

POPs-WASTES APPLICABILITY (REFS. 4 AND 16):

ISTD is a thermally enhanced in-situ treatment technology that uses conductive heating elements to directly transfer heat to environmental media. ISTD can heat soil or sediment in situ to average temperatures of 1,000 degrees Fahrenheit (°F), and as a result has been used to treat compounds with relatively high boiling points. Some of these include semivolatile organic contaminants (SVOCs) such as polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), pesticides, and herbicides. Pilot- and full-scale applications have been performed where ISTD has been used to remove PCBs, and where dioxins and furans were trace contaminants. TerraTherm is the sole vendor for ISTD. According to TerraTherm, laboratory-scale work and extrapolation techniques have suggested the potential applicability of ISTD to POPs other than PCBs, dioxins, and furans (including aldrin, dieldrin, endrin, chlordane, heptachlor, DDT, mirex, hexachlorobenzene, and toxaphene); however, these contaminants have not yet been treated using ISTD on a full- or pilot-scale basis. ISTD has been used to treat contaminants in most hydrogeologic settings, including beneath structures.

POPs Treated:	PCBs, dioxins, and furans, aldrin, chlordane, dieldrin, and endrin
Other Contaminants Treated:	Hexachlorocyclopentadiene, isodrin, VOCs, SVOCs, oils, creosotes, coal tar PAHs, gasoline and diesel range organics, and MTBE

TECHNOLOGY DESCRIPTION (REFS. 2, 4, 13 AND 16):

OVERVIEW

ISTD involves simultaneous application of heat and vacuum to subsurface soils. There are three basic elements in an ISTD process: (1) application of heat to contaminated media; (2) collection of desorbed contaminants through vapor extraction; and (3) treatment of collected vapors. Figure 1 presents a typical ISTD system.

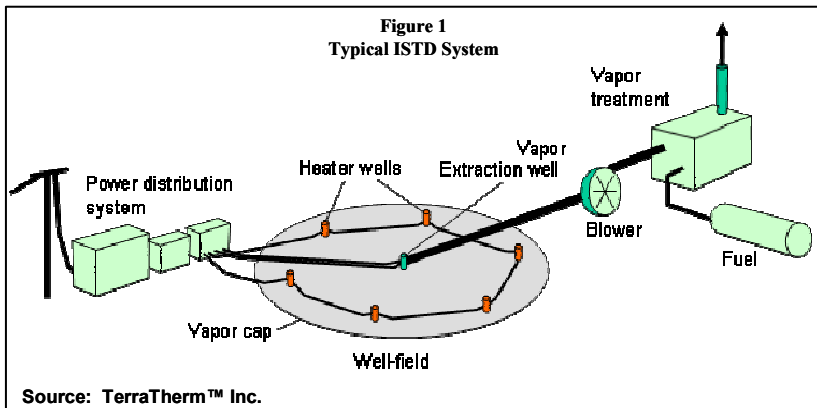
ISTD has been used at full scale to treat PCBs, PAHs, dioxins, and chlorinated volatile organic compounds (CVOC). At the temperatures achieved by the ISTD process, volatiles metals such as mercury may also be recovered.

In-Situ Heating

ISTD uses surface or buried electrically powered heaters to heat contaminated media. The most common setup uses a vertical array of heaters placed inside wells drilled into the remediation zone. A less common setup uses the same type of heaters installed horizontally on the surface of the contaminated zone. This method of heating (often called blanket heating) is typically used when contamination is shallow (usually 1 to 3 feet below ground surface (bgs)). Figure 2 illustrates the two different methods of heating.

