
Thermally Enhanced
In Situ Source Zone Removal
reconsite
VII Seminário Internacional Sobre
Remediação e Revitalização
de Áreas Contaminadas
São Paulo, 21.10.2010
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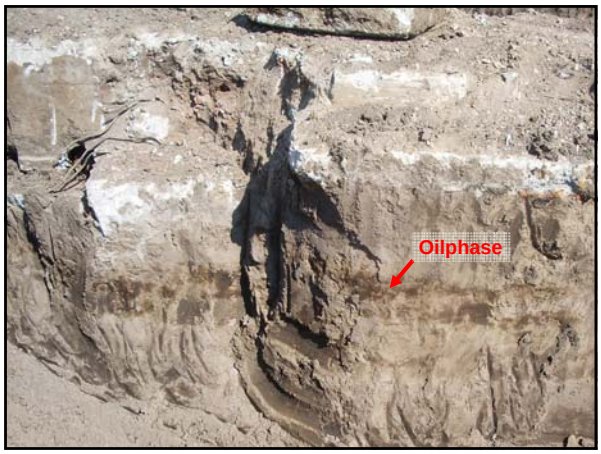
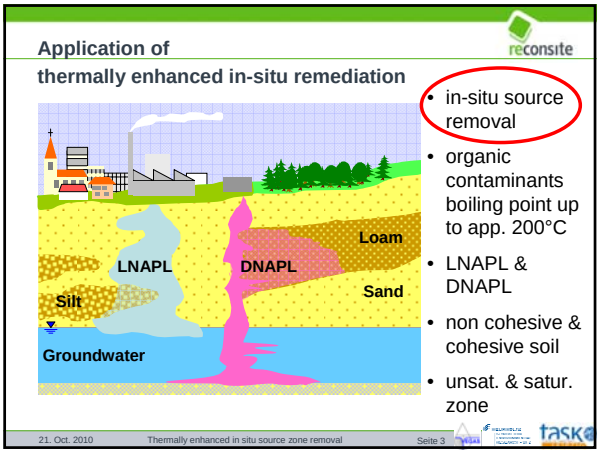
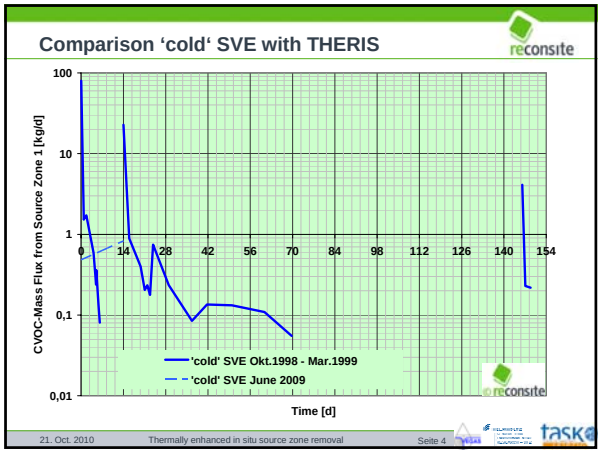

Oilphase


Application of
thermally enhanced in-situ remediation
reconsite
LNAPL
DNAPL
Loam
Sand
Silt
Groundwater
• in-situ source removal
• organic contaminants boiling point up to app. 200°C
• LNAPL & DNAPL
• non cohesive & cohesive soil
• unsat. & satur. zone
21. Oct. 2010
Thermally enhanced in situ source zone removal
Seite 3


