1

Thermal Conductive Heating/ In-Situ Thermal Desorption (ISTD)

Ralph S. Baker, Ph.D.

CEO and Technology Manager

John LaChance

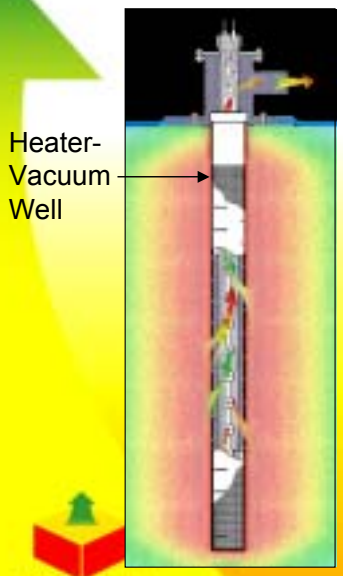
Program Manager

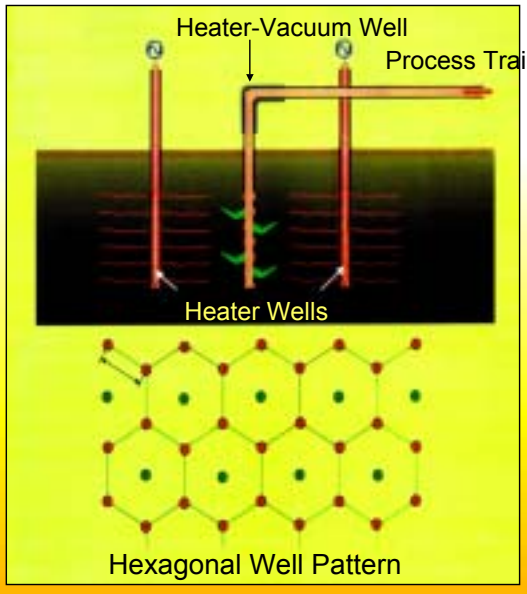
TerraTherm, Inc.

Fitchburg, MA

2

ISTD: Simultaneous Application of Heat and Vacuum





TERRATHERM Inc.

