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COMPLETION OF IN-SITU THERMAL REMEDIATION OF PAHs, PCP AND DIOXINS AT A FORMER WOOD TREATMENT FACILITY

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ABSTRACT

The largest in-situ thermal conduction heating project ever undertaken at a wood treatment site was completed in March 2006. The site was a former utility pole treatment facility that Southern California Edison (SCE) operated from 1922 to 1957. The subsurface soils were contaminated primarily with polycyclic aromatic hydrocarbons (PAHs), pentachlorophenol (PCP), and polychlorinated dibenzodioxins and furans (PCDD/Fs), with soil treatment standards of 0.065 mg/kg Benzo(a)Pyrene Equivalents (B(a)P-E), 2.5 mg/kg PCP, and 1.0 µg/kg PCDD/Fs, expressed as 2,3,7,8-Tetrachlorodibenzodioxin (TCDD) Toxic Equivalents (TEQ), respectively. A feasibility study led to the selection of TerraTherm’s patented In-Situ Thermal Destruction (ISTD) technology, also known as In-Situ Thermal Desorption, which utilizes simultaneous application of thermal conduction heating and vacuum to treat contaminated soil without excavation. The applied heat volatilizes organic contaminants within the soil, enabling them to be carried in the vapor stream toward heater-vacuum wells.

Approximately 12,385 m^3 (16,200 cubic yards [CY]) of predominantly silty soil was treated to a maximum depth of 32 m (105 ft). TerraTherm installed 785 thermal wells, including 654 heater-only and 131 heater-vacuum wells, in a hexagonal pattern at 2.1-m (7.0-foot) spacing. Subsurface temperature monitoring tracked the progress of heating. The heating goal for inter-well temperatures was 335°C (635°F) for three days, or 300°C (570°F) sustained for thirty days.

Gases emerging from the heated soil were collected under vacuum and conveyed to an Air Quality Control (AQC) system, permitted by the South Coast Air Quality Management District. The AQC system consisted of a thermal oxidizer, heat exchanger to cool the gases, and serial vessels of granular activated carbon. AQC system performance was gauged by a Continuous Emissions Monitoring (CEM) system operated by TerraTherm, vapor sampling, and four source tests conducted by an independent stack testing firm.

Over the course of the project, TerraTherm reduced mean B(a)P-E and TEQ concentrations in soil from 30.6 mg/kg and 0.018 mg/kg (pre-treatment) to 0.059 mg/kg and 0.00011 mg/kg (post-treatment), respectively; thereby meeting the remedial goals, and resulting in a No Further Action letter from the Department of Toxic Substances Control. Attainment of such stringent soil treatment goals with an in-situ technology is unprecedented. Dioxin (PCDD/F) emissions based on four source tests averaged 0.0071 ng TEQ/dsm^3, compared to the standard of 0.2 ng TEQ/dsm^3. Averaged over the life of the project, this is equal to 0.00023 g TCDD, one-quarter of the projected (design) amount. Furthermore, this stack emission rate is equivalent to a TCDD TEQ concentration in the air of less than 2 parts per quadrillion, an extremely low emission rate for any remediation off-gas treatment system.

INTRODUCTION

The TerraTherm ISTD process utilizes conductive heating and vacuum to remediate soils contaminated with a wide range of organic compounds. Heat and vacuum are applied simultaneously to the soil with an array of vertical heaters. Heat flows through the soil primarily by thermal conduction from electrically powered heating elements. Because their temperature can be easily controlled, like the burners on an electric range, they can be operated at any desired temperature from ambient to about 870ºC (1600ºF), allowing the heating process to be tailored to the needs of a particular project.

ISTD remediation uses a network of thermal wells to achieve the soil clean-up standards within the target treatment zone (TTZ). At the Alhambra site, one-fifth of the thermal wells within the limits of the TTZ (Fig. 1) were configured as heater-vacuum wells to allow collection of the volatilized contaminants, and the remaining wells functioned as heater-only wells, delivering heat only. Electrical heating elements placed in all the thermal wells were designed to reach temperatures of approximately 700-870ºC (1300-1600ºF), resulting in an extremely hot zone surrounding each heater well. With ISTD, as the thermal heat front advances radially outward from each of the heater wells through the surrounding soils, most of the heat transfer occurs via thermal conduction (1).

