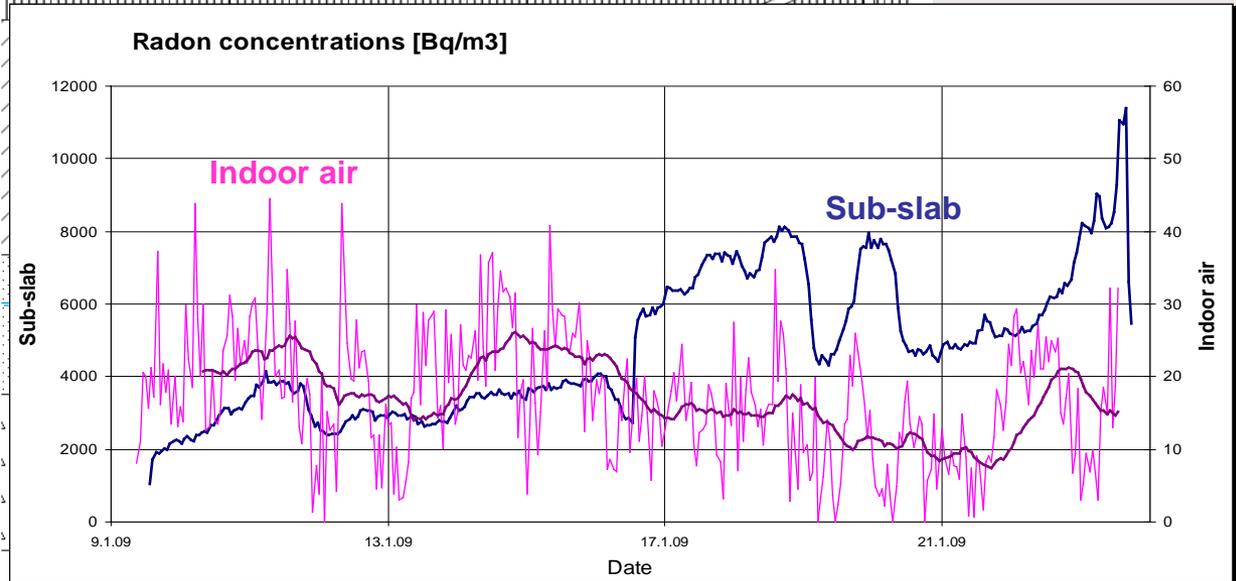
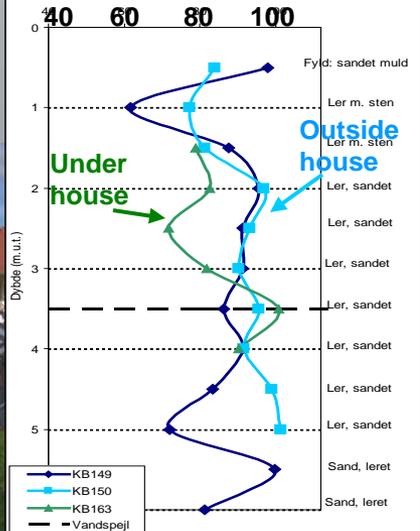
# House 1 investigations: source = soil gas?

✦ Continuous radon measurements in sub-slab and indoor air:

Attenuation factor 250

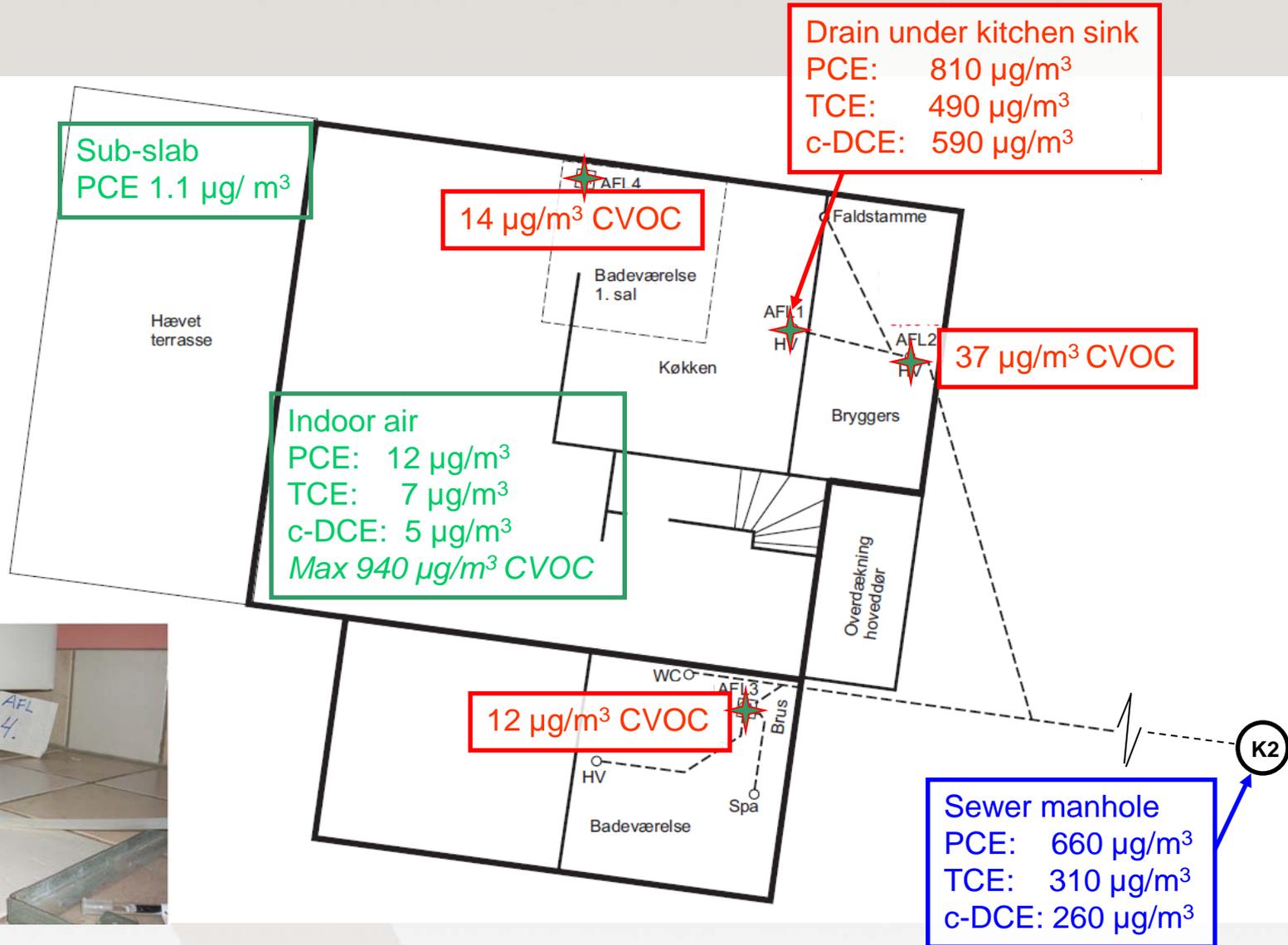


Water saturation (% porosity)





# House 1 – investigations: source = sewer?



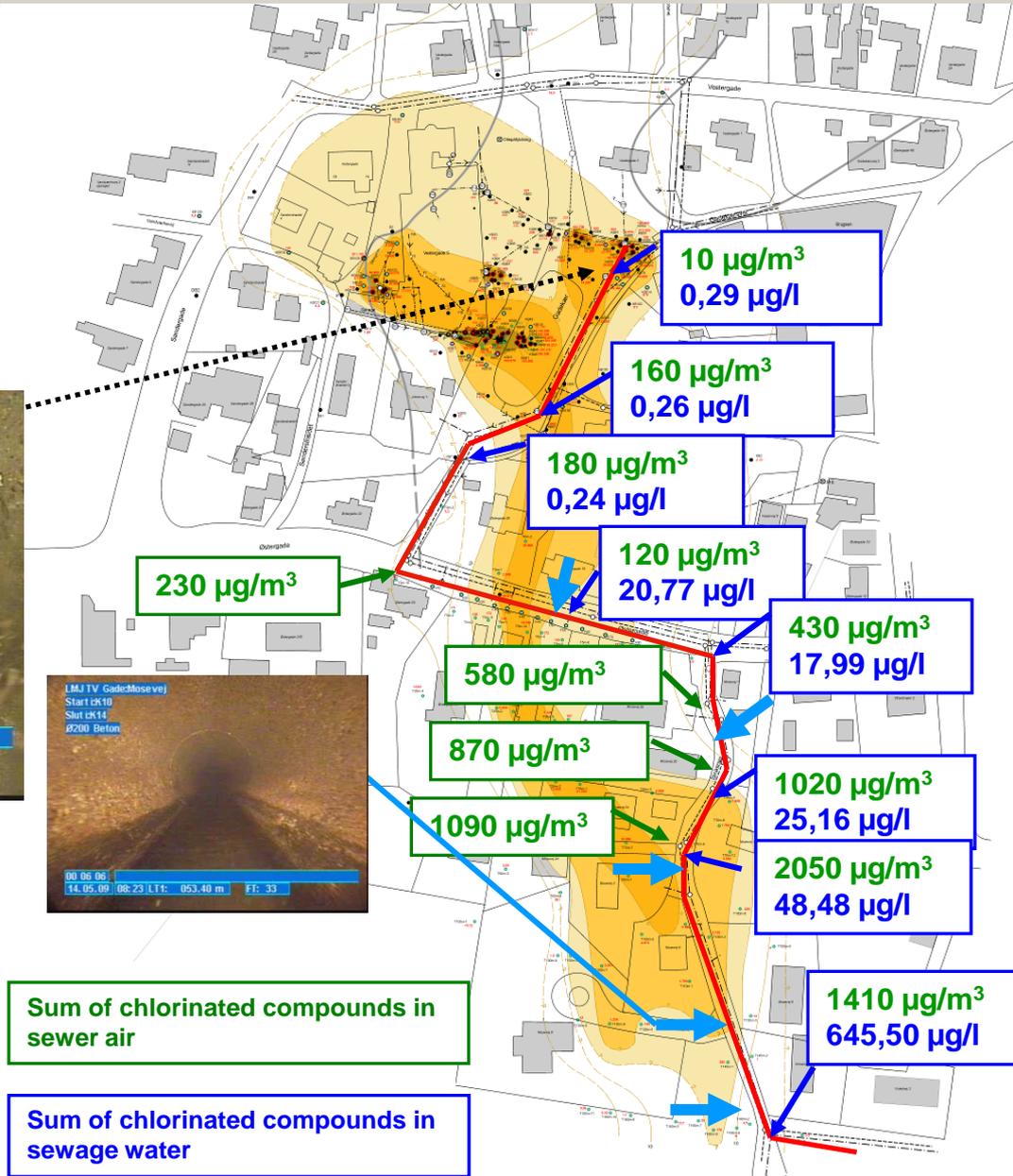
# Investigations of sewer line

- Video inspection of 500 m of the sewer line
- Registration of broken pipes, shear failures and influx of ground water