3

ISTD Processes

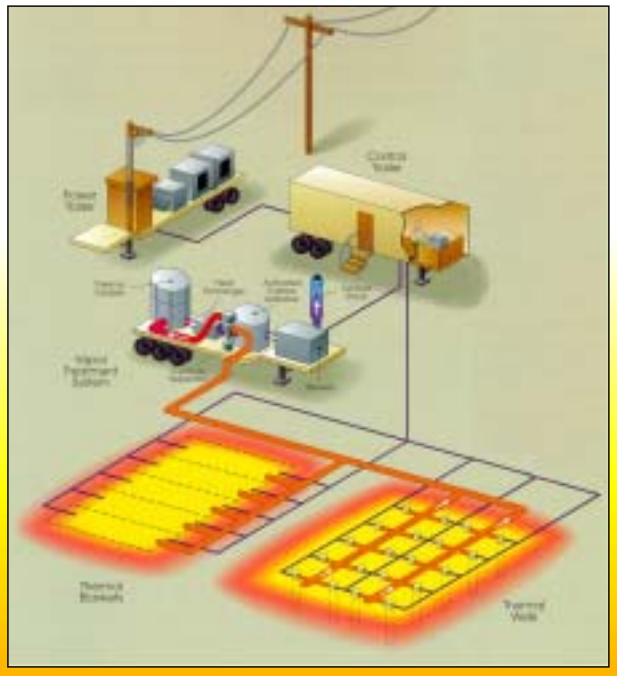
Thermal Conduction into Soil

Vaporization of Fluids and Contaminants within Soil

Collection of Vapors

In-Situ Oxidation and Pyrolysis - >95-99% In-Situ Destruction

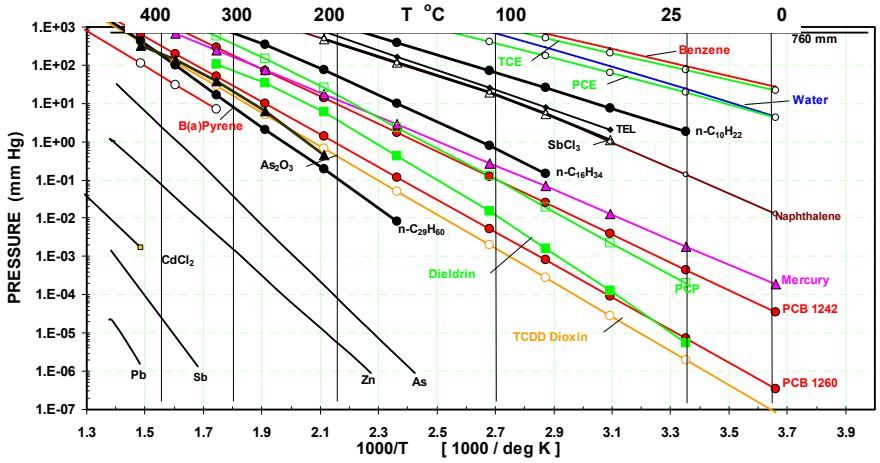
Aboveground Treatment of Vapors (may be simpler than illustrated)



TERRATHERM Inc.

4

Vapor Pressure of Contaminants



(Stegemeier and Vinegar, 2001)

TERRATHERM Inc.

5

S. Glens Falls, NY Drag Strip (PCBs)

TERRATHERM, Inc.

Missouri Electric Works (MEW) 12-Well ISTD Demo

Superfund site in Cape Girardeau, MO

PCBs (Aroclor 1260)

Boiling Point: 730 - 780 °F

Depth of contamination: 10 ft.

Soil Type: Clay

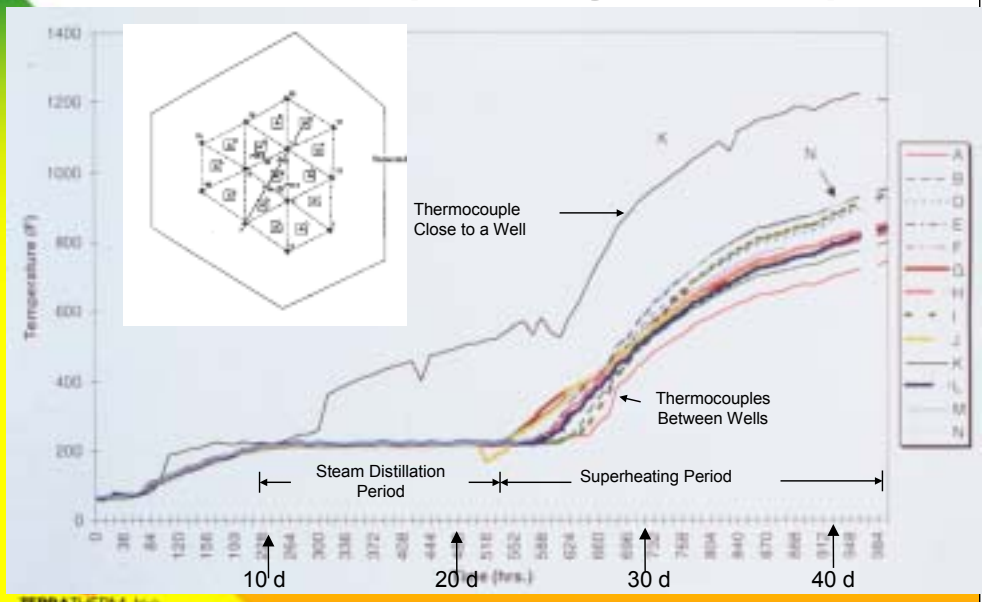
Maximum Concentration: 20,000 mg/kg (⇒NAPL)

Mean Concentration: 782 mg/kg (n=92)

TERRATHERM Inc.