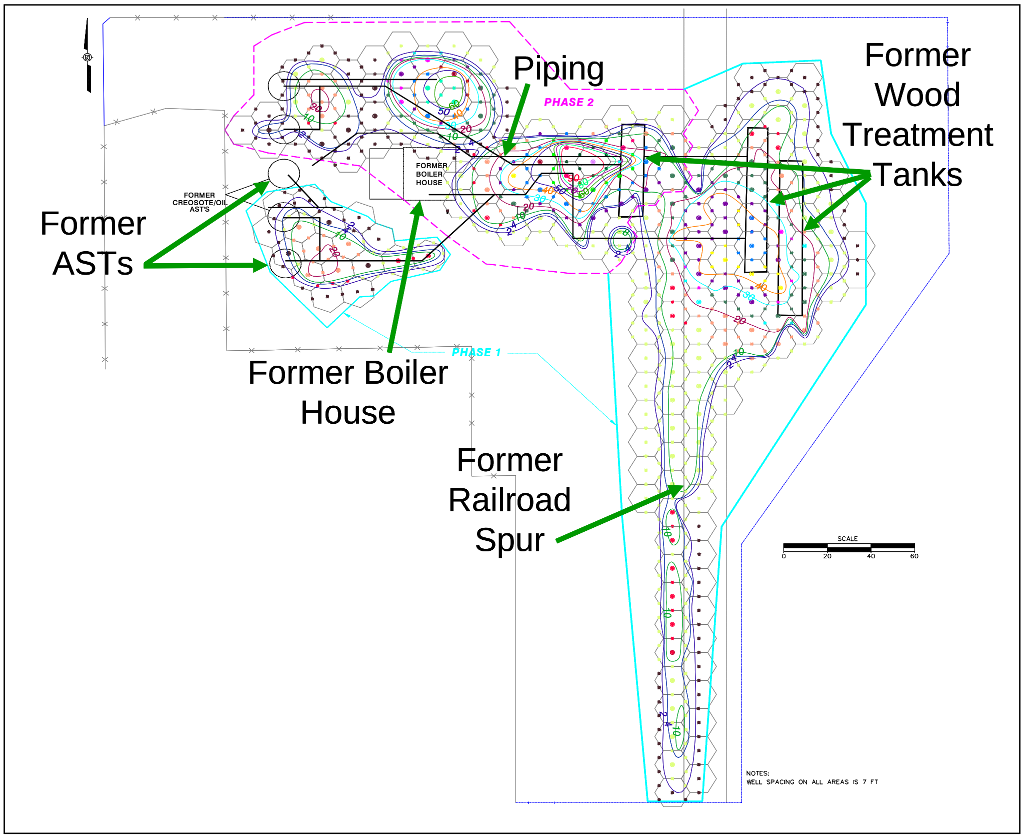

Fig. 1. Former Wood Treatment Facilities and ISTD Wellfield Layout. Colored contour lines indicate depth of contamination.

SITE HISTORY

The former wood treating facilities (AOC-2) were constructed in 1922-1923 for chemical treatment of utility poles by immersion in creosote. The facilities consisted of two full-length tanks (~3 m (10 ft) wide x 21.3 m (70 ft) long x 1.7 m (5.5 ft) deep), two butt-dip tanks (~3 m (10 ft) wide x 13.7 m (45 ft) long x 4 m (13 ft) deep), a boiler house, an aboveground storage tank farm, buried pipe lines and railroad spurs. Wood treatment operations continued until 1957.

PCP was employed briefly prior to shutdown of wood treatment operations, and is believed to be the source of the dioxins. Since then, the site has been used by SCE as a maintenance facility. SCE and their consulting engineer, IT Corporation performed a treatability study and selected ISTD in 2000. TerraTherm mobilized to the site in 2002 and implemented ISTD as a Voluntary Action under the Expedited Remedial Action Program administered by the California Department of Toxic Substances Control (DTSC).

