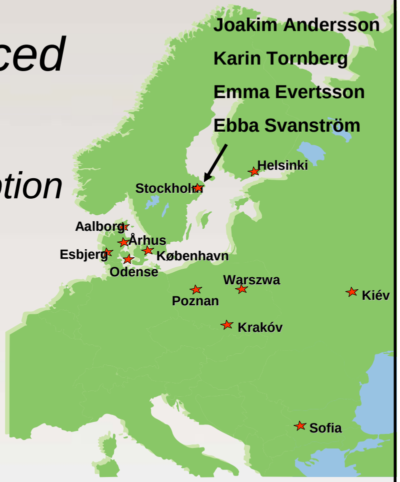
NIRAS

Thermally enhanced remediation

In Situ Thermal Desorption

Tom Heron

Division Director, geologist



1050 colleques

250 environmentalists

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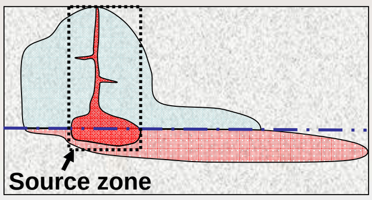
Important tools in the toolbox

- Heavily contaminated source zones
- Stringent remediation requirements
- Fast clean-up
- Large volumes
- Clay/silts/fractured
- Deep contamination
- Many contaminants and mixtures



Treatable contaminants

- Chlorinated Ethenes
- Oil products, BTEX
- Coal Tar
- Creosote
- PAH's, Naphthalene
- PCB's
- Chlorobenzenes
- Pentachlorophenol (PCP)
- Dioxins
- Mercury
- Many pesticides
- Mixtures

Data on much of this in NIRAS' and Krügers booth up stairs!!

Remediation Mechanisms

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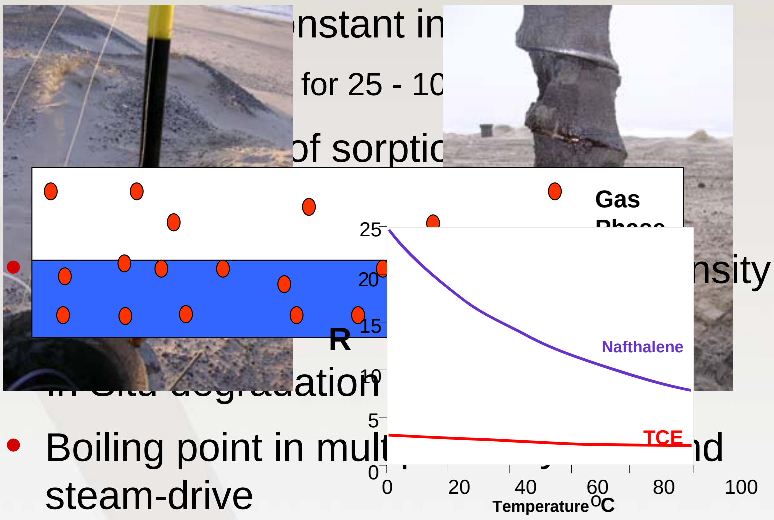
Mechanisms and values for TCE

- Vapor pressure increases
  - TCE: 18 times for 10 - 100 °C



- Boiling point in mult… nd steam-drive

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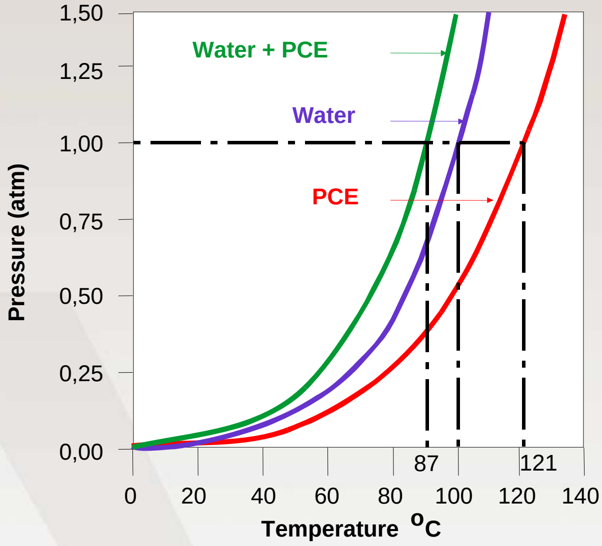
Boiling point in a two phase system



