Completion of In-Situ Thermal Remediation of PAHs, PCP and Dioxins at a Former Wood Treatment Facility

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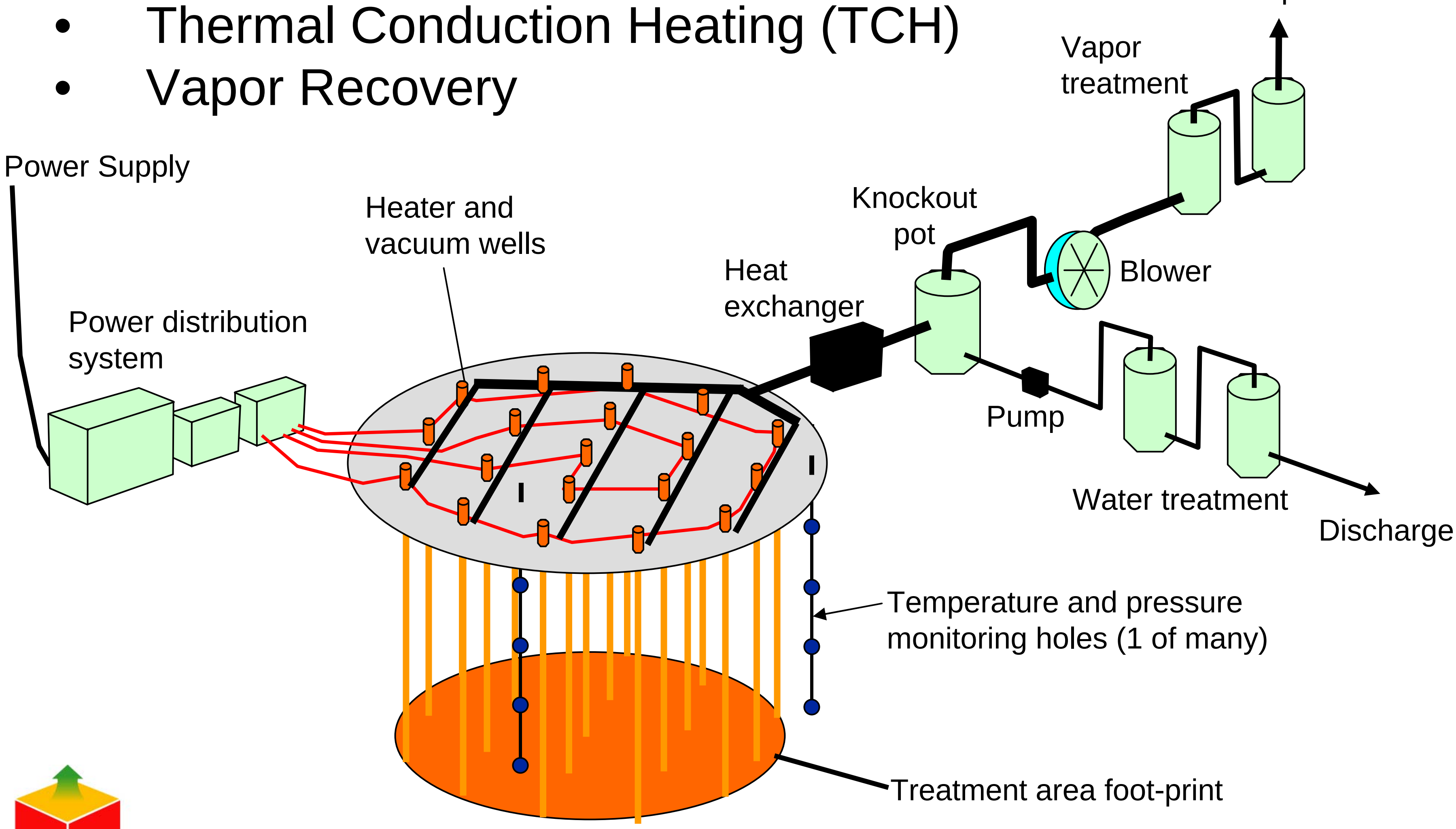
Sketch of ISTD Process

ISTD is the Simultaneous Application of:

- Thermal Conduction Heating (TCH)
- Vapor Recovery



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What Makes Thermal Conduction Heating (TCH) so Unique?

- The Thermal Conductivity of a Wide Range of Soil Materials (gravel, sand, silt, clay) Varies Only by a Factor of ~3
- By Contrast:
  - Hydraulic / Pneumatic Conductivities Vary >10^6 – 10^8
  - Electrical Conductivities Vary > 10^2
- TCH Heats the Entire Target Zone – No Locations are Bypassed or Unaffected
- Soil Immediately Adjacent to TCH Wells Dries, Creating Permeability, Assisting Efficient Vapor Recovery
- TCH Heaters Can Be Readily Controlled, to Achieve Low, Moderate or Higher Soil Temperatures as Needed