Comparison 'cold' SVE with THERIS
reconsite
CVOC-Mass Flux from Source Zone 1 [kg/d]
100
10
1
0,1
0,01
0
14
28
42
56
70
84
98
112
126
140
154
'cold' SVE Okt.1998 - Mar.1999
'cold' SVE June 2009
Time [d]
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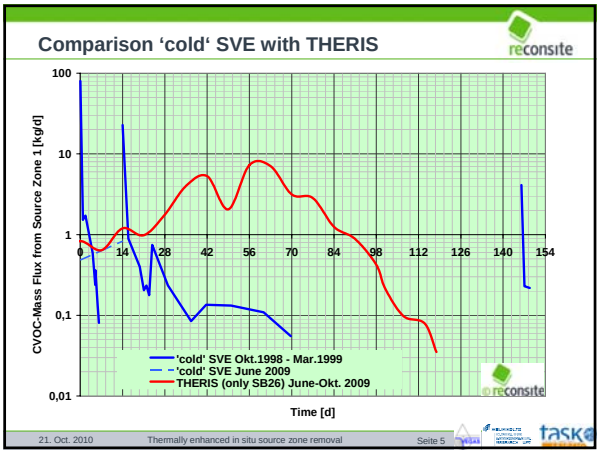
Thermally enhanced in situ source zone removal
Seite 4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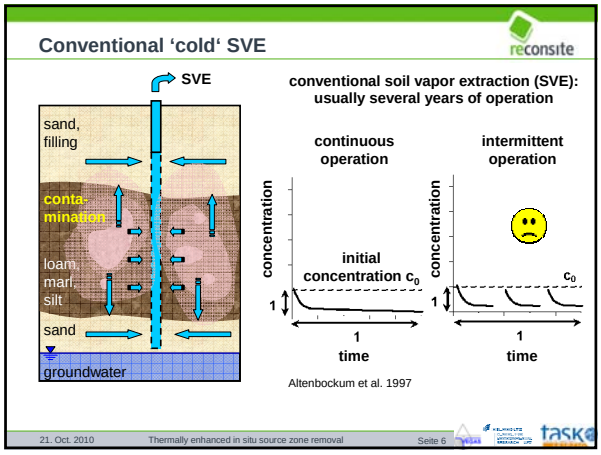
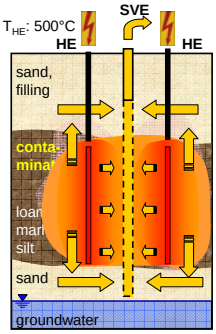
'cold' SVE Okt.1998 - Mar.1999
'cold' SVE June 2009
THERIS (only SB26) June-Okt. 2009
Time [d]
21. Oct. 2010
Thermally enhanced in situ source zone removal
Seite 5


Conventional 'cold' SVE
reconsite
SVE
sand, filling
contamination
loam, marl, silt
sand
groundwater
conventional soil vapor extraction (SVE):
usually several years of operation
continuous operation
intermittent operation
concentration
initial concentration c0
c0
1
time
Altenbockum et al. 1997
21. Oct. 2010
Thermally enhanced in situ source zone removal
Seite 6

Thermally enhanced SVE



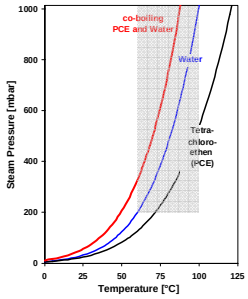
- soil vapor extraction (SVE)
- air treatment system

Target:

- liquid contaminant (10 °C) ⇒ gaseous phase
- short remediation time

THERIS = **Ther**mally enhanced in-**s**itu remediation with thermal wells

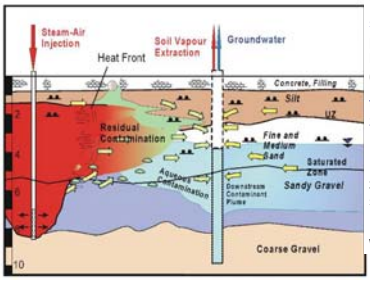
Boiling of water and contaminant phase



Thermally enhanced in-situ remediation

- **convective heat supply into soil layer with good to high permeability e.g. sand**
  - ➢ **Steam- (Air-) Injection (TUBA-method)**
- **direct heat generation e.g. in dry or humid sand**
  - ➢ **Radio frequency**
- **conductive heat supply into soil layer moderate to low soil permeablility, e.g. silt, loam, clay**
  - ➢ **Thermal wells (THERIS-method)**