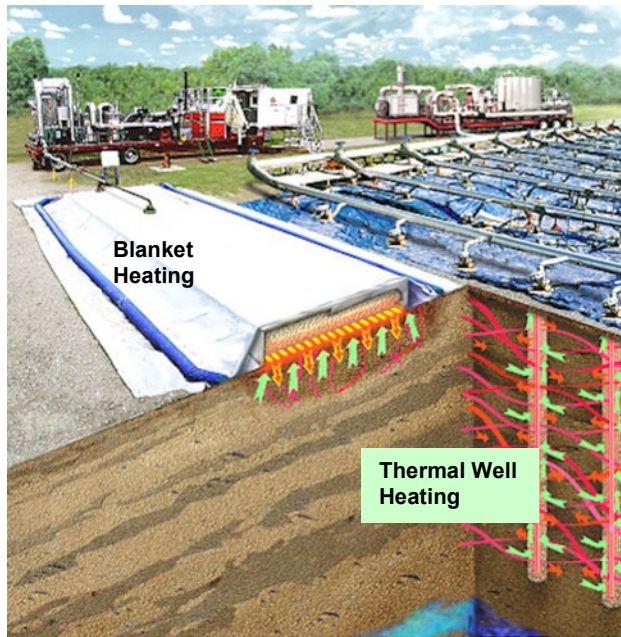
ISTD heaters can attain temperatures as high as 1,600 degrees °F, and can produce average media temperatures exceeding 1,000 °F. Heat originates from a heating element and is transferred to the subsurface largely via thermal conduction and radiant heat transport, which dominates near the heat sources. There is also a contribution through convective heat transfer that occurs during the formation of steam from pore water present in the soil or sediment.

The thermal conductivity values of a wide range of soil types (e.g., clay, silt, sand, gravel) vary only by a factor of approximately four. Therefore, the rate of heat transfer from the linear heaters to the surrounding media is radially uniform. When heating commences, the temperature profile in the remediation zone is characterized by large gradients, and temperatures decrease sharply with distance from the source. Over time, superposition of heat from adjacent heaters tends to even out these differences.



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Figure 2
Blanket and Thermal Well Heating



Source: TerraTherm™ Inc.

Vapor Extraction

As the matrix is heated, adsorbed and liquid-phase contaminants begin to vaporize. A significant portion of organic contaminants either oxidize (if sufficient air is present) or pyrolyze once high soil temperatures are achieved. Desorbed contaminants are recovered through a network of vapor-extraction wells.

Vapor extraction wells are also heated to prevent condensation of contaminants inside the well. A vacuum is applied to these wells to induce air flow through the contaminated media creating a zone of capture. Contaminant vapors captured by the extraction wells are conveyed to an offgas treatment system for treatment prior to discharge to the atmosphere.

Offgas Treatment (Ref. 2)

TerraTherm offers two different methods of vapor treatment. One treats extracted vapor without phase separation (Figure 1), and the

other cools heated vapor, separates the resulting phases, and manages each phase separately.

The vapor treatment option depicted by Figure 1 uses a thermal oxidizer to break down organic vapors to primarily carbon dioxide and water. Stack sampling has demonstrated that toxic pollutants in offgas, including dioxins, are substantially below regulatory standards. When influent vapors contain chlorinated compounds, hydrogen chloride (HCl) gas is produced. In such cases, the exhaust from the thermal oxidizer is passed through an acid gas scrubber to capture HCl gas.

The other vapor treatment option uses a heat exchanger to cool extracted vapors. The resulting liquid phase is then separated into aqueous and nonaqueous phases. The nonaqueous phase liquid (NAPL) is usually disposed of at a licensed treatment storage and disposal facility. The aqueous phase is passed through liquid-phase activated carbon adsorption units and then released into the environment. Cooled, uncondensed vapor is passed through vapor-phase activated carbon adsorption units and then vented to atmosphere.

Although setup varies from site to site, several components of the remediation system including heaters, blowers, and offgas treatment equipment are either standard or adaptable to new situations, with equipment reused from site to site. Downhole wells may not be salvageable and may be plugged and abandoned in place.

STATUS AND AVAILABILITY (REFS. 4 AND 5):

ISTD is a patented technology originally developed by Shell Oil. While U.S. Patent rights were donated to the University of Texas (UT), patent rights outside the U.S. were retained by Shell. TerraTherm holds the exclusive license to this technology from both UT and Shell, and is currently the only vendor. ISTD has been commercial for several years. Its ability to remove PCBs from contaminated soil was first demonstrated more than 6 years ago. As shown on Table 1, ISTD has been used at six POP-contaminated sites. Implementation at four of these sites was full scale, and the other two were pilot scale.