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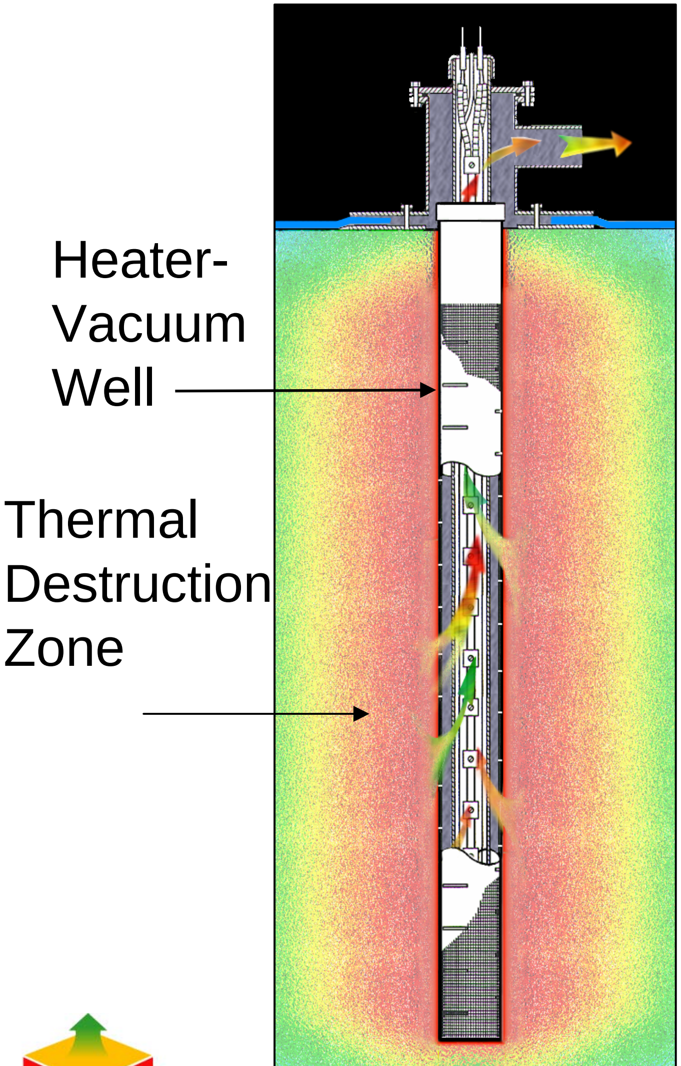
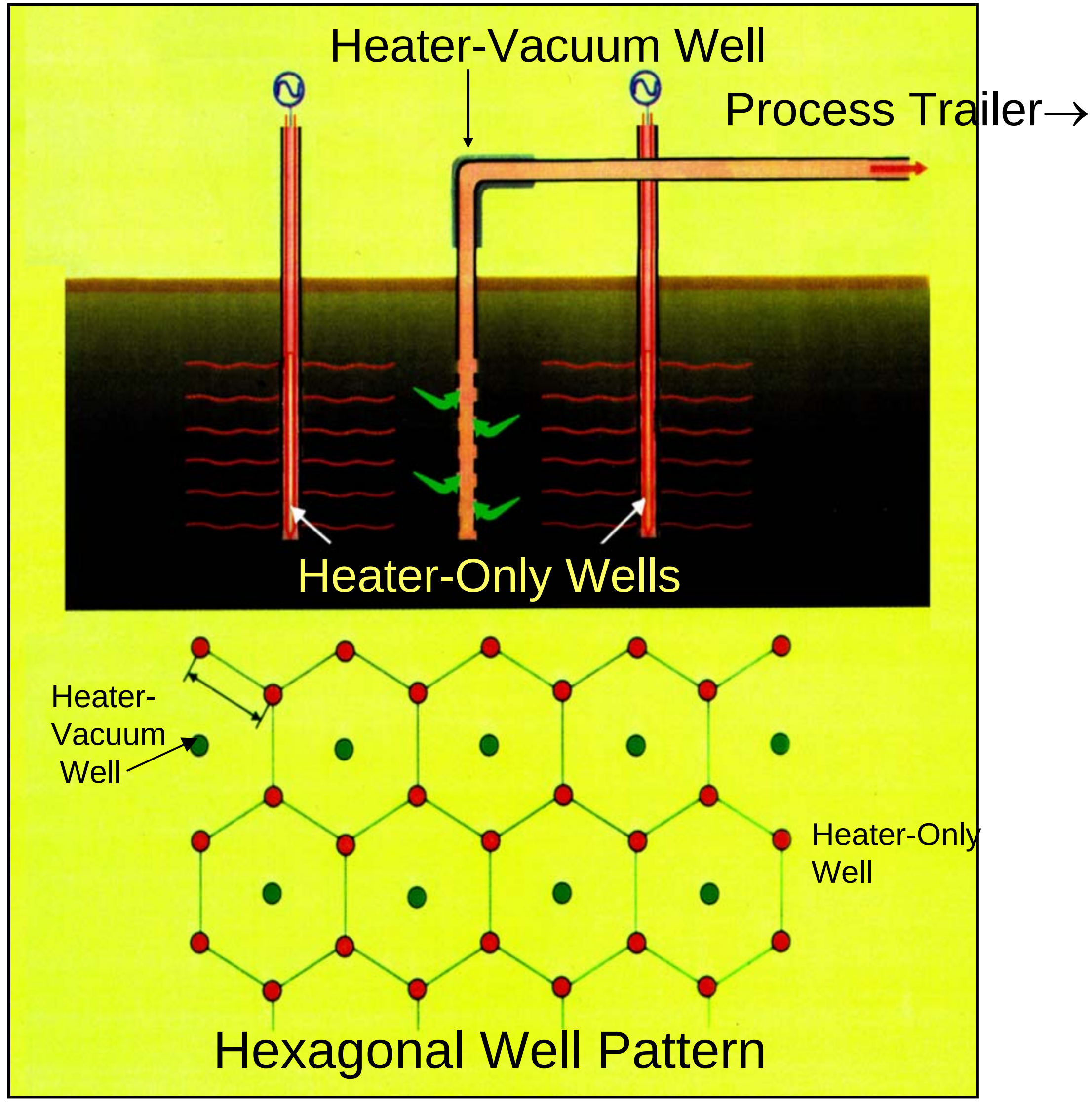
ISTD Thermal Wells





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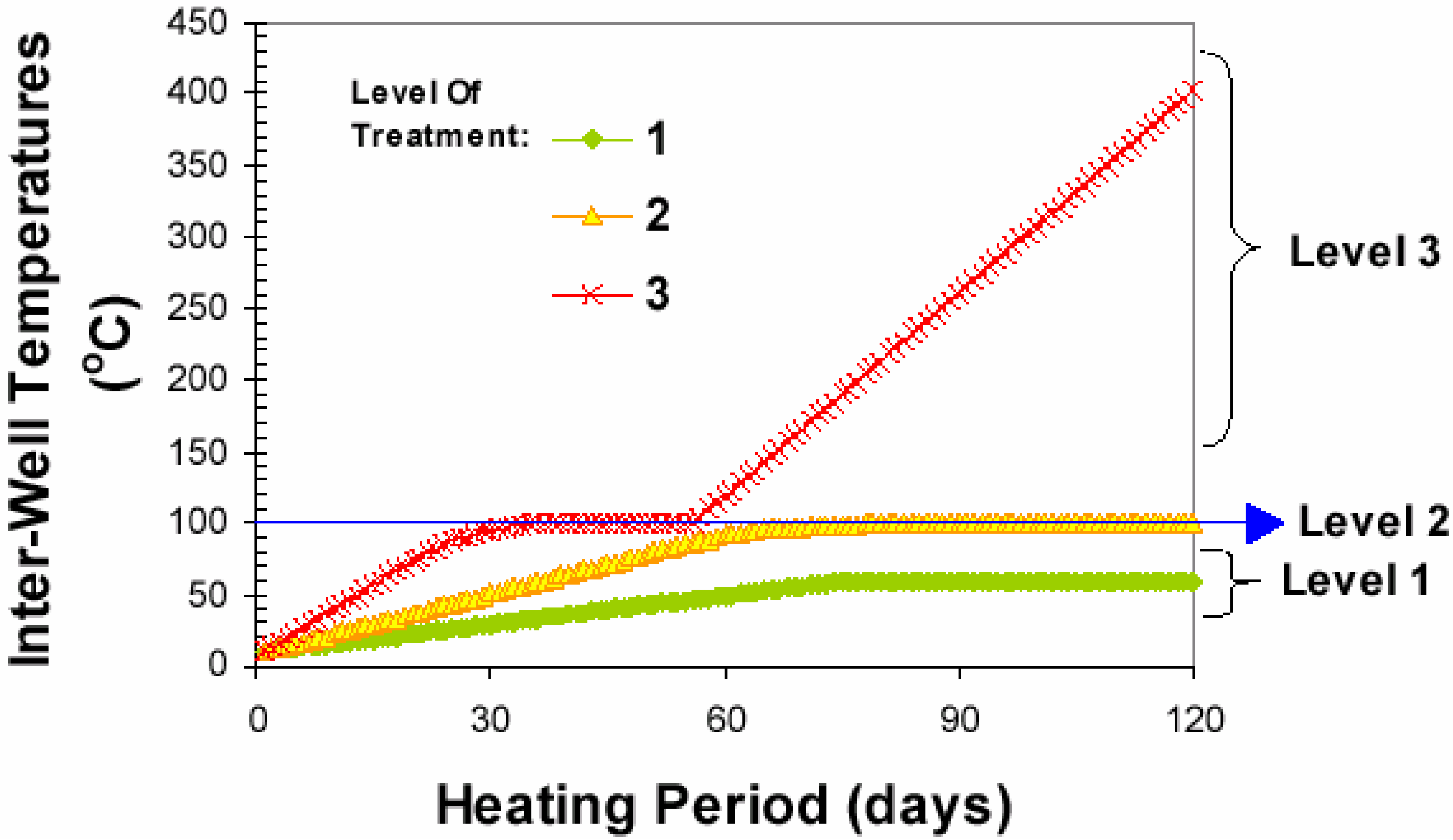
Typical Heating Progression for Various Levels of ISTD Treatment