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Technologies

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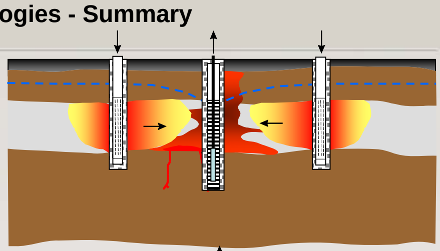
Important Heating Technologies - Summary

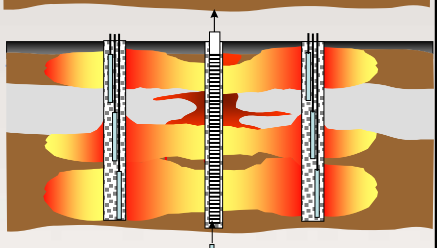
Steam

SEE - heating governed by **hydraulic conductivity** – non-uniform steam flow



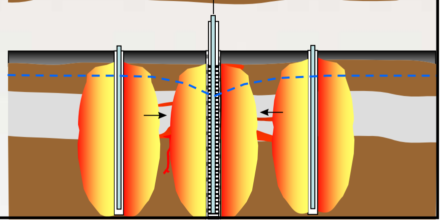
Electrical

ERH - heating governed by **electrical conductivity**

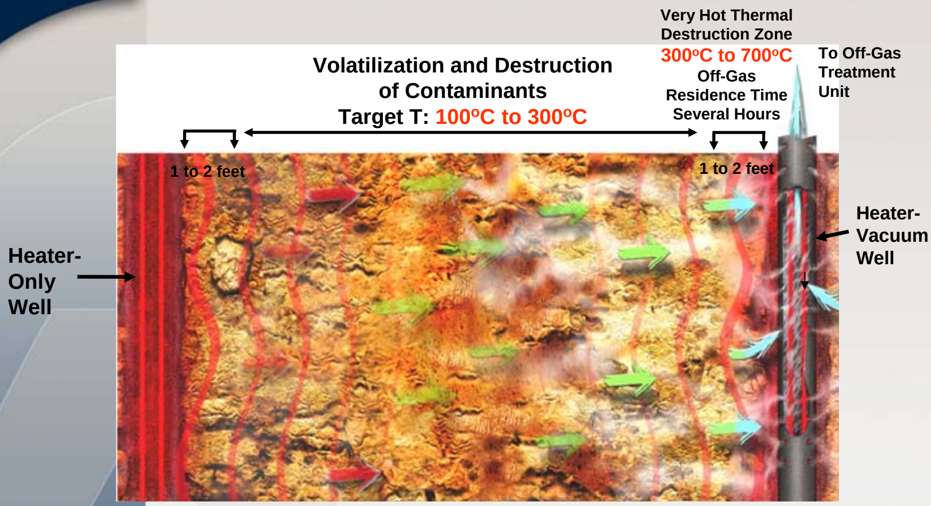


Conductive

ISTD/TCH - heating governed by **thermal conductivity** – nearly uniform distribution of heat



In Situ Thermal Desorption and destruction



Important design issues:

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Important design issues

- Goals / effect on risk or value
- Time
- Price
- Liquid and vapor capture
- Condensation fronts
- Boiling water is expensive
- Temperature distribution
- Energy balance
- Organic rich soils
- Underground utilities / buildings etc.

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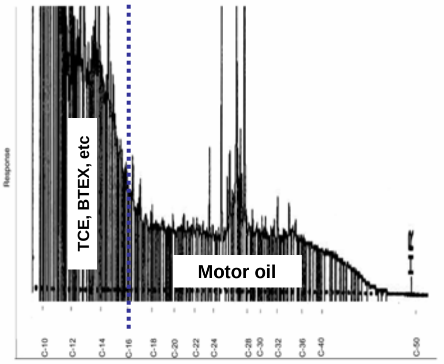
Examples of completed projects

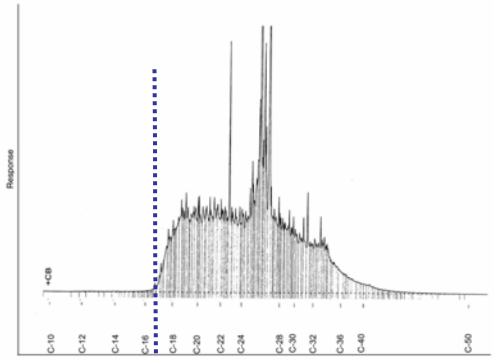
Naval Air Station Alameda, Site 5, San Francisco

Goal: MCL in soil and groundwater for BTEX og chlorinated solvents
TCE: 2 mg/kg og 5 µg/l