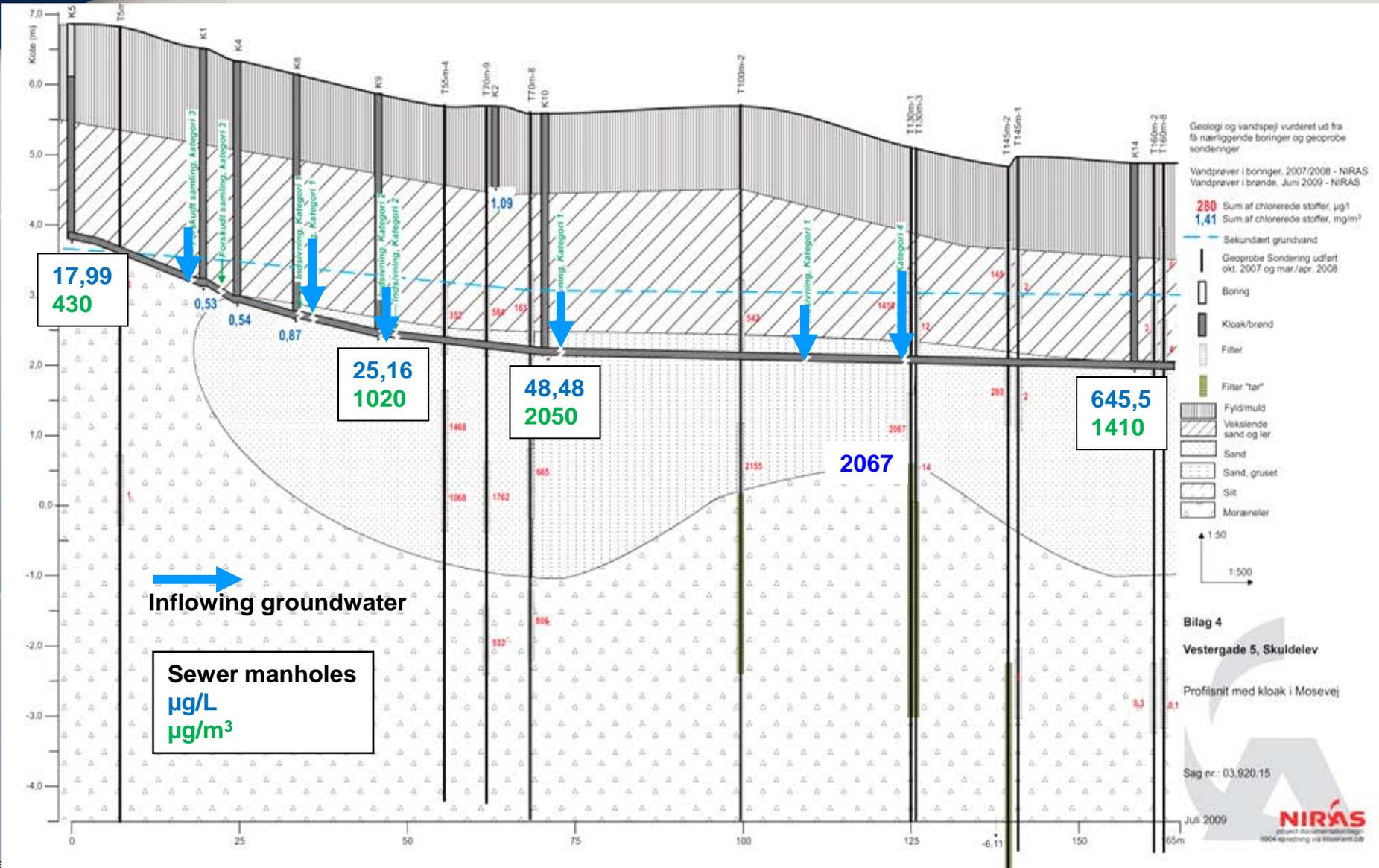
- Water
- Soil
- Air



- Significant degradation products in sewer system (water & air)



# Migration through sewer line – down gradient section



# Is the sewage system the primary migration pathway for vapor intrusion?

Investigations show:

- Vapor intrusion in houses
- Primary migration pathway related to drains in houses
- Significant CVOOC concentrations in sewer system

Documentation through Tracer gas testing:

- Active test: house 2
- Passive test: house 1, 2, 3

# Active tracer test: (5% H<sub>2</sub>/ 95% N<sub>2</sub>)

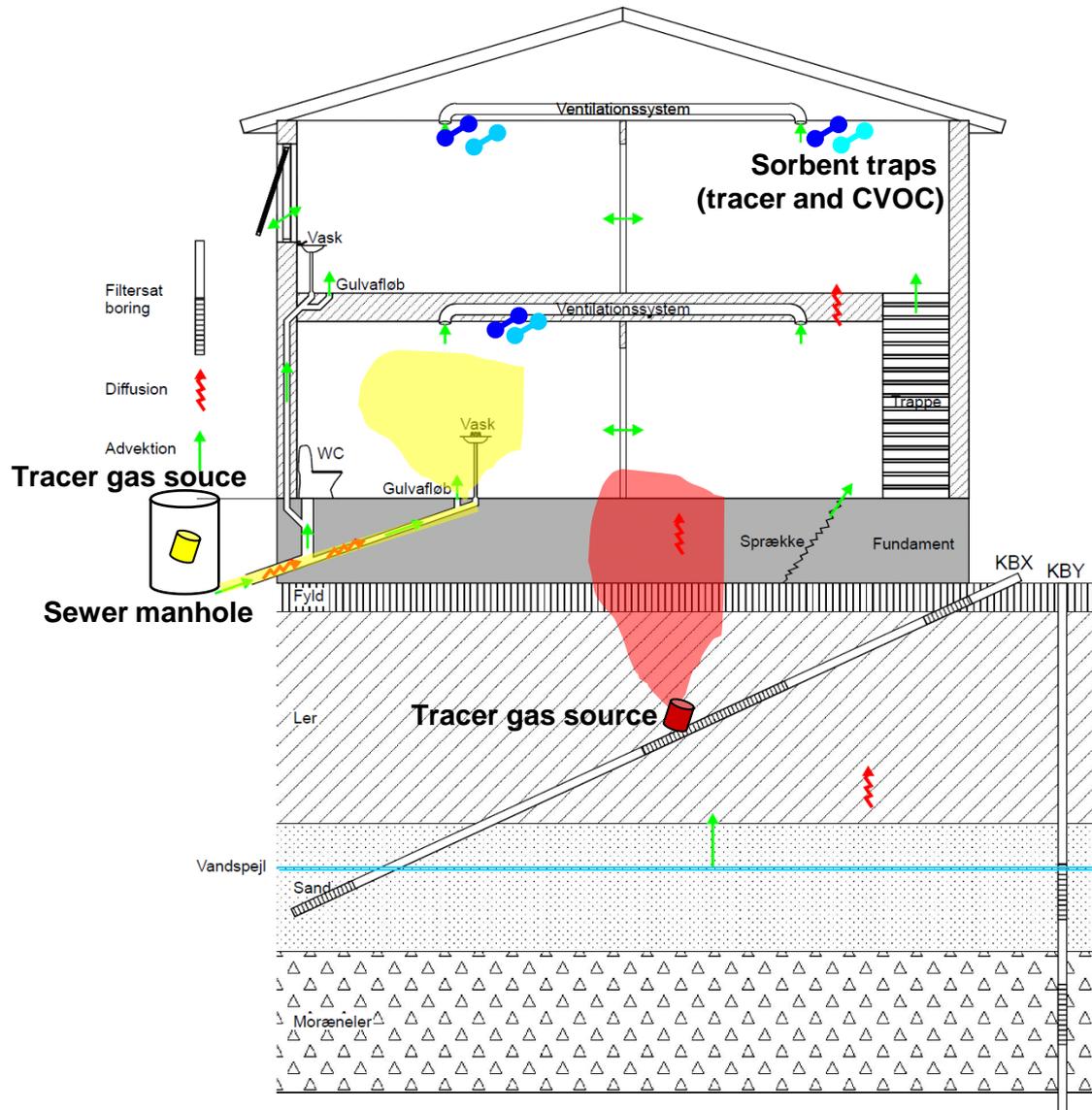


- Continuous injection of gas in sealed sewer manhole
- Handheld detector
- Leakage detection: joints, pipe penetrations, floor drains etc.
- No detection of diffusive pathways



**Per Loll: Tuesday 8.25 am G-session**

# Passive test: Perfluorcarbon (PMCP and PMCH)



- 2 different gas sources
- Gas source in sewer manhole and in angled well under building
- Passive samplers (sorbent traps) for tracers and CVOC at 15 sampling locations in the house
- Measuring period: 2 weeks