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Contrasting Applications of ISTD/TCH

Level of Heating and Contaminant Type	Target Treatment Temperature (°C)	Thermal Well Spacing (m)	Desiccate Target Treatment Zone (TTZ)?	Range of Costs (Turnkey)* ($/m^3)
1. VOCs: Gentle Heating** (BTEX, CVOCs)	<100	>6	No	40-240*
2. VOCs (BTEX, CVOCs)	100	4-7	Not Necessary	65-330*
3. SVOCs (PAHs, PCBs, dioxins)	>100	2-4	Yes	200-600*

****Thermally enhanced SVE, NAPL recovery, and bioremediation**

*For volumes > 1,500 m^3

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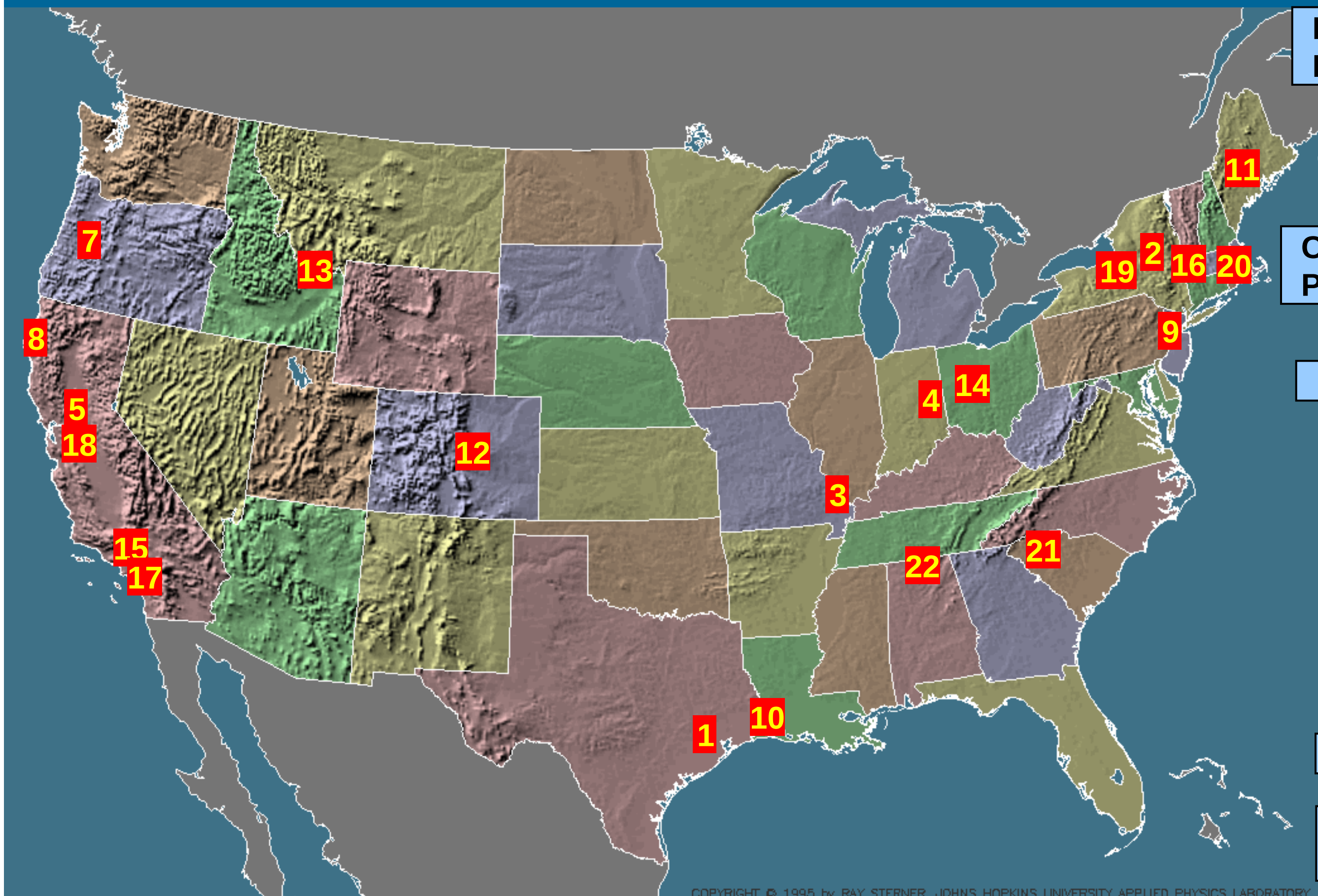
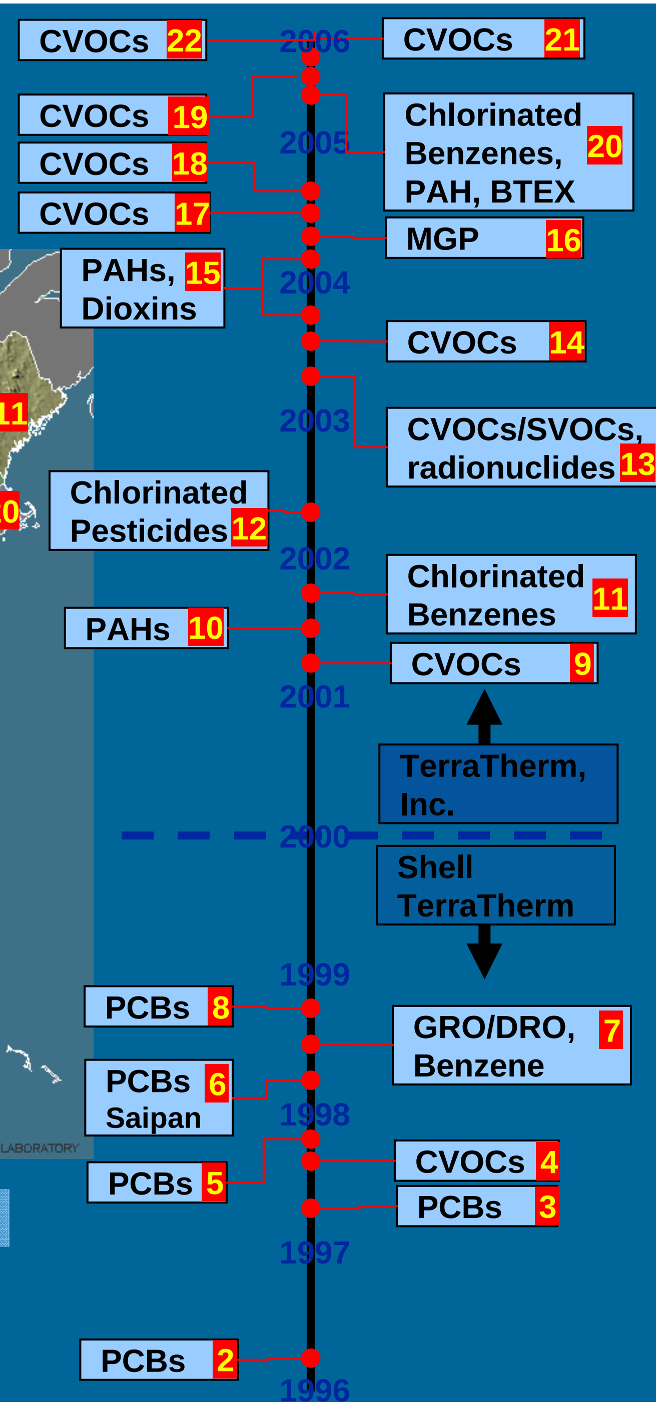
ISTD Development and Deployment