7

MEW - Soil Temp. History at 2 m Depth



Results - MEW, Cape Girardeau, MO

PCBs reduced from mean of 782 mg/kg (n = 92), to mean of <0.033 mg/kg (n = 83)

Treatment temperatures and results demonstrate 100% sweep efficiency

Stack testing showed 99.9999998% DRE

No evidence of contaminant migration

Dioxins in treated soil below background level (< 6 ppt)

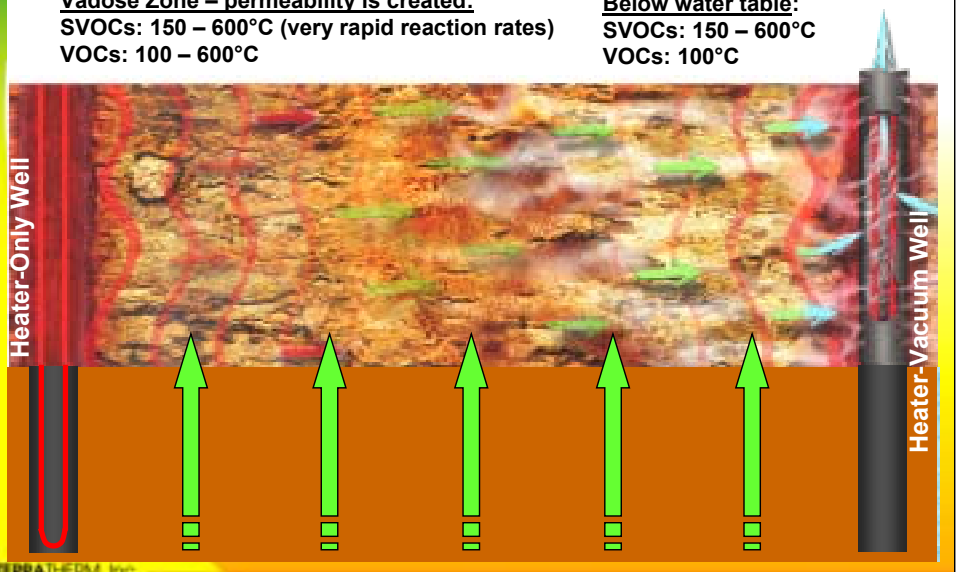
(Vinegar et al., 1997; France-Isetts, 1998)

9

Zones of In-Situ Thermal Desorption and Destruction

Vadose Zone – permeability is created:
SVOCs: 150 – 600°C (very rapid reaction rates)
VOCs: 100 – 600°C

Below water table:
SVOCs: 150 – 600°C
VOCs: 100°C



TERRATHERM, Inc.

ISTD at Former Shell Bulk Storage Terminal, Eugene OR

TERRATHERM, Inc.

ISTD at Eugene, OR (cont.)

Diesel Range Organics (DRO), gasoline and benzene:

- in soil and groundwater to depths up to 12 feet bgs;
- maximum soil concentrations of 9,300 mg/kg (DRO), 3,500 mg/kg (gasoline); and in groundwater, 1,300 µg/l (benzene);
- as much as 7.9 ft of free product in monitoring wells.

Gravel layer 1-4', over silt to ~11-16' bgs.

Perched groundwater encountered in the unconfined top gravel and silt layers.

Project goal was removal of free product and benzene, and closure of the site under RBCA UST program with Oregon DEQ.

(Conley et al., 2000)

TERRATHERM Inc.

Eugene, OR ISTD Project Results

Free phase LNAPL removed from the entire 1-acre site.

Estimated 200,000 lbs of hydrocarbons removed and treated during the 120-day heating cycle.

All confirmation (post-remediation) soil and groundwater samples were below the ODEQ's Tier 1 Risk-Based Concentrations:

- Benzene concentrations in groundwater within the treatment area were reduced from 1,300 µg/L to ≤2.50 µg/L.
- All post-treatment off-site groundwater samples (4 quarterly rounds) were below the analytical detection limit (i.e., <0.5 µg/L).

Oregon DEQ issued a "No Further Action" letter for the site on March 14, 2000

- Closure 2 ½ yr after startup (incl. 1-yr post-treatment monitoring).