SOIL TREATMENT STANDARDS

Maximum and average pre-treatment concentrations of the contaminants of concern (COCs) are displayed in Table I, along with the soil cleanup standards.

Table I. Soil Contaminant Concentrations and Cleanup Standards (2)

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-E]
Creosote	61,000	4,505	N/A
PCP	58	2.94*	2.5
Dioxins (2,3,7,8-TCDD TEQ)	0.194	0.018	0.001

* Average of 15 detected samples; PCP was not detected in the other 231 samples collected.

DESIGN CONCEPT

TerraTherm developed its design concept for the site using data from a treatability test that was performed on site soil, numerical simulation modeling, electrical power supply limitations, and air emission standards. An extensive community involvement program was undertaken by SCE and TerraTherm, and in response to community concerns additional contingencies were included in the system design, including redundant air treatment equipment, process blowers, stack testing events and longer operator hours.

Target Treatment Temperature. Laboratory treatability testing on site soils showed total contaminant mass removal of more than 99.96% when heating was applied to temperatures of 371ºC (700ºF) and 427ºC (800ºF) for 24 hours. Thermal desorption research shows that time, in addition to temperature, is a key factor in determining treatment effectiveness (3). For example, treatability testing (4) has shown that PAH-contaminated soils treated at 300ºC (592ºF) for three days achieved much lower residual contaminant concentrations than soils treated at 400ºC (752ºF) for just one day. The ability to effect treatment of these high-boiling point compounds at temperatures well below their boiling points is largely due to the significant increase in vapor pressure that accompanies the elevated subsurface temperatures created by ISTD, and the relatively long contaminant residence times in the hot subsurface during ISTD remediation.

TerraTherm also performed simulation modeling to evaluate the duration of treatment given the selected target temperature. Based on the treatability testing, simulation modeling, and previous experience with high-boiling point compounds, TerraTherm selected a target temperature of 335ºC (635ºF). The target temperature was defined as the temperature to be achieved within the coolest points in the wellfield (centroids midway between wells) and maintained for a period of 3 days.

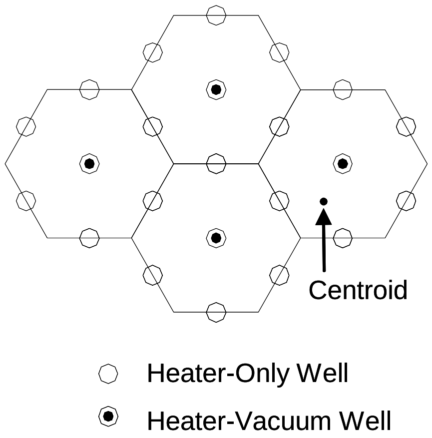

Fig. 2 – Hexagonal Grid Pattern Wellfield Layout (2).

Well Layout. TerraTherm installed a total of 785 thermal wells (131 heater-vacuum wells and 654 heater-only wells) within the 2,920 m^2 (31,430 ft^2) area of the TTZ. The thermal wells were arrayed in a hexagonal grid pattern (Fig. 2) at a spacing interval of 2.1 m (7.0 ft) on center. TerraTherm positioned heater-only wells at the center of each side of each hexagon and a heater-vacuum well at the center of each hexagon. Thermal wells ranged in depth from 2.1 m (7.0 ft) to 31.1 m (102 ft), and averaged 6.1 m (20 ft).

Vapor Seal. Due to electrical power constraints (discussed in more detail below), operation of the ISTD process proceeded using a phased approach. For Phase 1, TerraTherm poured a light aggregate cement surface cover over the wellfield to insulate the surface, preventing excessive heat loss from the soil, and providing a vapor seal that prevented steam and vapors from escaping to the atmosphere through the surface. To improve the insulation, TerraTherm poured a similar light aggregate, high insulating value cement above and below a layer of insulation board prior to Phase 2.