ISTD Projects are also ongoing in Denmark and the U.K.

Shell R&D 1
1980's through 2000's

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Alhambra, California
Site Features
Former Wood Treatment Facility

PLATE 2 - BUTT TREATMENT PROCESS

- Two Former Full-length Treatment Tanks (~3 x 21 x 1.7 m deep)
- Two Former Butt-Dip Tanks (~3 x 14 x 4 m deep)
- Former Boiler House and Tank Farm
- Decommissioned Pipe Lines
- Railroad Spurs

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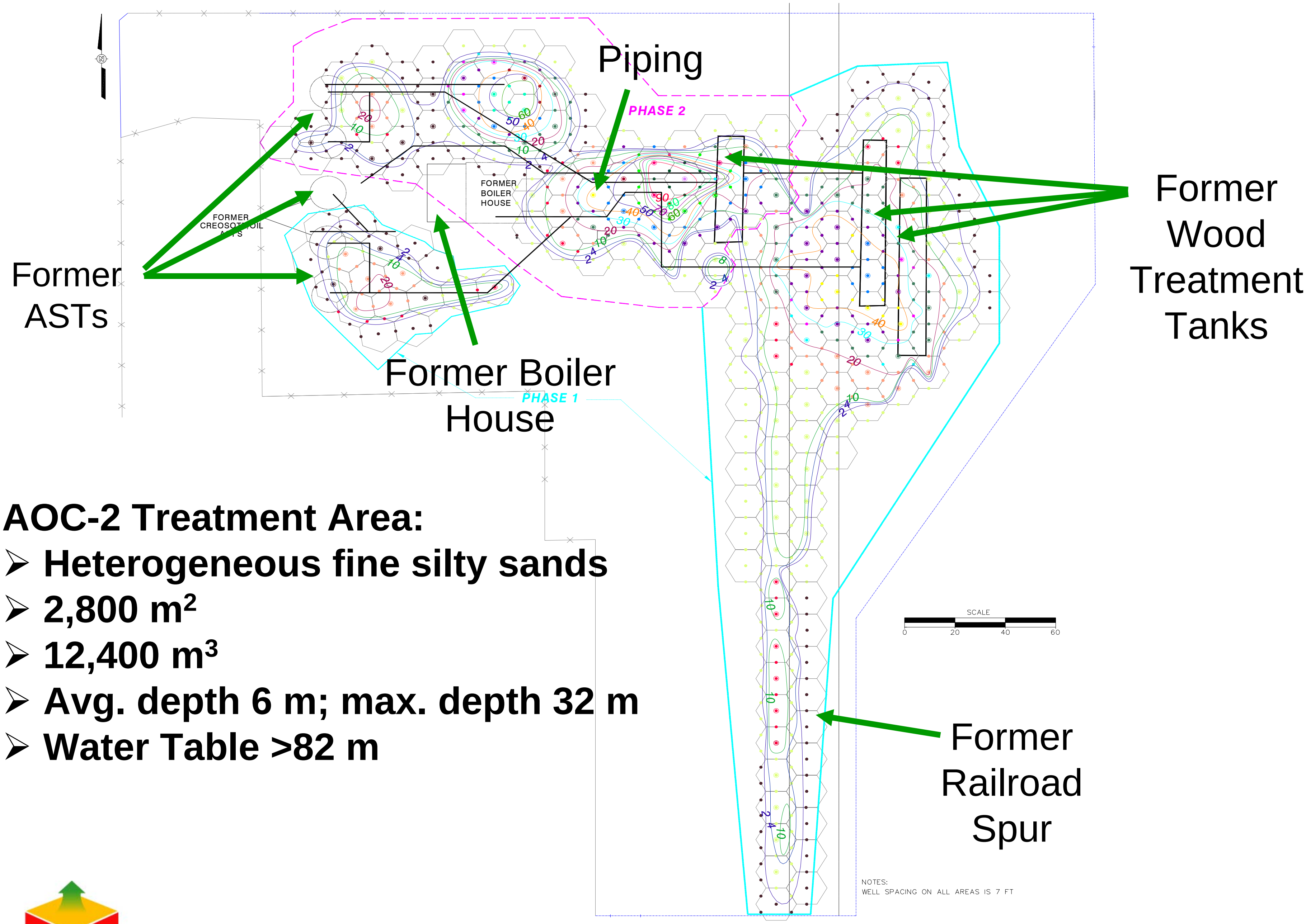

AOC-2 Treatment Area:

- **Heterogeneous fine silty sands**
- **2,800 m^2**
- **12,400 m^3**
- **Avg. depth 6 m; max. depth 32 m**
- **Water Table >82 m**