TERRATHERM Inc.

13

ISTD at Former Molded Plastics Manufacturing Facility, Portland, IN

7500 sq.ft. x 18 ft = 5000 CY Treatment Zone

PCE as high as 3,500 mg/kg

- IDEM Voluntary Tier II industrial cleanup goal (< 8.01 mg/kg for depths > 2 ft)

TCE as high as 79 mg/kg

- IDEM cleanup goal < 25 mg/kg

Silty-Clay Soil (Till), < 2.5 x 10-8 cm/s

Water Table at 22 ft BGS

TERRATHERM Inc.

Adjacent Residences, Portland, IN

ISTD
Well
Field

TERRATHERM, Inc.

Portland, IN Site Closure by IDEM, 2000

Removal Action Summary:

Location	Depth (feet)	Pre-Heating (mg/kg)	Post-Heating (mg/kg)
SA4	4 to 5	PCE = 23	PCE = 0.530
		TCE = 0.25	TCE = ND
SB20	4 to 5	PCE = 2.9	PCE = 0.046
		TCE = 0.67	TCE = ND
SA13	9 to 10	PCE = 3500	PCE = 0.011
		TCE = 79	TCE = 0.020
SB19	12 to 14	PCE = 76	PCE = 0.048
CS12*		TCE = 1.6	TCE = ND
GP31	15 to 16	PCE = 570	PCE = 0.18
		TCE = NA	TCE = 0.008

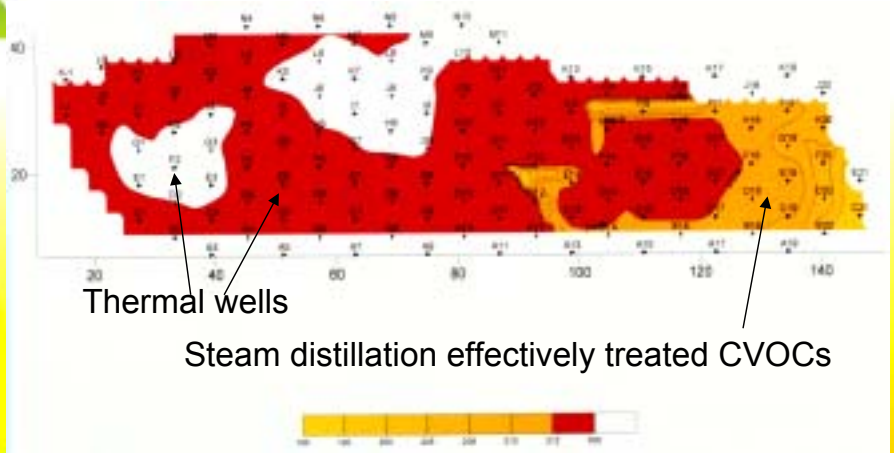
ND – non-detect; NA – not available; *8 ft away from SB19

TERRATHERM, Inc.

(Vinegar et al., 1999)

Portland, IN ISTD Temp. Distribution

13 Ft BGS, 11/2/97



TERRATHERM, Inc.

(Vinegar et al., 1999)

17

Summary of Completed Thermal Conduction/ISTD Field Projects

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
Portland, IN	PCE	3,500	< 0.5
	TCE	79	< 0.02
Saipan, NMI	PCB 1254/1260	10,000	< 1
Eugene, OR	Benzene Gasoline/Diesel	3.3 3,500/9,300 + free product	< 0.044 250,000 lbs. free product removed
Ferndale, CA	PCB 1254	800	< 0.17

TERRATHERM Inc.