Electrical and Mechanical Systems. Two 2,500-kVA transformers were installed to provide power to the heater circuits, AQC system components, and trailers. The large power demand necessitated that the project proceed in two separate phases to avoid exceeding the capacity of the local power supply. Phase 1 utilized four distribution panels fed from the main switchgear that connected to the secondary side of the main transformers. The thermal well circuits were powered off the distribution panels and controlled by silicon controlled rectifiers (SCRs), which governed the duty cycle of the heaters based on representative in-well temperatures. A total of 16 circuits powered approximately 2,650 m (8,700 ft) of heaters operated at approximately 984 W/m (300 W/ft) for a total heater power demand of approximately 2,600 kW. Licensed electricians performed the electrical work and all electrical and mechanical equipment was bonded and grounded to ensure safety.

Insulated manifold piping connected the lateral piping from each heater-vacuum well to the main piping trunk line that led to the inlet of the AQC system. TerraTherm installed insertion heaters inside the manifold piping to keep the vapor stream warm and minimize condensation within the piping. Per City of Alhambra requirements, TerraTherm installed seismic bracing to secure the manifold piping and the AQC system components. Fig. 3 is an aerial view of the wellfield and immediate surroundings in December 2004, during operation of Phase 1.

AQC System and Emission Standards. The South Coast Air Quality Management District (SCAQMD) permitted the AQC system, which consisted of the following: three cyclone separators plumbed in parallel for particulate removal, a regenerative thermal oxidizer (RTO) with 99% Destruction and Removal Efficiency (DRE) for contaminant removal, a heat exchanger to cool the RTO exhaust, and two 2,268-kg (5,000-lb) granular activated carbon (GAC) vessels (plus an installed 1,361-kg (3,000-lb) spare) piped in series for additional contaminant removal. Vapors were pulled through the AQC system by two blowers, operated by variable frequency drives to apply a consistent vacuum on the wellfield, and then emitted via a discharge stack. A third blower was also installed as a spare. The AQC system was operated using a programmable logic controller (PLC) and operations staff were on site 24 hours/day, 7 days/week, as required by SCAQMD permit. A photograph of the AQC system and related equipment is presented in Fig. 4.