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Soil Contaminant Concentrations and Cleanup Standards

Constituent	Max. Conc. (mg/kg)	Mean Conc. (mg/kg)	Cleanup Standard (mg/kg)
TPH	50,000	2,730	N/A
Total PAH	**35,000**	**2,306**	**0.065 [B(a)P-Eq]**
Creosote	61,000	4,505	N/A
PCP	**58**	**2.94***	**2.5**
Dioxins (TEQ)	**0.194**	**0.018**	**0.001**

***Mean of 15 detects; PCP not detected in 231 samples**
B(a)P-Eq = Benzo(a)pyrene equivalents
TEQ = 2,3,7,8-Tetrachlorodibenzodioxin Toxicity Equivalents

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Alhambra ISTD Design Features

- Target temperature (treatability results) of 335°C (635°F), maintained for 3 days
- 2.1-m thermal well spacing, 3:1 edge-centered hexagonal pattern
- 785 thermal wells, total (131 heater-vacuum and 654 heater-only wells)
- Insulated surface seal
- Two treatment phases

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Aerial View – December 2004

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Thermal Well Fields Installed

Phase 1

Phase 2

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Air Quality Control System

- 24/7 Continuous Manned Operation
- Monitoring Well Field Temperatures & Vacuum, Continuous Emissions Monitoring (CEM) of Off-Gas System Parameters

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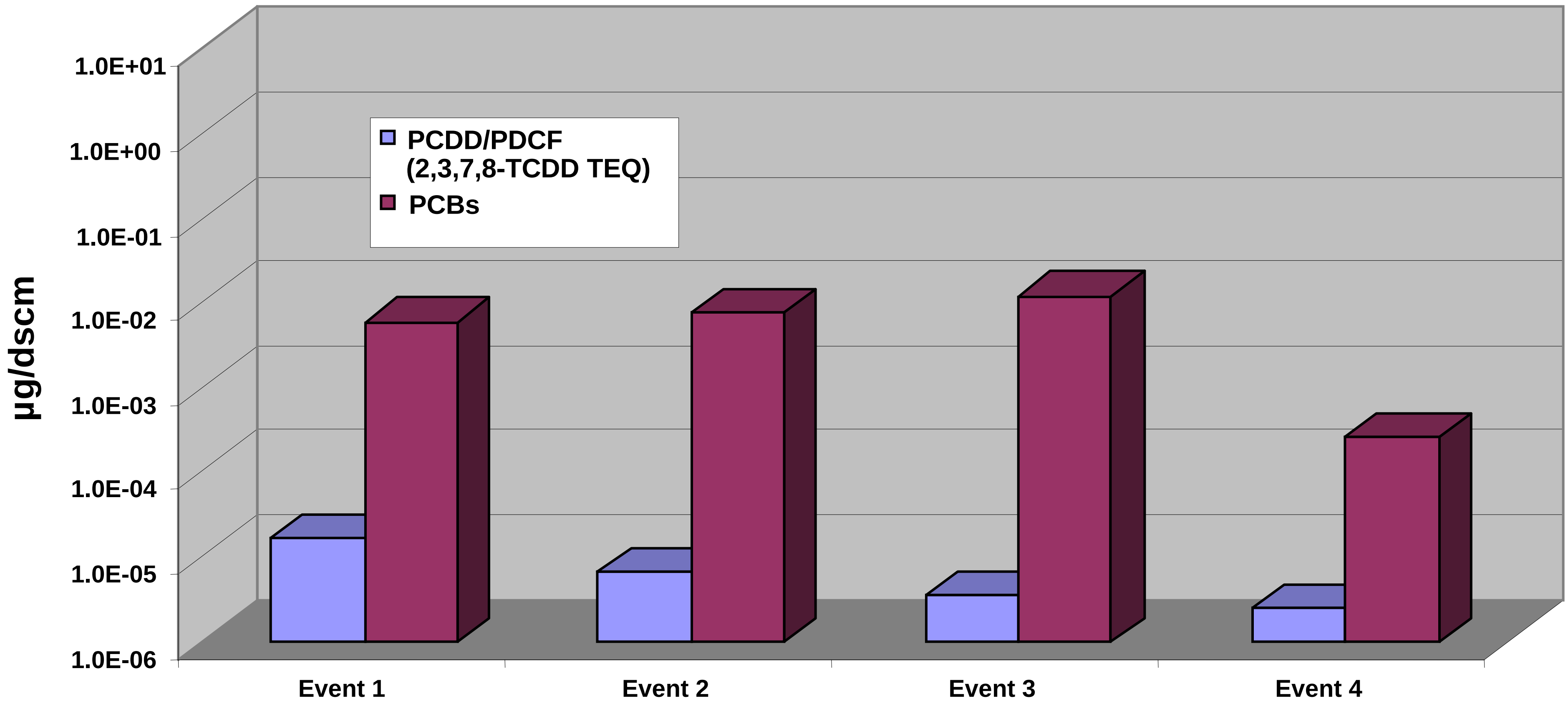
Source Testing Results



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Source Testing Results
Carcinogenic PAHs

Compound	MICR Limit (µg/m^3)	Phase 1 Event 1 (µg/m^3)	Phase 1 Event 2 (µg/m^3)	Phase 1 Event 3 (µg/m^3)	Phase 2 Event 1 (µg/m^3)
Benzo(a)anthracene	23.9	0.869	0.610	1.00	0.946
Chrysene	239	1.27	1.34	1.83	2.89
Benzo(b)fluoranthene	23.9	0.341	0.172	0.898	0.686
Benzo(k)fluoranthene	23.9	0.149	0.0894	0.317	0.252
Benzo(a)pyrene	2.39	0.0954	0.0378	0.0839	0.1150
Indenopyrene	23.9	0.0793	0.0099	0.0681	0.0750
Dibenz(a,h)anthracene	6.74	0.0371	0.0069	0.0391	0.0400