Steam-Air Injection: Field of Application



vadoze zone:
high to medium permeability (gravel to sandy silt)

saturated zone:
porous aquifers
K: 5 x 10^{-5} to 1 x 10^{-3} m/s (sand -> silt) for

thermal range in saturated zone:

- **K: 0,5 – 5 x 10^{-4} m/s**
- **radial steam propagation: 3 - 5 m in radius for 150 kg/h steam (120 kW)**
- **the higher anisotropy the wider steam propagation**

Zeitz - Impressions From The Pilot Field

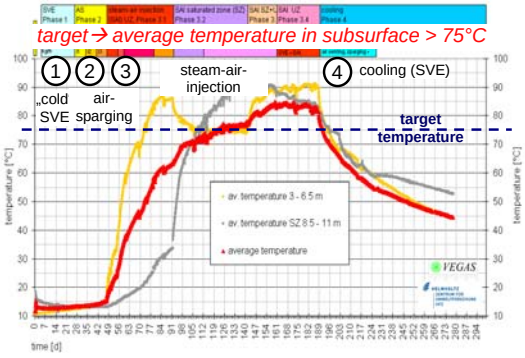
Remediation goals of the pilot in-situ remediation

- *→ horizontal radial steam expansion > 2.5 m in the saturated zone*
- *→ reduction of benzene concentration in soil vapor > 99%*
- *→ removal of contaminant mass > 95%*
- ***→ to be achieved during six months** (1600 m³ of soil)*

injection well

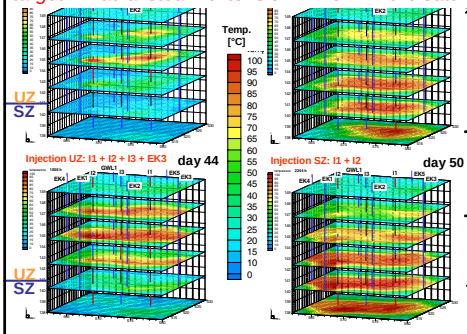
test field during operation (June 2007)

Zeitz - Heating Of The Subsurface



Zeitz - Heat Propagation

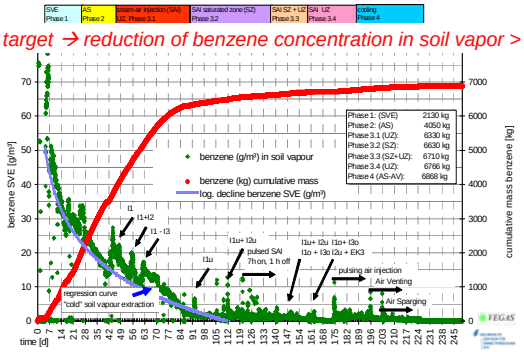
target → radial steam extension > 2.5 m in the saturated zone



- → injection in extraction well EK3 to steam the vadoze zone
- → symmetric steam propagation
- → "thermal radius" ~ 5m
- → operation of two wells

Zeitz - Mass Extraction of Benzene by SVE

target → reduction of benzene concentration in soil vapor > 99%



Indication of Remediation Progress by SVE

- →reduction of benzene concentration in SVE by 99%
- →removal of more than 99% in soil (soil vapour-soil eq. K_{OC}-method) 0.16 mg benzene / kg soil
- →soil sampling eight months after steam-air injection confirmed 0.1 mg/kg for unsaturated zone and 0.5 mg/kg including saturated zone

Zeitz - Summary

Heating of Subsurface

- → effective heating to exceed target temperature
- → effective, fast & wide-ranging steam propagation in saturated zone