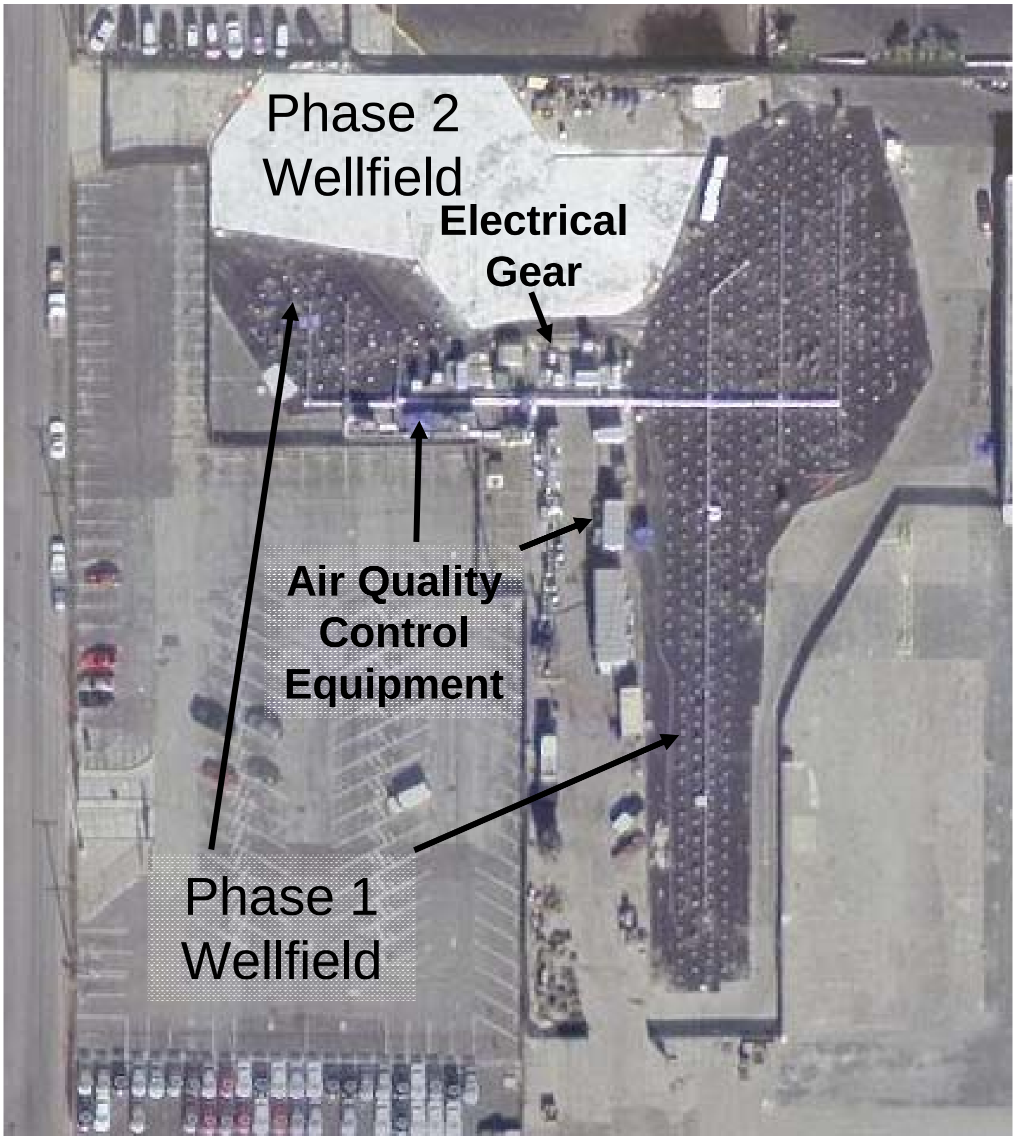

Fig. 3. Aerial View of Phase 1 ISTD under Operation, December 2004.

Air monitoring requirements included a Continuous Emissions Monitoring (CEM) system installed on the discharge stack, which measured carbon monoxide (CO), carbon dioxide (CO_2), wet and dry oxygen (O_2), and total hydrocarbons (THC). Volatile organic compound (VOC) samples were collected monthly from several locations in the AQC stream and analyzed by SCAQMD Method 25.1. An independent firm conducted source testing, including VOCs, PAHs, particulate matter (PM), hydrochloric acid (HCl), and PCDD/F, three times during Phase 1 of operations, and once during Phase 2.

ISTD OPERATIONS PROGRESS MONITORING

To evaluate the progress of in-situ heating and the performance of the AQC system, TerraTherm collected operational data frequently. The most pertinent data used for this evaluation were in-situ soil temperatures and pressures, AQC system source testing results, and soil sampling results.