MICR = maximum individual cancer risk

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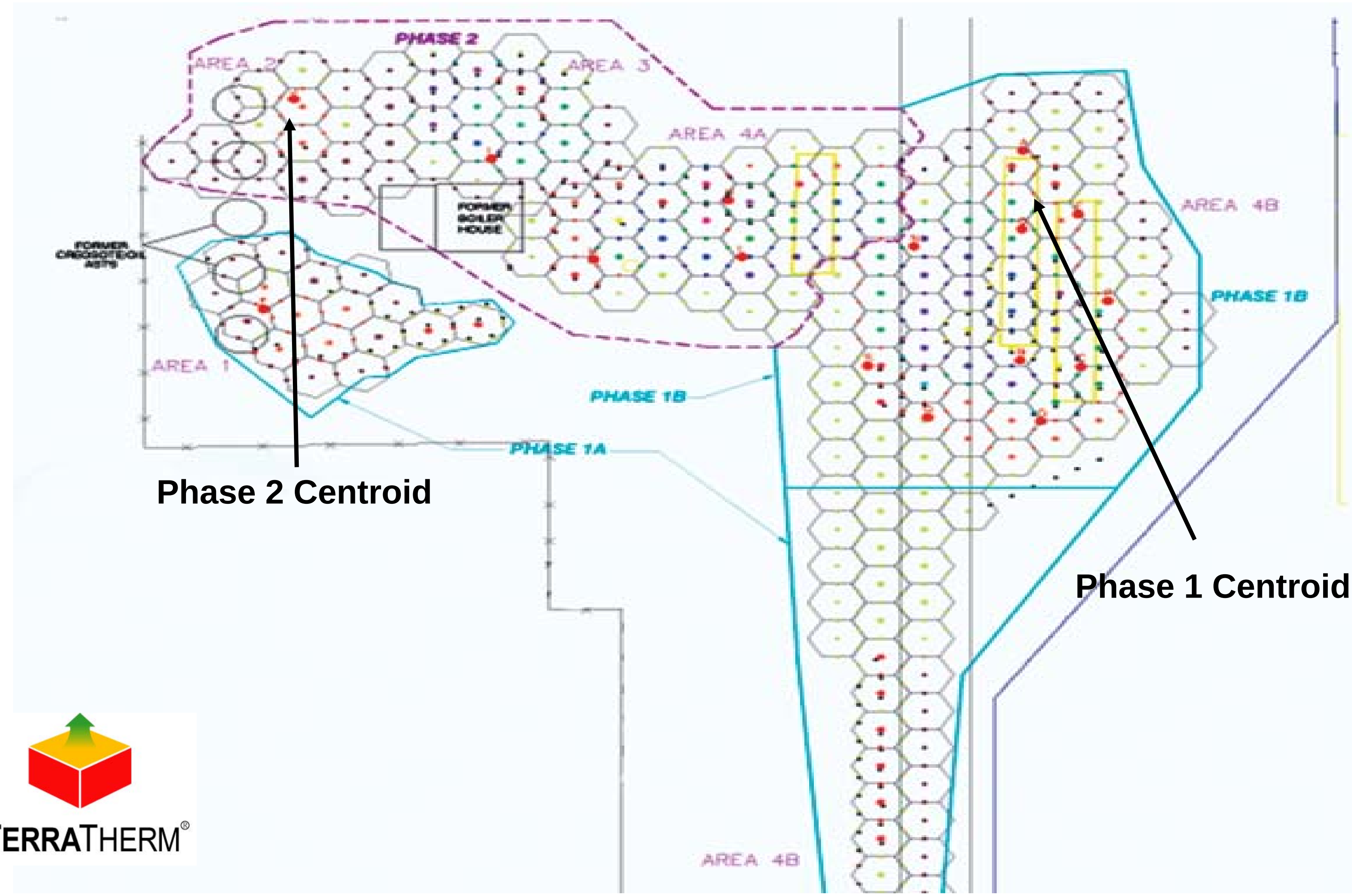
Well Field Layout and Representative Centroid Locations



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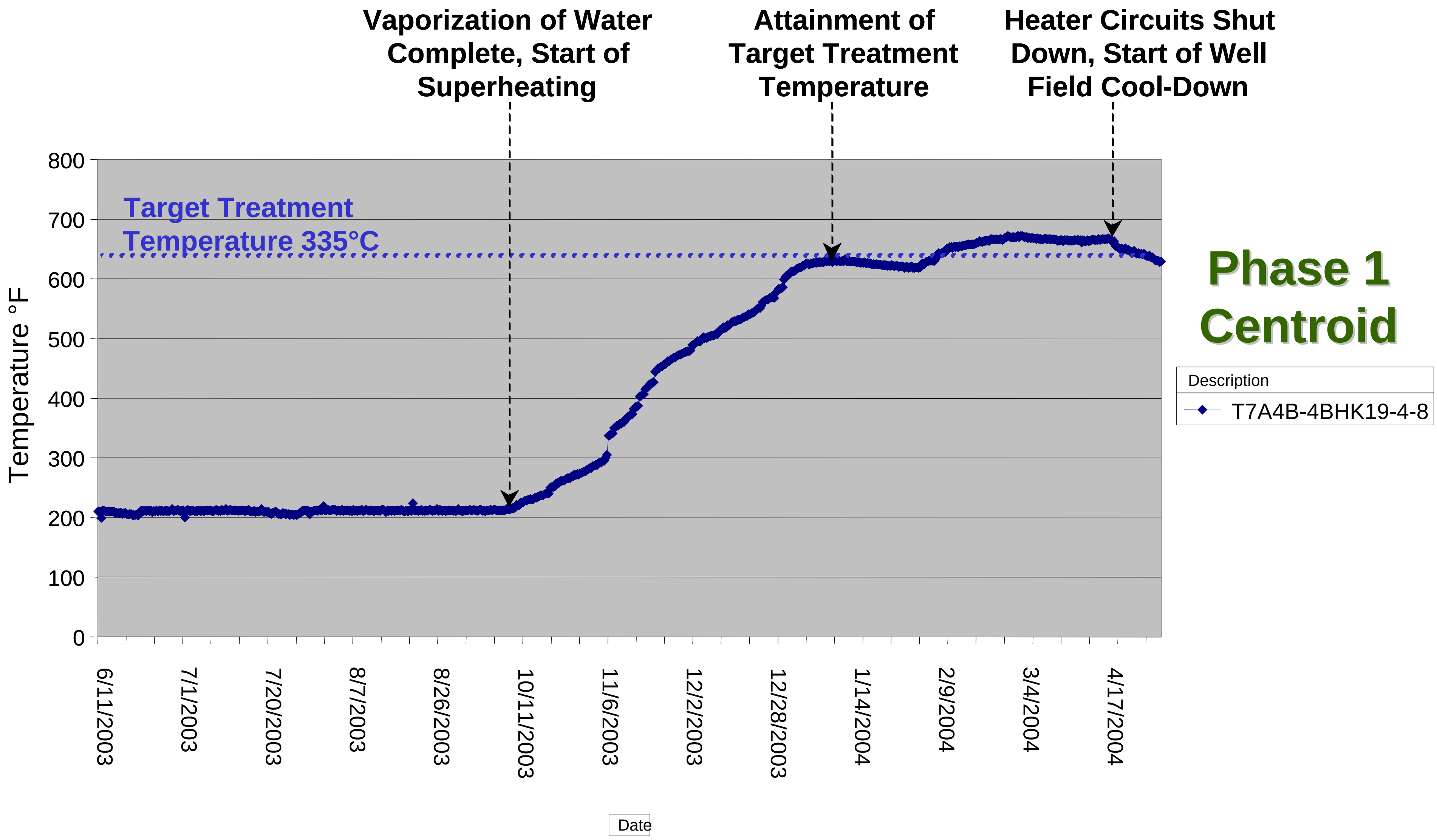
Phase 1 Centroid