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**Table 1
Performance of ISTD at POPs Contaminated Sites (Refs. 2, 4 and 7)**

Site Name	Year	Scale	Contaminant	Concentration			
				Initial	Final	Goal	Units
Former South Glens Falls Dragstrip, Moreau, New York	1996	Full	PCB 1248/1254	5,000 (Max)	< 0.8	2	mg/kg
Tanapag Village, Saipan, NMI	1997 - 1998	Full	PCB 1254/1260	10,000 (Max)	< 1	10	mg/kg
Centerville Beach, Ferndale, CA	1998 - 1999	Full	PCB 1254	860 (Max)	< 0.17	1	mg/kg
			Dioxins and Furans	3.2 (Max)	0.006 ¹	1	ug/kg TCDD
Missouri Electric Works, Cape Girardeau, MO	1997	Pilot	PCB 1260	20,000 (Max)	< 0.033	2	mg/kg
Former Mare Island Naval Shipyard, Vallejo, CA	1997	Pilot	PCB 1254/1260	2,200 (Max)	< 0.033	1	mg/kg
Former Wood Treatment Area, Alhambra, CA	2002 - 2005	Full	Dioxins	18 (Mean)	0.01	1	ug/kg

Note:

Avg Average concentration
 Max Maximum concentration
 mg/kg Milligrams per kilogram (or parts per million)
 NMI Northern Mariana Islands
 ND Below detection limit
 TCDD Tetrachlorodibenzodioxin equivalents
 ug/kg Micrograms per kilogram (or parts per billion)

¹ Final concentration presented as average of residual concentrations in treatment area.

DESIGN (REF. 12):

Key design factors for ISTD include the number and depth of heater wells and vacuum wells, as well as the requirements for electrical power and treatment of off gasses. These factors are affected by the type of contaminants present, concentration of the contaminants, extent of contamination, soil type, hydraulic conductivity, permeability, thermal properties, location of the water table, availability of site facilities such as electrical power supply, and regulatory issues.

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THROUGHPUT (REF. 5):

ISTD has been used to treat volumes as low as a few hundred cubic yards to greater than 20,000 cubic yards in 6 to 9 months. Factors affecting cleanup durations can include type of contaminants, cleanup/remedial goals, and site geology.

WASTES/RESIDUALS (REFS. 3 AND 5):

Wastes produced by ISTD are likely to result from the treatment of extracted vapors, and vary according to the type of treatment they are subjected to. Offgas treatment options that employ phase separation techniques could produce process wastes such as NAPL, spent liquid- and vapor-phase activated carbon, and inorganic salts as waste products. For example, the treatment of chlorinated vapors in a thermal oxidizer results in the production of HCL gas. A wet or dry acid gas scrubber used to neutralize HCl gas will produce inorganic salts as a waste product.

NAPL is typically transported off site for disposal at a licensed facility. Spent activated carbon may either be disposed of, or regenerated at a licensed facility. Inorganic salts produced from neutralization processes are typically considered nonhazardous and are consequently disposed of as nonhazardous waste.

MAINTENANCE (REF. 4):

Maintenance associated with ISTD includes the occasional replacement of heater elements. ISTD operation is typically characterized by less than 5% downtime. Other maintenance needs include treatment media replacement and thermal oxidizer refueling.

LIMITATIONS (REF. 4):

The following are some of the limitations of this technology:

- ISTD cannot address contaminants that do not volatilize within the temperature range of approximately 15-1000°C.
- As long as liquid water remains within the remediation zone, the temperature that can be attained is limited to the boiling point of water (212 °F). Once the water is boiled off, higher temperatures can be attained. A continuing source of water influx into the treatment zone will undermine the ability of this technology to produce temperatures necessary for the removal of POPs. For this reason, formation dewatering and implementation of water control measures are needed prior to the implementation of ISTD in high-permeability, water-saturated zones.
- Though not always the case, cost can be a limiting factor. Unit costs for treatment are influenced by several factors including scale of the project, depth of the treatment zone, depth to water table, air emission controls, cost of labor and cost of power. However, in general, unit costs in USD range from \$200 to \$600 per cubic yard corresponding to treatment volumes ranging from less than 5,000 to approximately 15,000 cubic yards for POP-type contaminants. Larger volumes may have lower unit costs. Treatment costs for VOC contaminants are lower.