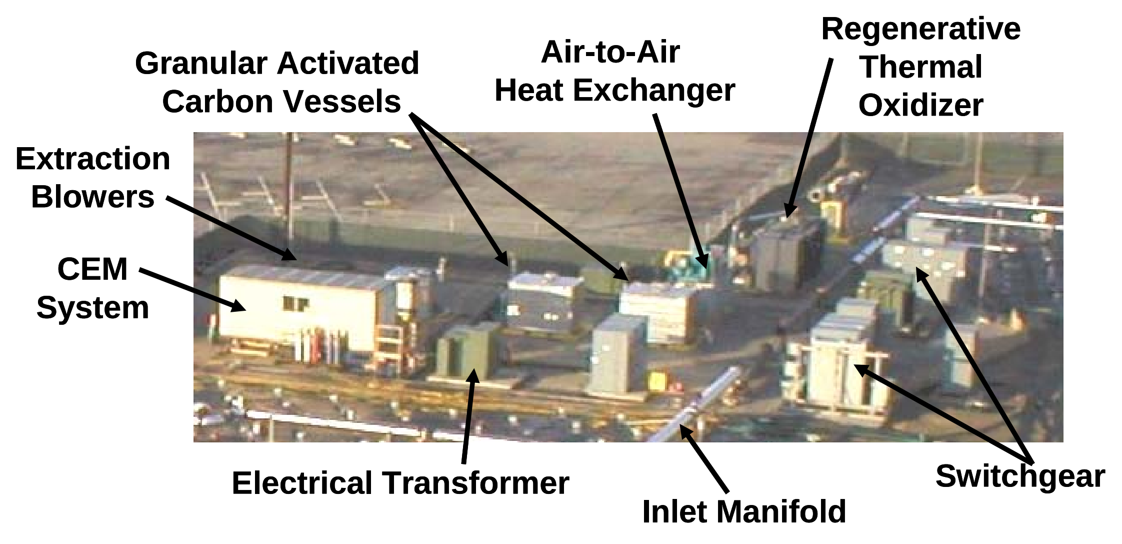

Fig. 4. AQC System and ISTD Mechanical and Electrical Equipment. A portion of the Phase 1 wellfield is evident in the foreground.

Wellfield Temperatures and Pressures. Thermocouples were installed inside temperature monitoring points at varying depths and locations throughout the wellfield to monitor soil temperature. The range of temperatures varied depending on the depth of the thermocouple and its proximity to thermal wells. The coolest point in each well pattern is always the centroid of the equilateral triangle formed by any three adjacent thermal wells (Fig. 2). The shallowest thermocouple in these centroid locations was generally the coolest due to heat loss through the surface cover. Temperature data for a representative centroid thermocouple in Phase 1 is presented in Fig. 5, showing the succession of rising temperatures up to attainment of the target temperature of 335°C (635°F).

In-situ pressures were monitored at eight locations around the perimeter of the wellfield to ensure that sufficient vacuum was being applied to the boundaries of the TTZ to prevent migration of steam and contaminants. Pressure data indicated that a negative pressure gradient was maintained on the boundaries of the wellfield throughout ISTD operation.

CEM and AQC Source Testing Results. CEM system measurements of THC and CO were monitored by the PLC. An alarm condition was defined to exist if the levels approached TerraTherm's self-imposed limits of 100 ppm_v for CO and 100 ppm_v as hexane for THC.

Three separate source-testing events were performed during Phase 1 of operations. Samples were collected from the RTO inlet and discharge stack and analyzed for HCl, PM, THC, chlorophenols, PAHs, polychlorinated biphenyls (PCBs), and PCDD/Fs. The three source-testing events within Phase 1 were conducted: (a) within the first five days of ISTD operation, and subsequently when the average of all centroid thermocouple temperatures reached (b) 100ºC (212ºF) and (c) 282ºC (540ºF), respectively. A single representative source testing event within Phase 2 was conducted within the first 60 days of Phase 2 ISTD operation. Tables II and III present data from all four events, along with associated emission standards (5). SCAQMD performed a detailed health risk assessment based on the data, which indicated full compliance with their Rule 1401.