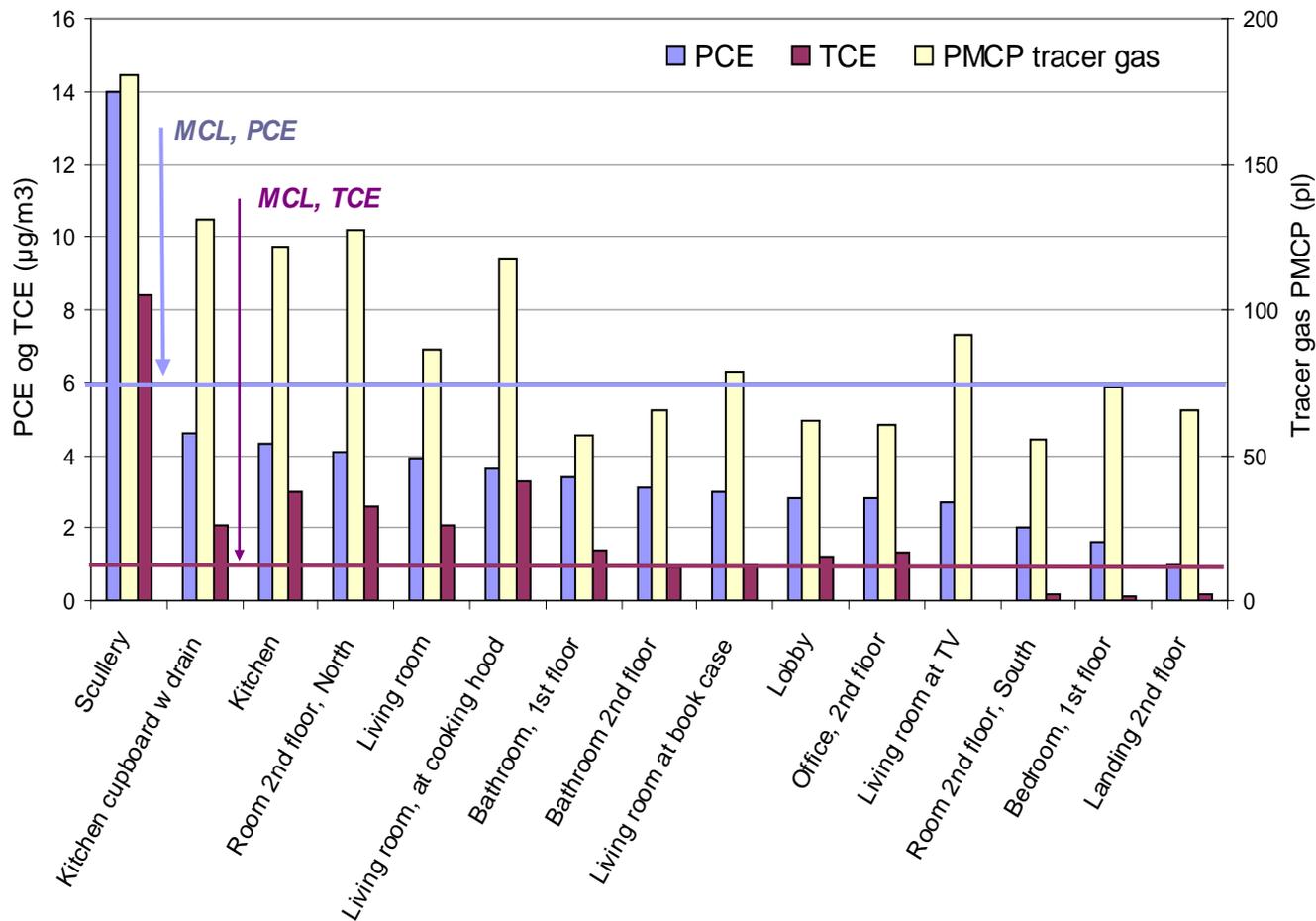
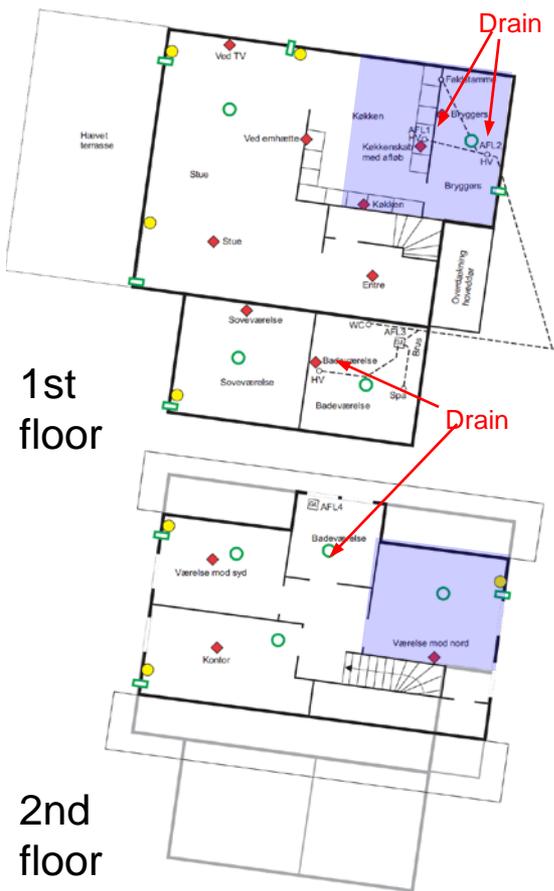