(Stegemeier and Vinegar, 2001)

Current ISTD Projects

Southern California Edison, Alhambra, CA – Former Pole Yard *(PAHs, PCP, dioxins)*; 15,000 CY silty sand to 100 ft depth; clean-up goals: < 0.033 mg/kg B(a)P TEQ and < 1 µg/kg TCDD TEQ; May 2002 – Dec. 2003

Confidential Site, OH – Active Manufacturing Facility *(CVOCs)*; 11,000 CY clay till to 15 ft depth; clean-up goal: 1 mg/kg TCE; July 2002 – June 2003

Confidential Client, CA – Former Manufacturing Facility *(CVOCs)*; Thermally-enhanced dual-phase extraction; 8,000 CY silty-clay soil, above and below water table, to 37 ft depth; clean-up goal: 1 mg/kg DCE; Sept. 2002 – Aug. 2003

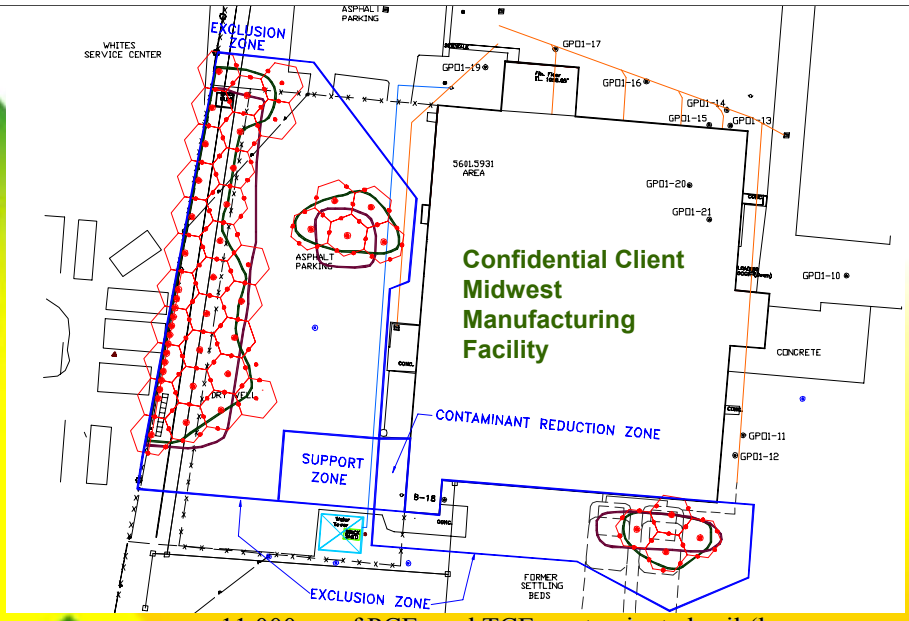
TERRATHERM INC.

SCE – Alhambra (under constr'n)

- 15,000 cy contaminated to 100' depth in silty sands
- TerraTherm currently installing $5.3M ISTD project

TERRATHERM, Inc.

20



- 11,000 cy of PCE- and TCE-contaminated soil (low-permeability clay till) to 15 ft depth; water table > 30 ft
- Total cost $1.2 M, or ~$110/cy treated.

TERRATHERM Inc.

TerraTherm's Approach for Chlorinated Solvents Sites

Employ Wider (e.g., 30 to 40-ft diameter) Well Patterns

Attain Steam Distillation Target Temperatures between Thermal Wells

Create Vapor Plenums to Enhance Vapor Collection, and Hot Floors (U.S. Patent No. 5,997,214) to Prevent Downward Migration of DNAPL

Simplify Off-Gas Treatment System:

- Condenser (if needed);
- No Oxidizer needed;
- Dry Scrubber and Carbon Adsorbers.

TERRATHERM, Inc.

Soil Heating Requirements

Soil

- Mineral Grains $(1-\Phi)\ \rho_s\ C_s\ \Delta T$

Water Saturation

- Sensible $\Phi\ S_w\ \rho_w\ C_w\ \Delta T$
- Latent $\Phi\ S_w\ \rho_w\ h_v$

Inflow Water

Air

Where:
Φ = porosity
ρ = density
C = heat capacity
ΔT = change in temperature
S = saturation
h_v = heat of vaporization
s = solids
w = water

Power ≈ 10-30% of overall cost

TERRATHERM Inc.