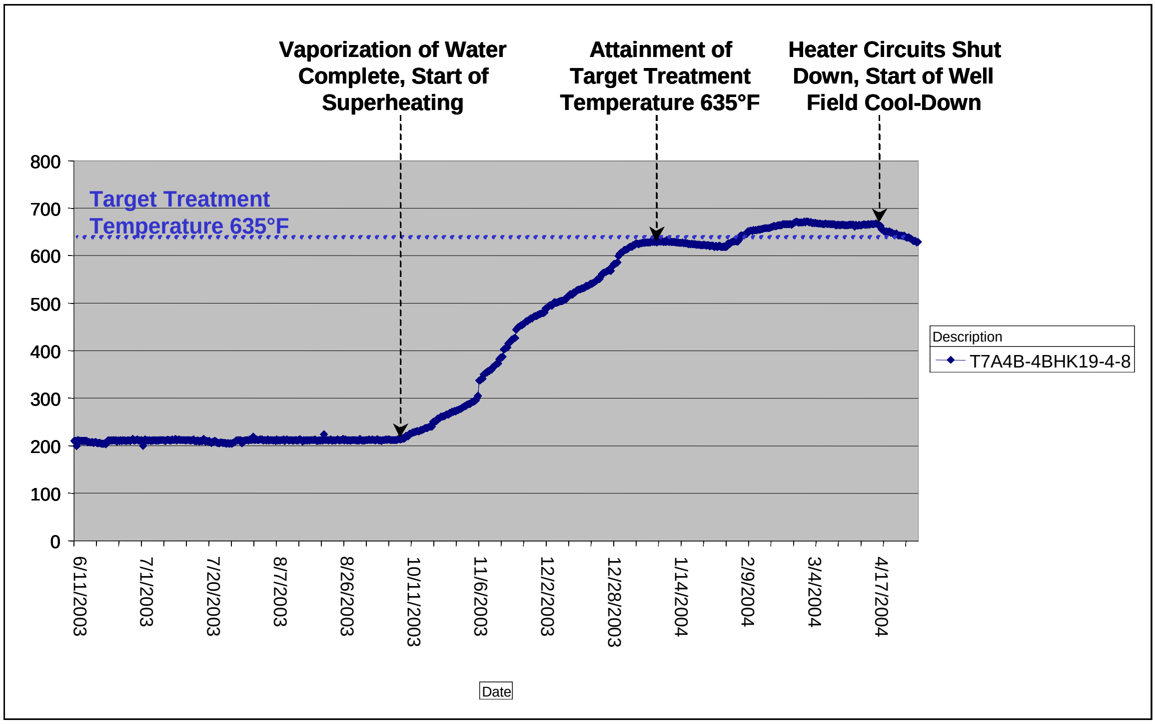

Fig. 5. Phase 1 Temperatures, Degrees Fahrenheit at a Representative Centroid Location.

VOC emission standards are listed in Table II as "varied" because emission limits corresponding to a maximum individual cancer risk (MICR) of 10^{-6} (i.e., one per million) varied depending on the chemical constituent. For all source-testing events, concentrations of VOC were ≤ 4.5% and of PAHs ≤ 4.1% of the MICR of 1 x 10^{-6} in all cases.

During the four source-testing events, DREs calculated by comparing mass emission rates from the RTO inlet and stack were > 99.7% for PAHs, PCBs, and PCDD/PCDF. The slight particulate matter exceedance (0.0021 vs. 0.002 gr/dscf in Phase 1, Event 2) may have been due to some fine carbon dust carried into the piping from the GAC.

Dioxin (PCDD/F) emissions based on four source tests averaged 0.0071 ng TEQ/dsm^3, compared to the standard of 0.2 ng TEQ/dsm^3. Averaged over the life of the project, this is equal to 0.00023 g TCDD, one-quarter of the projected (design) amount of 0.0009 g TCDD (6, 7). This value is much less than one hundredth of the TCDD emission from a typical oxidizer unit (8). Furthermore, this stack emission rate is equivalent to a TCDD TEQ concentration in the air of 1.8 parts per quadrillion[i], an extremely low emission rate, for any remediation off-gas treatment system.

Table II. Phase 1 and 2 Source Testing Results (5)

Compound	Units	Emission Limit	Phase 1 Event 1	Phase 1 Event 2	Phase 1 Event 3	Phase 2 Event 1
THC [(a)]	ppm$_v$ as Hexane	100	1.23	0.71	1.65	1.92
PCDD/ PCDF [(b)]	ng/dscm	0.2	1.61×10^{-2}	6.53×10^{-3}	3.53×10^{-3}	2.4×10^{-3}
PCP	µg/dscm	1,630	< 9.31	< 8.68	< 23.7	< 19.03
HCl [(c)]	µg/dscm	N/A	1,434	171	< 169	1,273
PM	gr/dscf	0.002	4.25×10^{-4}	2.10×10^{-3}	7.98×10^{-4}	9.49×10^{-4}
PCBs [(d)]	µg/dscm	2.44	5.94×10^{-3}	7.54×10^{-3}	0.0121	2.59×10^{-4}
VOC [(e)]	ppb$_v$ [(f)]	Varied	None Detected	3.7	None Detected	323.3

(a) Total hydrocarbons (b) Expressed as 2,3,7,8-TCDD TEQ; (c) Hydrochloric Acid (d) Polychlorinated Biphenyls; (e) The emission limit for VOCs varied depending upon the specific contaminant; (f) Sum of all VOCs analyzed.