Tracer gas source

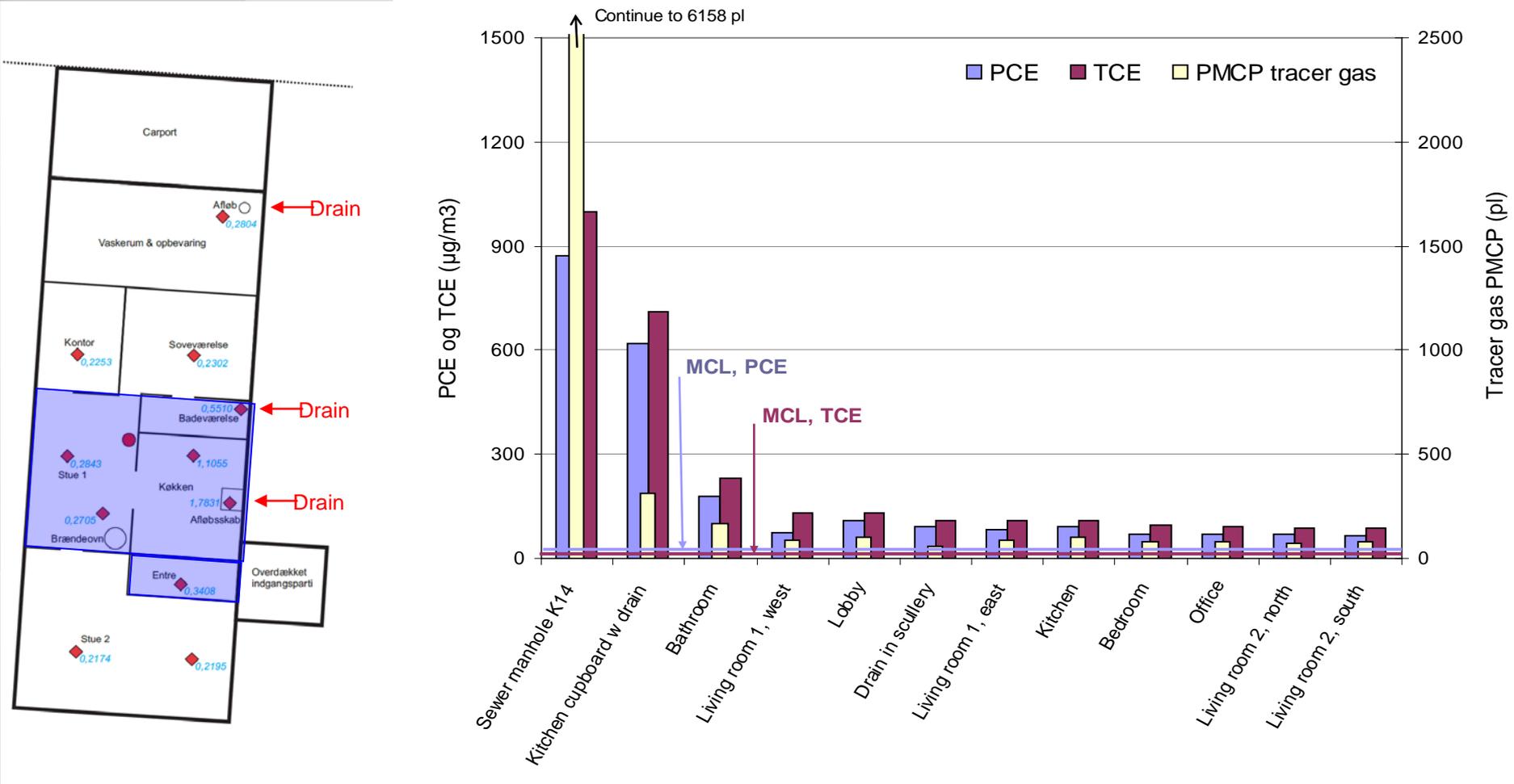


Sorbent trap for tracer

# Results: passive tracer test – house 1



# Results: passive tracer test – house 3

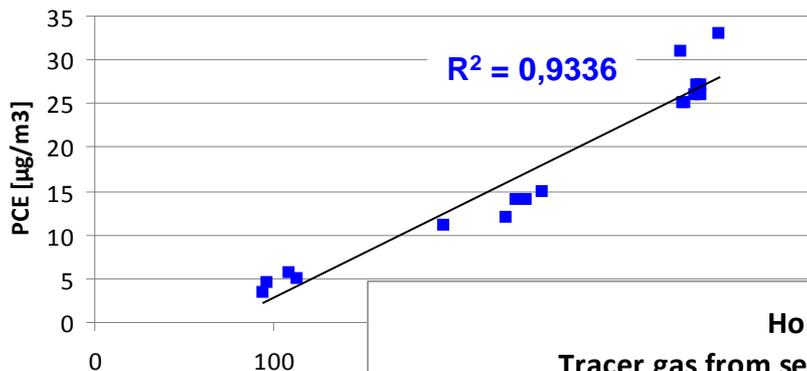


# Correlation between indoor CVOOC and tracer gas

Tracer gas and chlorinated compounds originate from the same source

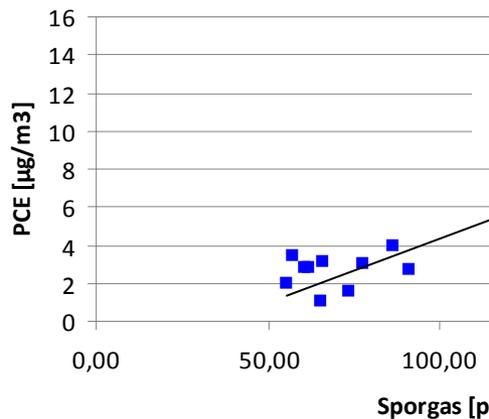
House 2

Tracer gas from sewer manhole vs PCE



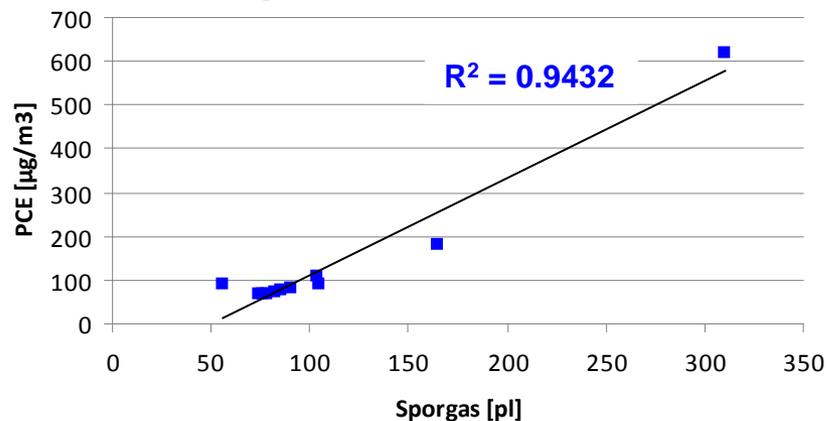
House 1

Tracer gas from sewer manhole vs PCE



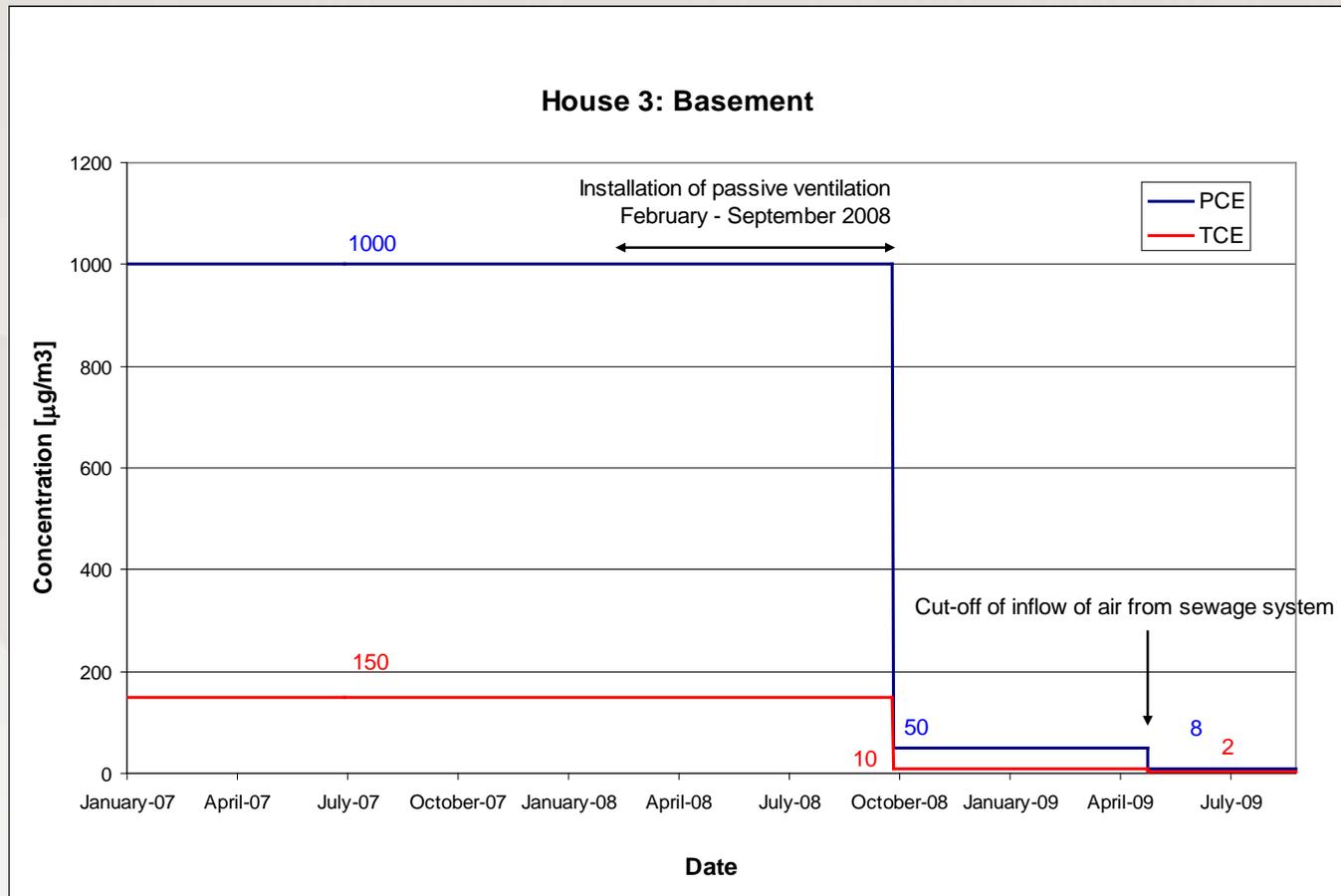
House 3

Tracer gas from sewer manhole vs PCE



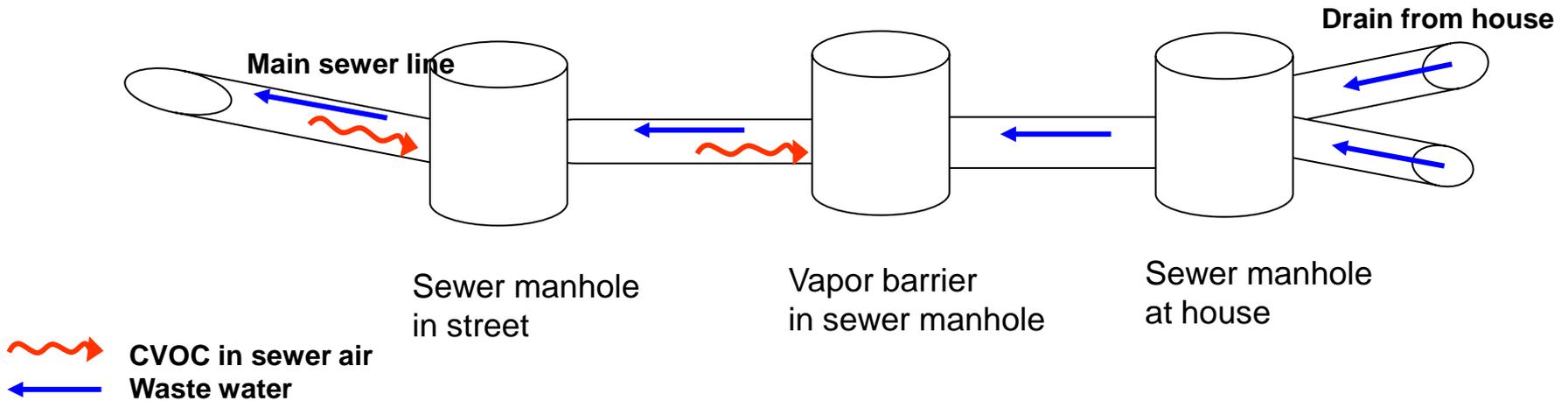
# Example of mitigation at house 3

- Mitigation of vapor intrusion from soil gas through passive ventilation in the basement sub-slab
- Contribution from sewer system ?
- Sealing of all drains, repeated measurement



# Example of mitigation at house 3

- Cut-off of air inflow between sewer line and building