Typical chromatogram:
Soil before Steam

After thermal treatment



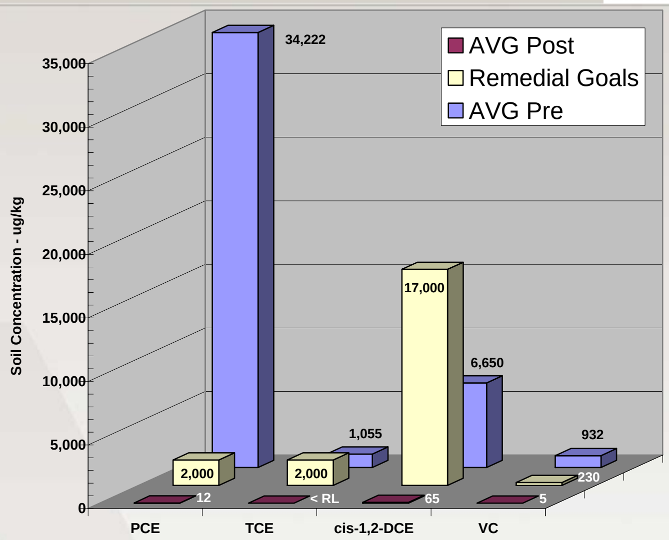


Courtesy of Kent S. Udell

UC Berkeley

ISTD – Free phase PCE in tight alluvial clay

Results – Average concentrations



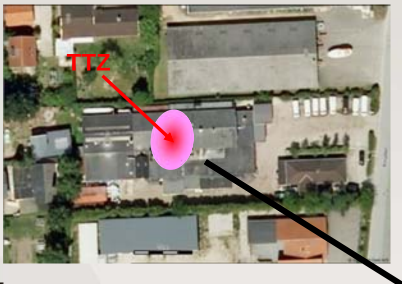
Reductions: 99.96% 99.63% 99.03% 99.49%

Results are based on 17 pre-treatment and 64 post-treatment samples

Ongoing Danish Projects

Knullen – Odense, Denmark

Worlds first thermal remediation using af combination of steam and ISTD



COC's: PCE, chlorinated solvents (800 kg)

Soil: Clay and sand

Treatment interv.: 3 – 14 m.b.g.

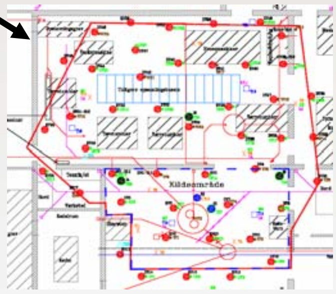
Area: 240 m²

Volume: 1.900 m³

Estimated cost: 15 mio. dkr

Number of HV-borings:	45
Steam injection wells:	5
Steam extraction wells:	2

All wells installed under a building



Region Syddanmark

Skuldelev – Denmark

Full-scale design based on results from pilot test

Pilot test, Skuldelev

COC's: PCE, chlorinated solvents (4000 kg)

Soil: Clay and sand

Treatment depth: 7,5 meters

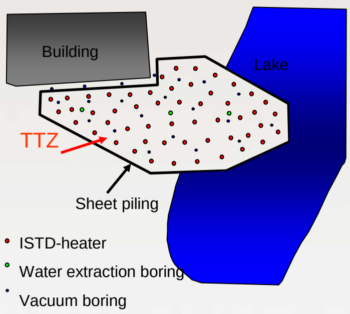
Area: 250 m²

Volume: 1.600 m³

Estimated cost: 12 mio. dkr

ISTD-wells:	53
Vacuum wells:	21
Water extraction wells:	3

Monitoring well, Skuldelev



Region Hovedstaden

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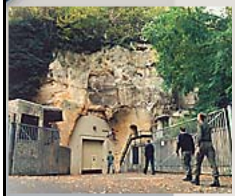
Ongoing projects



Netherlands – Confidential site

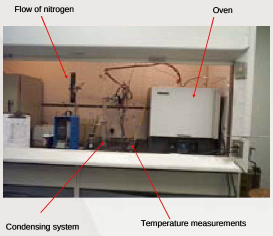
COC: Diesel (mass currently unknown)

Soil: Fractured limestone

Treatment depth: 6,5 meters

Area: 100 – 3.500 m²

Design based on treatability study – indicated remediation efficiencies better than 99.9% at treatment temperatures between 100 and 200 °C.