Table III. Summary of Source Testing Results (µg/M^3 Discharge Concentrations) for PAHs (5)

Compound	MICR Limit	Phase 1 Event 1	Phase 1 Event 2	Phase 1 Event 3	Phase 2 Event 1
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

Soil Sampling Results. Soil samples were collected in accordance with the prescribed sampling and analysis plan at 20 locations within the TTZ where the highest pre-treatment concentrations had been found. At each such location, a sample was collected from 0 to 0.30 m (2.0 ft) from the top, 0.30 m (2.0 ft) from the bottom, and at the midway point within the vertical limits of the TTZ. The site-wide mean for carcinogenic PAHs (cPAHs), expressed as B(a)P Toxicity Equivalents was 0.059 mg/kg as compared to the cleanup standard of 0.065 mg/kg. EPA Method 8270C-SIM (low detection limit) was used to analyze PAHs. The site-wide mean for dioxins and furans, expressed as 2,3,7,8-TCDD TEQ was 0.11 µg/kg compared to the remediation goal of 1 µg/kg. EPA Method 8290 was used to analyze dioxin and furan samples. Finally, PCP was not detected in any of the soil samples at or above the remediation goal of 2.5 mg/kg (EPA 8270C). For those samples whose analytical result were below the laboratory detection limit, the PAH, PCDD/F, and PCP soil concentrations were each calculated by taking 1/2 the respective detection limit. Using this method, the mean PCP soil concentration was 1.25 mg/kg. These results are summarized in Table IV.

Table IV. Summary of Soil Sampling Results

Contaminant	Clean-up Standard (µg/kg)	Mean Soil Concentration (µg/kg)	
		Pre-Treatment	Post-Treatment
B(a)P-E	< 65	30,600 (n = 47)	59 (n = 60)
PCP	< 2,500	2,940 (n = 15*)	1,250 (n = 60)
TCDD TEQ	< 1	18	0.11 (n = 18)

*See Table I. n indicates the number of samples

CONCLUSIONS

On Feb. 8, 2007, DTSC certified that "the AOC-2 portion of the site has been remediated to allow for unrestricted land use, and that no further action is required" (9). To the authors' knowledge, achievement of unrestricted/residential land use at a facility of this type has never before been accomplished with an in-situ remediation method. In fact, during project planning, the only other remediation alternative deemed capable of achieving the unrestricted land use goal was soil excavation followed by off-site incineration. Although ISTD remediation costs exceeded the originally estimated cost, the all-in project cost was still approximately 40% lower than the excavation/incineration alternative for this F-listed waste. The ISTD project was completed without the complications and inherent risks associated with excavation projects, such as: strong odors, potential for chemical exposure, transportation of waste through city streets/communities, and the potential for other environmental impacts on the community.

Based on the completion of this project, and the lessons learned, TerraTherm prepared a cost estimate for a similar sized wood treatment site. The estimate assumed ISTD treatment in one operational phase lasting 130 days. The turnkey project cost is estimated to be $\$500/m^3$ (\$383/cy), broken into the following cost elements:

- Design/Installation/Commissioning – capital cost: \$3.9M
- Operation – includes electricity, source and confirmation sampling: \$2.2M
- Demobilization/Reporting/License Fee: \$0.23M

Based on these results, ISTD deserves consideration for treatment of sites contaminated with Persistant Organic Pollutants (POPs) such as those that were addressed at this site (10).

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[i] Calculated as follows: (2.65 x 10E-10 lb TCDD/hr)*(1hr/60 min)*(1 lbmole TCDD/308 lb TCDD)*(1 min/3000 cfm air)*(379 ft^3 air/1 lbmole air) =1.8E-15 parts TCDD/parts air, or 1.8 parts per quadrillion (wt/wt).