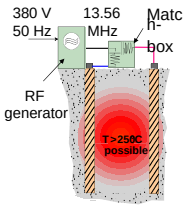
Remediation Progress

- → mass extraction by „cold" SVE and air-sparging (59% of total mass)
- → remediation target achieved by SI (35% of total mass in 13 weeks)
- → minor mass of Benzene in saturated zone: approximately 300 kg (~ 4%)

Remediation goals

- → **mass removal:** more than 99% of Benzene extracted (6,75 to Benzene)
- → **groundwater:** reduction of benzene concentrations by 75%

Set up and working principle of dielectric soil heating



- Similar to microwave oven
- fast re-orientation of polar molecules (e.g. water) or other polar structures in the external electrical field

- interaction within the material
- heat formation

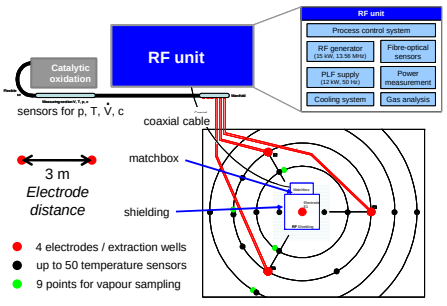
Applied electrode geometries

- Parallel plate or net-shaped electrodes
- Arrays of rod-like electrodes *(optional: also used as extraction wells)*
- Radio-wave antenna

ISRFH with a modular RF system

Arrangement for ISRFH project





ISRFH – new electrode design

Site characterization *Electrode / extraction well*

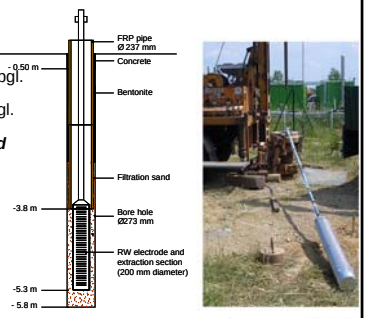
Soil: very inhomogeneous

Groundwater table: 8.5 m bgl.

Lignite: > 9 m bgl.

Treatment of the ***unsaturated zone*** between 3 and 7 m bgl.

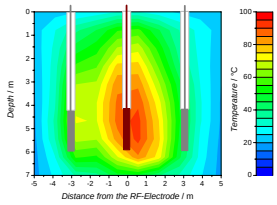
Contamination:
mainly benzene < 3.5 g/kg
variety of aromatic and aliphatic VOC



ISRFH with a modular RF system

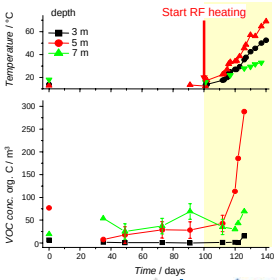
Temperature profile

Temperature distribution in a soil volume of about 300 m³ after 60 d RF heating with 15 kW