FULL-SCALE TREATMENT EXAMPLES:

Centerville Beach (Refs. 6, 8, 10 and 14)

The Centerville Beach Naval Facility is a 30-acre site in Ferndale, California that was used for oceanographic research and undersea surveillance. The site was decommissioned in 1993. Operations at the site lead to contamination of a particular area with PCBs. The PCB of concern was Aroclor 1254 which was present in concentrations ranging from 0.15 to 860 milligrams per kilogram (mg/kg). Dioxins and furans were also present at a maximum concentration of 3.2 micrograms per kilogram (µg/kg) as 2,3,7,8-tetrachlorodibenzodioxin (TCDD) equivalents. The contaminated medium was primarily silty clay. Groundwater was encountered below the contaminated zone at depths exceeding 60 feet bgs.

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From September 1998 through February 1999, approximately 1,000 cubic yards of PCB-contaminated soil was treated using ISTD. Heater and vapor extraction wells were installed in a zone measuring 40 feet long, 30 feet wide, and 15 feet deep. The wells were installed 6 feet apart. Two sealed vacuum blowers were used in parallel for vapor extraction. Offgas was treated using a flameless thermal oxidizer (with greater than 99.99% demonstrated treatment efficiency), and two granular activated carbon units configured in series. The total cost of the implementation in USD was approximately \$650,000.

The treatment goal was 1 mg/kg for PCBs and 1 µg/kg TCDD equivalent for dioxins and furans. Remediation took place between September 1998 and February 1999. Treatment goals were met in the bulk of the treatment area; however, one portion (178 cubic yards) still contained elevated concentrations of PCBs. This was found to be caused by a previously undiscovered bank of PCB-containing electrical conduits emanating from outside the treatment zone and passed into the treatment area. Excavation and disposal was subsequently used to remove this area of contaminated soil and the associated conduits.

Alhambra (Refs. 3, 9, 17 and 18)

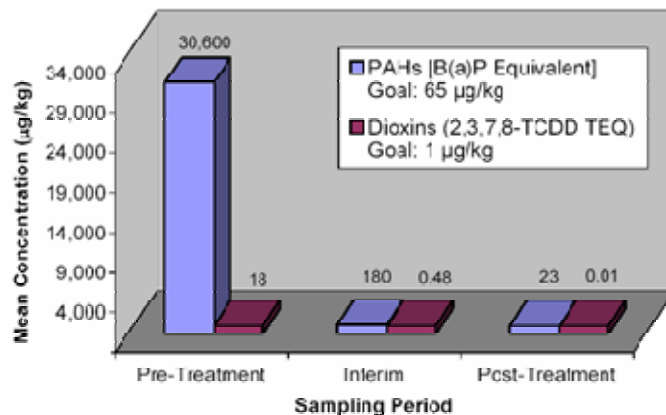
Southern California Edison's (SCE) Alhambra Combined Facility occupies approximately 33 acres and is currently used for storage, maintenance, and employee training. SCE carried out wood treatment operations in SCE's 2-acre former wood treatment area between 1921 and 1957. The total volume of contaminated soil was estimated to be 16,200 cubic yards of soil. The contaminated zone included a variety of buried features including treatment tanks, the structural remains of the former boiler house and tank farm, and various buried utilities. The contaminants of concern were PAHs, pentachlorophenol (PCP), and dioxins. Total PAHs were present in site soils at a maximum concentration of 35,000 mg/kg and an average concentration of 2,306 mg/kg. PCP was present at a maximum concentration of 58 mg/kg and an average concentration of less than 1 mg/kg. Dioxins were present at a maximum concentration of 0.194 mg/kg and an average concentration of 0.018 mg/kg (expressed as 2,3,7,8-tetrachloro-dibenzodioxin [TCDD] Toxic Equivalency Quotient [TEQ]). The soil in the remediation zone was composed of silty sands, inter-bedded with sands, silts, and clays. The average thermal treatment depth was approximately 20 feet bgs and extended to 100 feet bgs in some areas. The depth to the water table was greater than 240 feet bgs. The treatment goals were 0.065 mg/kg (expressed as benzo(a)pyrene [B(a)P] toxic equivalents) for PAHs; 2.5 mg/kg for PCP, and 0.001 mg/kg for dioxins (expressed as TEQ).