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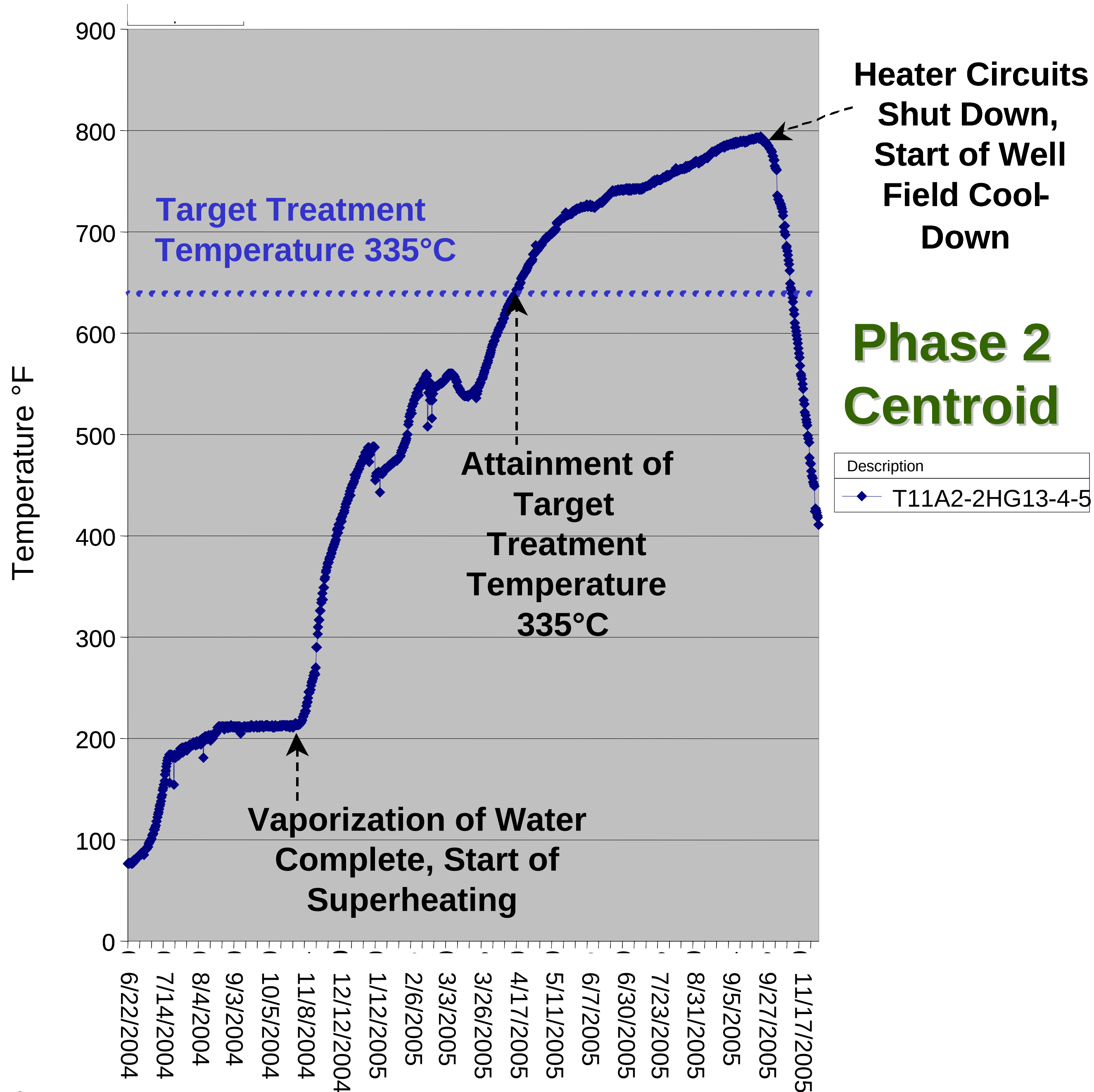

Phase 2 Centroid

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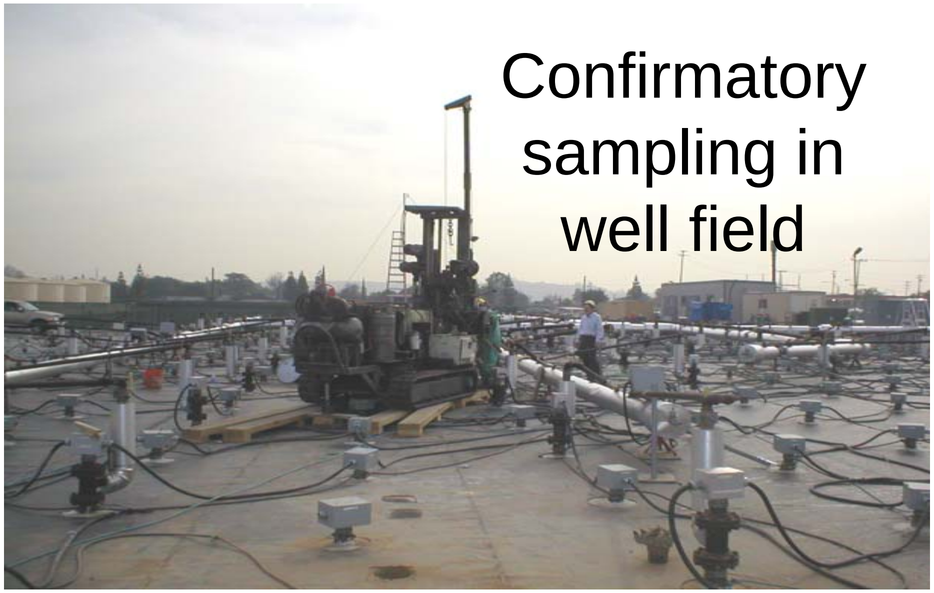
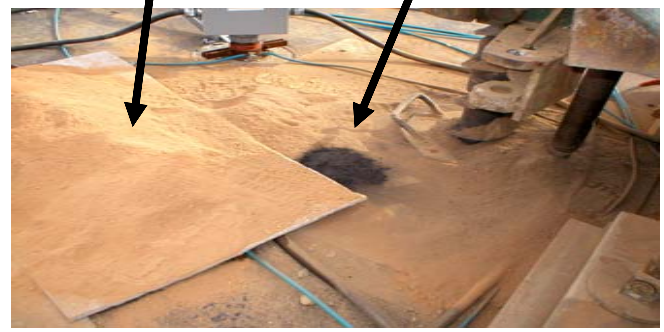
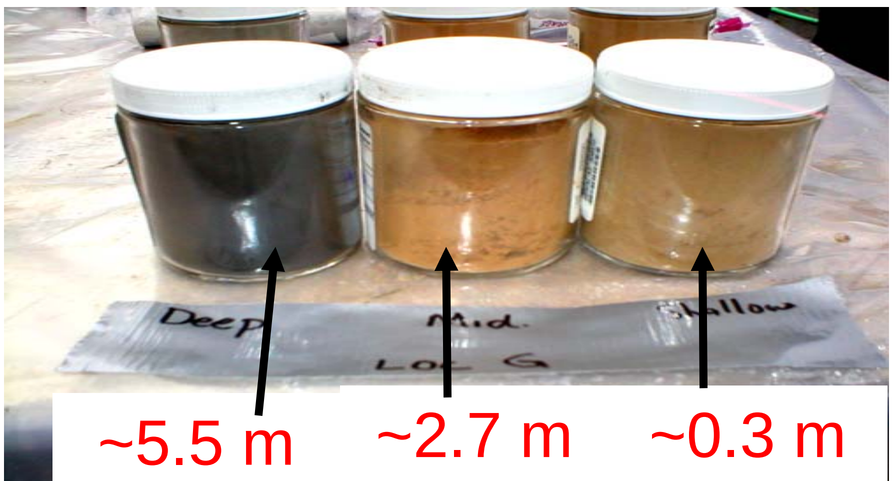