Test setup – laboratory experiments

Witteveen Bos

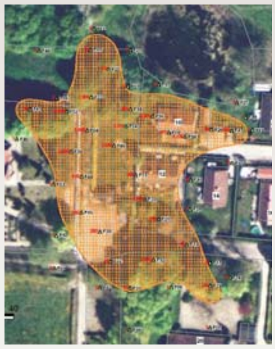
Reerslev – Denmark

COC: PCE – 10.000 kg

Soil: Clay

Treatment depth: 8 meters

Area: 900 – 4.700 m²



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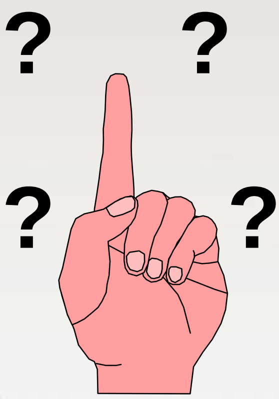
Thank you and:



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Physical processes/changes (below 120 °C)

Component property	Oil based LNAPL	Chlorinated solvents	Creosote	Coal tar	PCB	Comment
Vapor pressure increase factor	**20-40**	**20-40**	**20-40**	**20-40**	**20-40**	Abundance of data in literature
Solubility increase factor	2-100?	1.5-3	10-1000	10-1000	10-1000	Chlorinated solvent less affected than larger hydrocarbons
Henry's constant increase factors		10-20	0-10	0-10	0-10	Data absent for most compounds, some decrease?
Viscosity reduction factor	2 to 100+	1.3-3	5-10	20-100+	3-100	The higher initial viscosity, the more reduction
Interfacial tension reduction factor	<2	<2	2-5	1-5	<5	Typically not dramatic effect (less than factor 2)
Density reduction (%)	10-20	10-20	10-20	10-20	10-20	Note that DNAPL may become LNAPL
K_d (reduction factor)	?	1-10	5-100	5-100	NA	Estimates based on limited data

Udell (1989, 1991, 1993, 1996).
Davis (1997, 1999).
Imhoff et al. (1997).
Sleep and Ma (1997).
Heron et al. (1998, 2000).

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Energy consumption (kWh/m³)

	Initial water content			
	100 %	80 %	10 %	0 %
Heating to 100 ºC, wet	80	61	47	43
Heating to 100 ºC & evaporating all porewater	299	171	69	43
Heating to 200 ºC	347	219	117	91

Target temperatures

	VOC	SVOC
Above water table	90-100 ºC (ERH, SEE, ISTD)	300 ºC (ISTD) ▼
Below water table	100-120 ºC (ERH, SEE, ISTD)	100 -120 ºC partial removal (ERH, SEE, ISTD low int.) 300 ºC complete removal (ISTD, dewater)

ERH: Electrical Resistivity Heating

SEE: Steam Enhanced Extraction

ISTD: In Situ Thermal Desorption

In Situ Thermal Desorption

PCB´s

ISTD: PCB Field Projects - Results

Location	Contaminant	Initial Max. Concentration (ppm)	Final Concentration (ppm)
S. Glens Falls, NY	PCB 1248/1254	5,000	< 0.8
Cape Girardeau, MO	PCB 1260	20,000	< 0.033
Vallejo, CA	PCB 1254/1260	2,200	< 0.033
Saipan, NMI	PCB 1254/1260	10,000	< 1
Ferndale, CA	PCB 1254	800	< 0.17

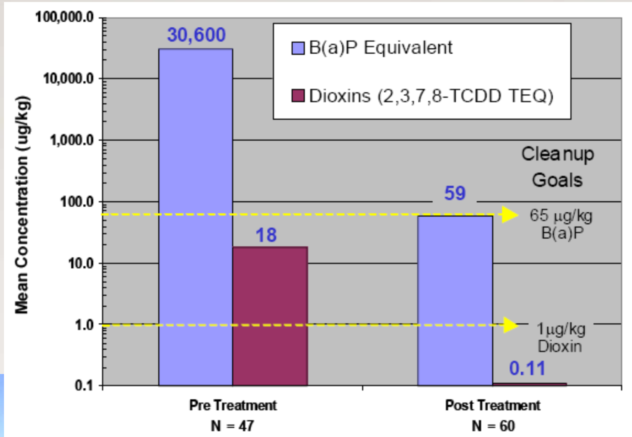
Source: Stegemeier and Vinegar (2001)
Terratherm Inc.