Remedial action at the site was conducted in two phases. Each phase addressed a different area of the site. The overall ISTD system for the two phases consisted of 785 thermal wells (131 heater-vacuum and 654 heater-only wells) at a 7.0-ft spacing between thermal wells, as well as an insulated surface seal, thermal oxidizer, heat exchanger, and granular activated carbon for off-gas treatment.

The ISTD began cleanup operations for Phase I of the remediation of Area of Concern (AOC)-2 in February 2003.

Confirmation soil samples were submitted to DTSC in July 2004 which confirmed that the cleanup goals for Phase I of AOC-2 had been achieved. Phase 2 of the cleanup began in July 2004 and was scheduled for completion by October 2004.

**Figure 3
Phase-1 Soil Sampling Results**



Source: TerraTherm™ Inc.

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However, a previously undiscovered volume of free product made it necessary to reduce in-situ temperatures in order to control organic contaminant concentrations in the offgas treatment system influent. This resulted in an anticipated 10-month increase in the cleanup duration. Phase 2 of the cleanup is expected to end in August 2005. The total cost of the implementation in USD was approximately \$10 million.

Rocky Mountain Arsenal Hex Pit (Ref. 15)

The Hex Pit was a former disposal pit at the U.S. Department of Army's Rocky Mountain Arsenal (RMA). Shell Oil Company leased a portion of the RMA from 1952 to 1982 to manufacture pesticides. The pit was used from 1947 to 1975 to dispose of residues from distillation and other processes used in the production of hexachlorocyclopentadiene (hex), an ingredient in the manufacture of pesticides.

The main part of the Hex Pit measured approximately 94 ft by 45 ft, and varied from 8 to 10 ft deep. The pit contained a total of 2,005 cubic yards of waste-contaminated materials, of which 833 cubic yards was estimated to be waste.

The Hex Pit consisted primarily of soil and waste material originally disposed of in the pit. The impacted soil (silty sand) was stained dark brown, rust orange, or black, and at times included granules or globules of hex. Black, tar-like, relatively pure hex residue occurred in distinct solid layers of waste (approximately 1-foot thick). Hex was not detected in groundwater downgradient of the Hex Pit boundaries.

The contaminants of concern were hex, aldrin, chlordane, dieldrin, endrin, and isodrin. Only hex, chlordane, and dieldrin had treatment goals. The treatment goals were 760 mg/kg, 67 mg/kg and 335 mg/kg respectively. Laboratory tests indicated that Hex Pit wastes could be effectively treated by the ISTD process.

ISTD at the Hex Pit was designed to heat a treatment soil volume of 3,198 cubic yards, extending from 0 to 12 ft bgs and 5 ft laterally beyond the boundaries of the Hex Pit. Thermal wells on 6-foot centers were installed in a hexagonal arrangement. A total of 266 wells were installed, of which 210 were heater-only and 56 were heater-vacuum wells.

The target treatment temperature based on the boiling point of COCs was 325 °C. All heater-only wells reached their operating temperatures in early March 2002. Treatment was expected to last 85 days and end in May 2002. However, twelve days after commencement, corrosion was observed in some of the well manifolds. Subsequent investigation and assessment determined that unforeseen concentration of HCL gas and production of HCL (liquid) in the vapor conveyance system, resulting from the highly concentrated wastes in the Hex Pit, had caused corrosion. Corrosion damage to the ISTD system was significant. A determination was made that replacements with necessary corrosion resisting matrices was cost prohibitive. Wastes were excavated and capped.

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PATENT NOTICE:

ISTD is covered by a total of 22 U.S. patents, with 6 patents pending. TerraTherm is the exclusive licensee through the University of Texas and Shell.

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