Confirmatory sampling in well field

Auger cuttings oxidation vs. pyrolysis





~5.5 m bgs

~2.7 m bgs

~0.3 m bgs

Coke from product zone

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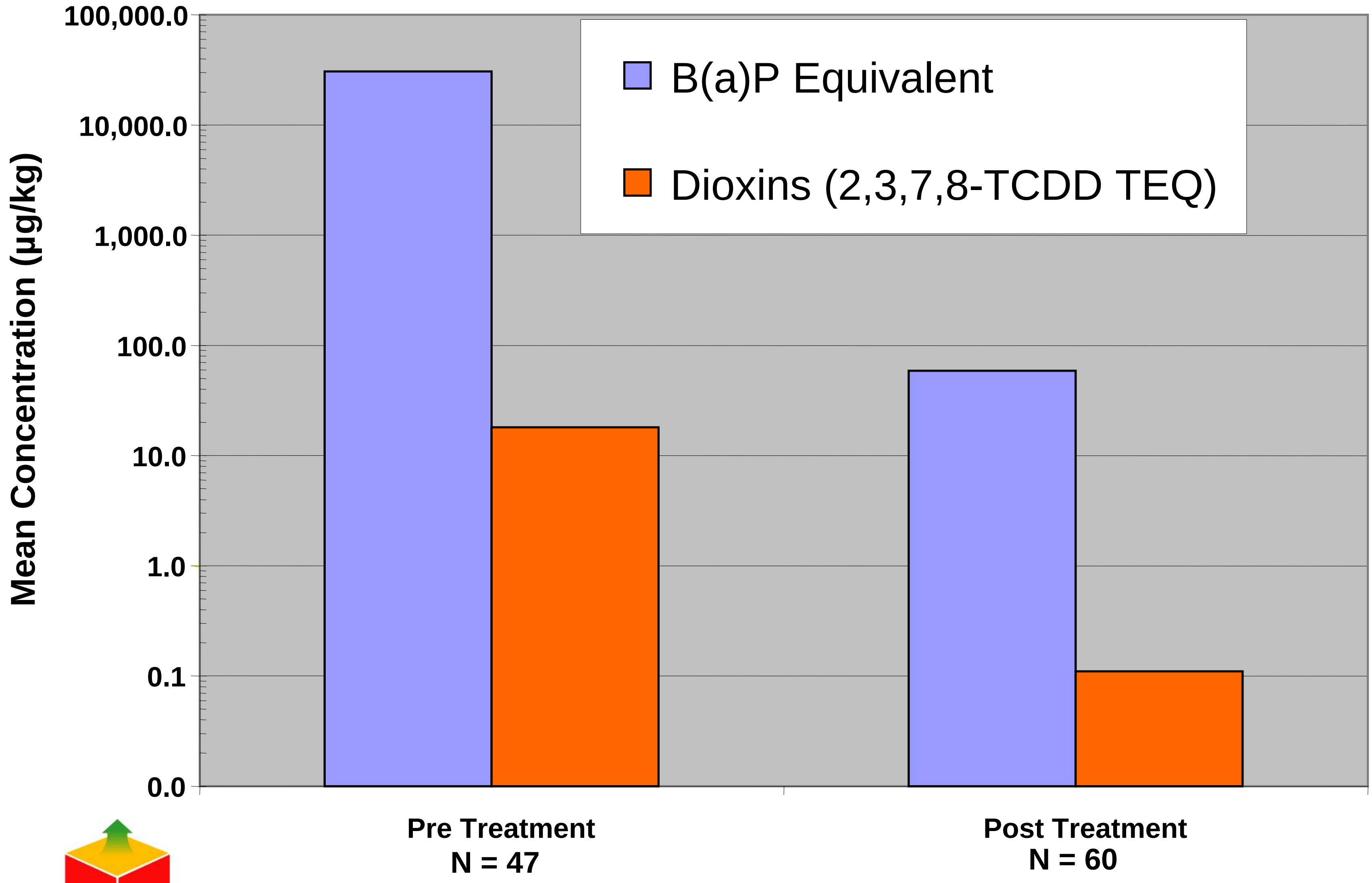
Comparison of Pre- and Post-Treatment Contaminant Concentrations



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Summary

- Site demob. completed March 2006
- Estimated mass removed via combustion (oxidizer and subsurface) 395,000 kg (CO_2 method)
- Additional mass destroyed *in situ* by pyrolysis (dark soil/coke)
- Air emissions were well below compliance requirements
- Post–treatment soil sampling results all below stringent clean-up requirements
- No Further Action letter (February 7, 2007) from California Department of Toxic Substances Control to Southern California Edison allows unrestricted land use

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Lessons Learned

- ISTD treatment did not change soil permeabilities
- Active cooling of well field to grouting temperatures can be accomplished
- Rotosonic drilling methods are effective and reduce installation costs
- Site characterization defined contaminant mass and off-gas treatment sizing
- Insulating covers are essential when considering thermal remediation due to heat loss

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Cost Implications of Lessons Learned for Future Applications of ISTD at Creosote Sites

- Achievement of unrestricted/residential land use by an in-situ remediation method is achievable and practical
- ISTD was initially compared and selected over excavation with offsite incineration
- ISTD remediation costs exceeded original estimates; however, all-in project cost was still ~40% lower than the excavation alternative
- TerraTherm's estimate for similar site of 12,600 m^3, with one 130-day treatment is \$500/m^3:
  - Capital cost: \$3.9M
  - Operations, source testing, and electricity: \$2.2M
  - Demobilization, reporting, licensing fee: \$0.23M

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