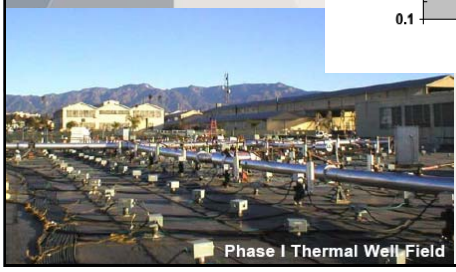
ISTD

PAH´s and Dioxins

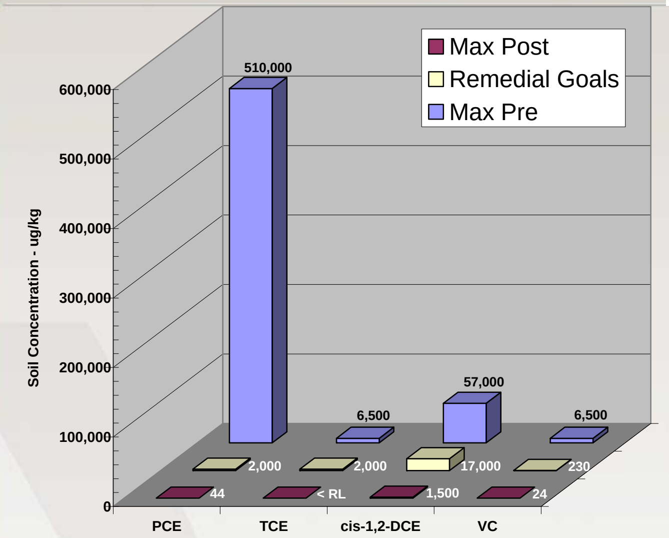
Woodtreatment facility, Alabama

Soil:
Fill, Silt with clay lenses and sand stringers



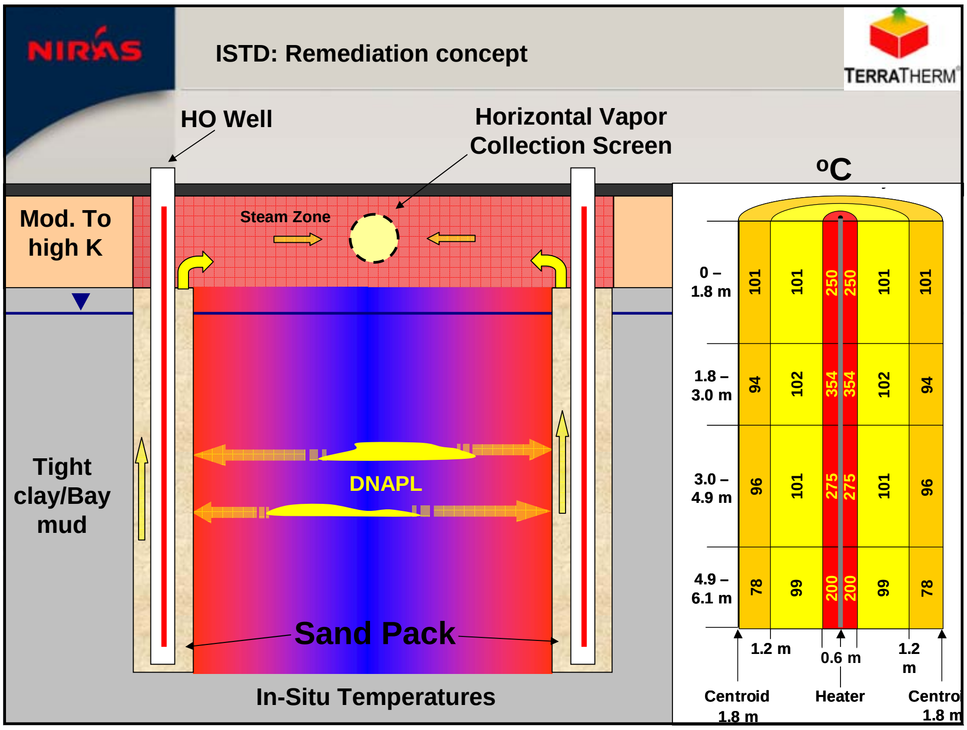


Results – Maximum concentrations



Reductions: 99.96% 99.63% 99.03% 99.49%

Results are based on 17 pre-treatment samples and 64 post-treatment samples.
Post-treatment samples were collected from centroids (i.e., coolest locations) at random and biased depths (15 or 23% were collected between 18 and 20 ft bgs).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ISTD: Remediation concept
TERRATHERM
HO Well
Horizontal Vapor Collection Screen
ºC
Mod. To high K
Steam Zone
Tight clay/Bay mud
DNAPL
Sand Pack
In-Situ Temperatures
0 – 1.8 m
101
101
250
250
101
101
1.8 – 3.0 m
94
102
354
354
102
94
3.0 – 4.9 m
96
101
275
275
101
96
4.9 – 6.1 m
78
99
200
200
99
78
1.2 m
0.6 m
1.2 m
Centroid 1.8 m
Heater