VOC concentration

Increase in VOC concentration by a factor of 4 to 8

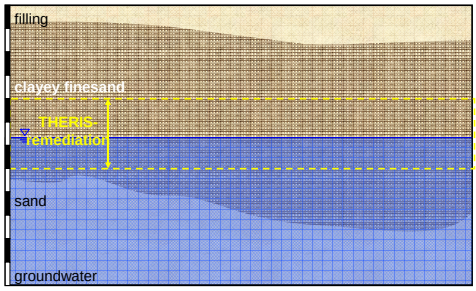


Heat transport supported by SVE
Radius of influence up to 5 m

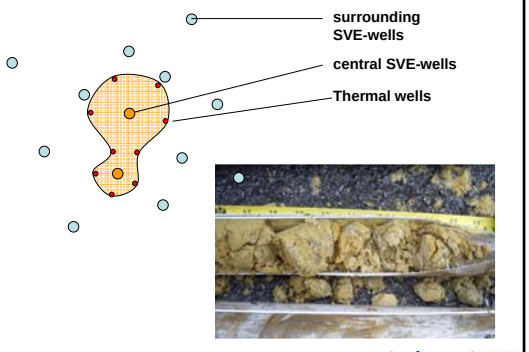
ISRFH – Main Results

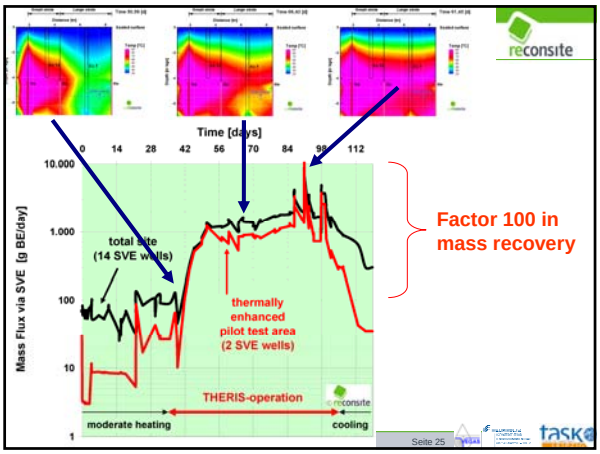
- The demonstration project consisted of three stages:
  1. „cold" SVE (24 days),
  2. RF heating alone (18 days)
  3. combined SVE + RFH (36 days)
- App. 300 m³ were heated to a mean temperature of 54°C.
- The radius of influence for RF heating was about 5 m.
- SVE supported heat transport in the soil.
- Extraction of VOCs was significantly enhanced by heating although quantification was difficult due to interference with the soil around the demonstration site (1.3 tonnes were eliminated).

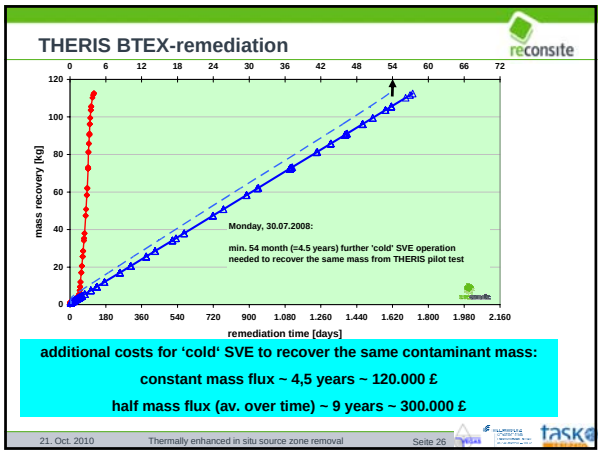
Site D: BTEX-petr. hydrocarbon remediation



Site D: BTEX-petr. hydrocarbon remediation




reconsite
Time [days]
0 14 28 42 56 70 84 98 112
10.000
1.000
100
10
1
Mass Flux via SVE [g BE/day]
total site
(14 SVE wells)
thermally
enhanced
pilot test area
(2 SVE wells)
THERIS-operation
moderate heating
cooling
Factor 100 in
mass recovery
Seite 25