- Installation vapor barrier in sewer manhole

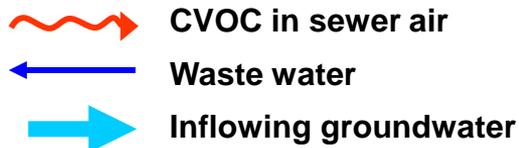
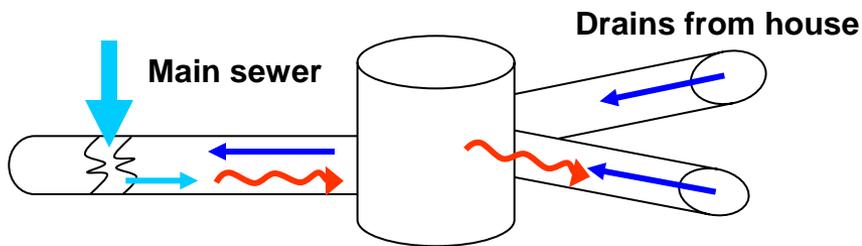


	$\mu\text{g}/\text{m}^3$	$\mu\text{g}/\text{m}^3$	$\mu\text{g}/\text{m}^3$
PCE	80	<1	<1
TCE	59	<0,1	<0,1
<i>cis</i> -DCE	37	<0,1	<0,1
VC	0,46	<0,04	<0,04

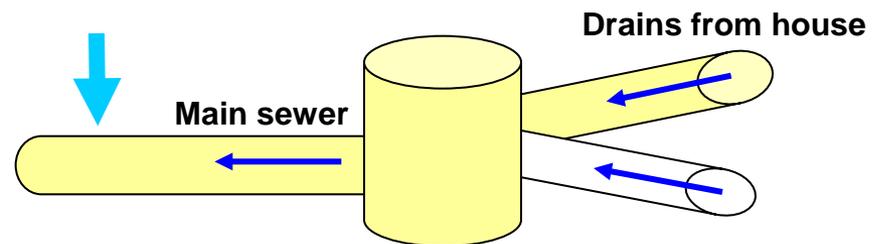
# Example of mitigation for the area around the sewer

- Cut-off of influx of contaminated groundwater from main sewer line
- Re-lining of main sewer line, local sewer lines, and sewer manholes
- Sealing of sewer lines will be carried out in May-August 2010

## Before re-lining



## After re-lining



## Investigations

- Influx of contaminated groundwater to the sewer line through fractures and shear failures
- Both PCE and degradation products have been detected in the sewer manhole air and water
- Gas phase transport of contaminants into the sewer line is insignificant
- Advective transport of groundwater into the sewer line is the primary migration pathway of contaminants
- Contaminants in inflowing groundwater vaporize to the sewer air and are advecting and diffusing into the houses through the sewer installations – creating vapor intrusion problems in houses along the sewer line
- Tracer gas testing document transport of contaminants into the houses through the sewer air

## Conclusions (2/2)

### Mitigation

- Cut-off of influx of contaminated groundwater into the sewer line i.e. through re-lining of the entire sewage system within the contaminated area
- Cut-off of sewer air into a specific house i.e. through installation of a vapor barrier in the sewer manhole

### Perspective

- At other sites - Do we overlook vapor intrusion problems in houses located outside the contaminated area



**Thank you!**

**Questions????????**