ISTD Heating Requirements: Past and Present

- Traditional Approach for SVOCs – boil off all water (latent heat of vaporization)
- Traditional Approach for CVOCs – assume boil 1 pore volume (to offer guaranteed results)
- Recent Work Suggests Less Power may be Sufficient
- Thermal Conduction Heating is As Efficient as Other In-Situ Thermal Heating Methods

TERRATHERM Inc.

ISTD Price Range

PCBs, PAHs, Dioxins

- ~$600/cy for small sites (1000 cy)
- ~$100/cy for large sites (100,000 cy)

BTEX, VOCs

- ~$170/cy for small sites (3000 cy)
- ~$60/cy for large sites (100,000 cy)

Price considerations incl.: site access, air discharge limits, need to control recharge, electricity costs, depth of heating zone/length of heaters, regulatory oversight

Attributes of ISTD

Widest heating range of any in situ thermal technology — effective at sites with DNAPL, LNAPL, mixtures

Can clean to very low/non-detect residual levels in situ

Typically achieves >95% in-situ destruction of contaminants ⇒ less loading to aboveground treatment

Past ISTD projects have all had emissions of <0.005 ng TEQ/dscm; no evidence of dioxin formation.

Minimal risk of mobilization due to application of vacuum and predictable heating

TERRATHERM Inc.

Attributes of ISTD, cont.

Process is not hindered by subsurface heterogeneity

- Gas permeabilities range over many orders of magnitude
- Electrical conductivities range over 1-2 orders of magnitude
- Thermal conductivities range only by factor of ± 2

100% Sweep - Highly Predictable and Reliable

Can be rapid (e.g., 2-3 months operation)

Safe, quiet, odorless (perfect safety record)

Cost-Effective

TERRATHERM Inc.

About TerraTherm, Inc.

Exclusive licensee of ISTD technology:

- Within the U.S., from the Univ. of Texas at Austin: Protected by 20 U.S. patents, + patents pending
- Outside the U.S., from Shell Oil Co.: Protected by 5 patents pending

Offices in Fitchburg, MA and Houston, TX

- Currently 20 Employees

For more information, please visit www.terratherm.com

TERRATHERM, Inc.

References Cited

Conley, D.M., and C.M. Lonie. 2000. "Field Scale Implementation of In Situ Thermal Desorption Thermal Well Technology." pp. 175-182. In: G.D. Wickramanayake and A.R. Gavaskar (eds.) *Physical and Thermal Technologies: Remediation of Chlorinated and Recalcitrant Compounds*. Battelle Press, Columbus, OH.

France–Isetts, P. 1998. "In Situ Thermal Blankets and Wells for PCB Removal in Tight Clay Soils," *Tech Trends*, EPA Region 7. (February, 1998). Available at: http://clu-in.org/products/newsltrs/TTREND/tt0298.htm

Stegemeier, G.L., and Vinegar, H.J. 2001. "Thermal Conduction Heating for In-Situ Thermal Desorption of Soils." Ch. 4.6-1 in: Chang H. Oh (ed.), *Hazardous and Radioactive Waste Treatment Technologies Handbook*, CRC Press, Boca Raton, FL.

References Cited (continued)

Vinegar, H.J., E.P. deRouffignac, R.L. Rosen, G.L Stegemeier, M.M. Bonn, D.M. Conley, S.H. Phillips, J.M Hirsch, F.G. Carl, J.R. Steed, D.H. Arrington, P.T. Brunette, W.M. Mueller, and T.E. Siedhoff. 1997. "In Situ Thermal Desorption (ISTD) of PCBs", *Proceedings of the HazWaste/World Superfund XVIII Conference*, Washington, DC, December 2, 1997

Vinegar, H.J., G.L. Stegemeier, F.G. Carl, J.D. Stevenson, and R.J. Dudley. 1999. "In Situ Thermal Desorption of Soils Impacted with Chlorinated Solvents." *Proceedings of the Annual Meetings of the Air and Waste Management Association*, Paper No. 99-450.