THERIS BTEX-remediation
reconsite
mass recovery [kg]
remediation time [days]
Monday, 30.07.2008:
min. 54 month (=4.5 years) further 'cold' SVE operation
needed to recover the same mass from THERIS pilot test
additional costs for 'cold' SVE to recover the same contaminant mass:
constant mass flux ~ 4,5 years ~ 120.000 £
half mass flux (av. over time) ~ 9 years ~ 300.000 £
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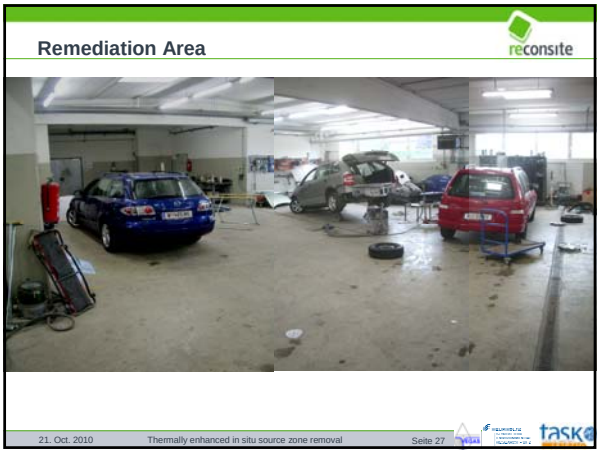
Remediation Area
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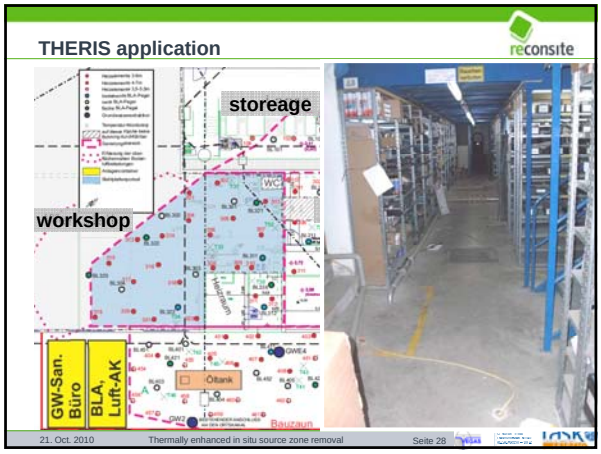
THERIS application
reconsite
storeage
workshop
GW-San.
Büro
BLA,
Luft-AK
Ölbank
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Thermally enhanced in situ source zone removal
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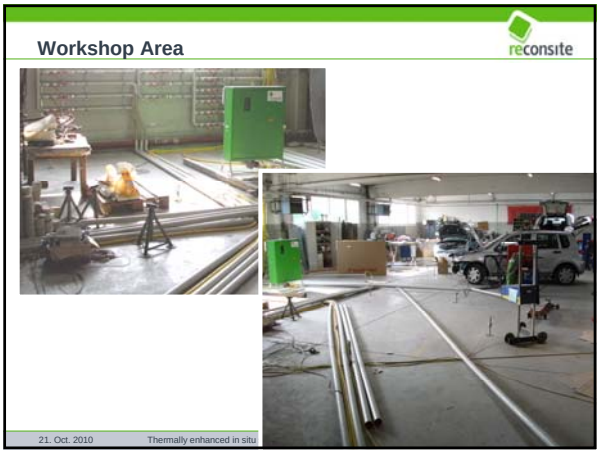
Workshop Area
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Thermally enhanced in situ


Street View
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Thermally enhanced in situ source zone removal
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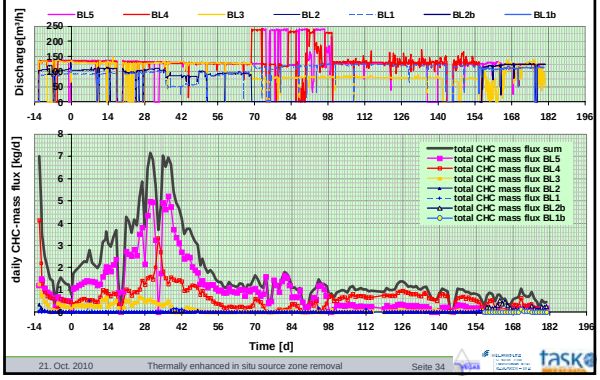
Treatment Container

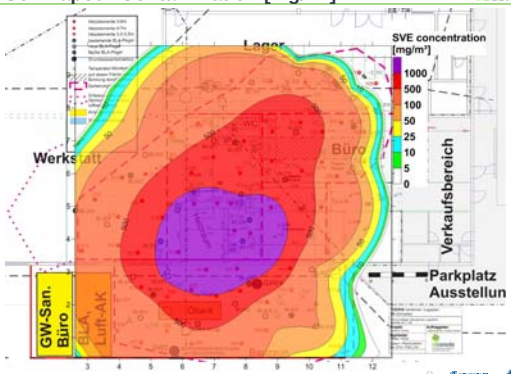
Online Measurement Systems

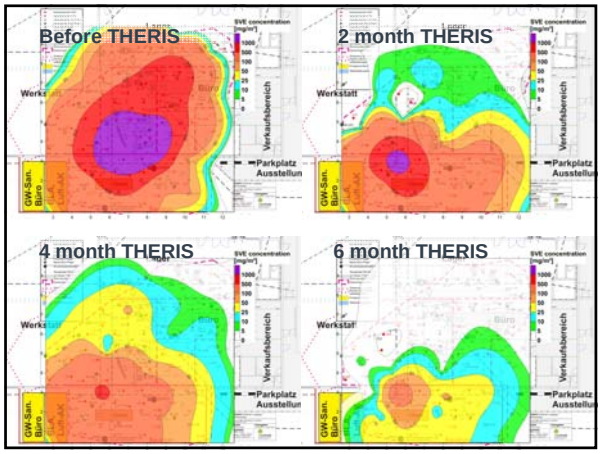
Online Measurement Systems

Mass flux BL1 – BL5 [kg]

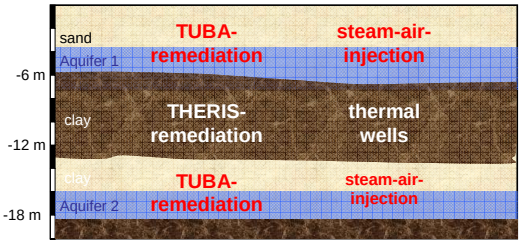


Soil Vapour Contamination [mg/m³]

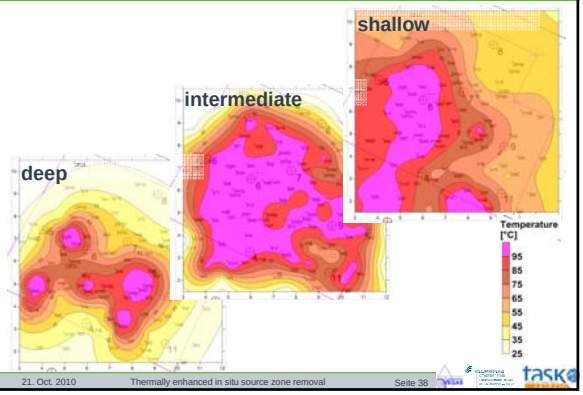




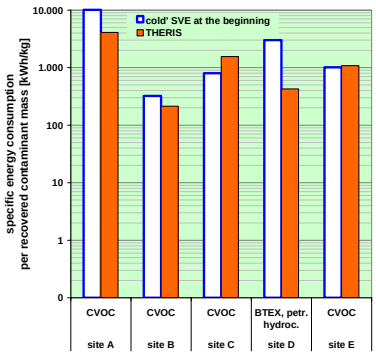
TUBA-THERIS-TUBA combination @ industrial site



Temperatures after 80 days



Workshop usage during THERIS remediation



Evaluation of the technology

Eurodemo sustainability demands:

- **processes understood**
- **results from applications are well documented**
- **high contaminant extraction rates**
- **fast decontamination**
- **costs & environmental impacts are significantly less**

Conclusions

- Thermally enhancements can be efficiently applied for the in-situ remediation of the **unsaturated and the saturated zone**.
- Thermally enhancements can enable a **continued usage of** the **building during remediation**.
- Thermally enhancements consume **less energy than 'cold' SVE**.
- The quality of **site evaluation** effects the **quality of the design**.
- The **remediation goals** can effect the **efficiency**.

Heat-up and relax

Thermally enhanced In-situ-Remediation

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