Investigations of Hazardous Waste Sites Using Thermal IR and Ground Penetrating Radar

Gary J. Weil, Richard J. Graf, and Leann M. Forister

Abstract

The remote sensing techniques of infrared thermography and ground penetrating radar can be used to detect buried waste sites, buried tanks/pits, and both potentially hazardous and non hazardous fluid leak plumes. These technologies can be used to investigate tens of acres per day when used in a combined format which includes rapid survey techniques and manual data analysis. This new fusion of technologies is demonstrated with the use of empirical data in the form of case studies.

Introduction

The increasing concern of property owners, potential property owners, real estate lawyers, and others associated with the selling and purchasing of properties potentially contaminated by hazardous wastes has led to a demand for accurate, efficient, and economical site assessment programs. The concern of these individuals is the possibility of unknown underground storage tanks (USTs), waste deposits, and/or contaminated subsurface soils that may be at the site. Depending on the nature of the purchase, location or confirmation of buried waste may be a deciding factor in the decision to purchase the proposed property. Due to the high cost of remediation of contaminated land, which is the responsibility of the property owner, it is imperative that the existence and amount of any subsurface contaminants be known prior to the purchase of the property.

Production and research organizations, with known waste deposit sites, also have a need for locating and characterizing subsurface contaminants. Many of these waste sites have been active for years, with little documentation or description of the waste materials. Pressure from government and private agencies to remediate these known waste sites has made this a top priority for many of these firms. It is essential that the extent and nature of these contaminants be known, so that proper and cost-effective remediation can be conducted.

Numerous avenues presently exist for gaining information as to the existence, or nonexistence, of subsurface waste deposits. Generally, the first step, a Level I site characterization, would include reviewing past drawings and records that may indicate prior tenants of the site. For example, the knowledge that a gasoline station or automotive repair shop previously existed on the site would aid in determining the possibility of USTs, waste deposits, heating oil tanks, etc. Unfortunately, drawings are many times unavailable, and most information retrieved does not go beyond the design plan stage and lacks as-built engineering drawings.

A Level II site characterization involves the construction of monitoring wells at the site and measurement and/or observation of escaping gases or a sheen on well water. If monitoring wells are not used, areas can be cored and analyzed for contaminants. This approach is problematic in that factors such as size of the site and an inadequate amount or poor placement of monitoring wells or corings will contribute to the possibility of overlooked contaminated materials. In addition to the cost of corings and monitoring wells, there is the added risk of coring into an existing filled tank, which can significantly increase the cost of clean-up.

An alternative method that may be used is the magnetometer which is a form of electromagnetic (EM) testing. This method has met with limited success due to the fact that most testing sites contain many metallic objects, such as concrete reinforcing steel, plumbing pipes, supply pipes, and past construction debris, on and beneath the surface, that generate false signals which may be erroneously interpreted as possible USTs. This method is also limited by its ability to locate only metallic materials, not materials such as fiberglass or PVC which are becoming widely used in piping and tank construction. Furthermore, this technique cannot locate non ferric contaminates that have leaked into the surrounding soils.

The recent combination of two remote sensing testing techniques has led to an improved solution for dependable, cost-effective location and characterization of underground waste deposits. The procedure uses infrared thermography as a primary testing method and ground penetrating radar as a secondary, complementary investigation technique. Both technologies have been proven effective in supporting nondestructive testing applications. This method of data fusion has proven to be accurate for gaining detailed information pertaining to subsurface conditions of both large and small sites and can be used to initiate further detailed sampling studies.

Technology Overview

Infrared Thermography

Infrared thermography (TIR) is a non-contact, non-invasive means of producing electronically generated images from the thermal energy emitted from an object. The thermal signature can be displayed in the form of an image with gray scale variations, or different colors, representing levels of infrared radiation exitance, or as calculated relative temperatures using emissivity algorithms. The system is designed for real-time analysis of static or dynamic thermal patterns.

Photogrammetric Engineering & Remote Sensing,
Vol. 60, No. 8, August 1994, pp. 999–1005.

0099-1112/94/$3.00/0

EnTech Engineering, Inc., 1846 Craig Park Court, St. Louis, MO 63146.

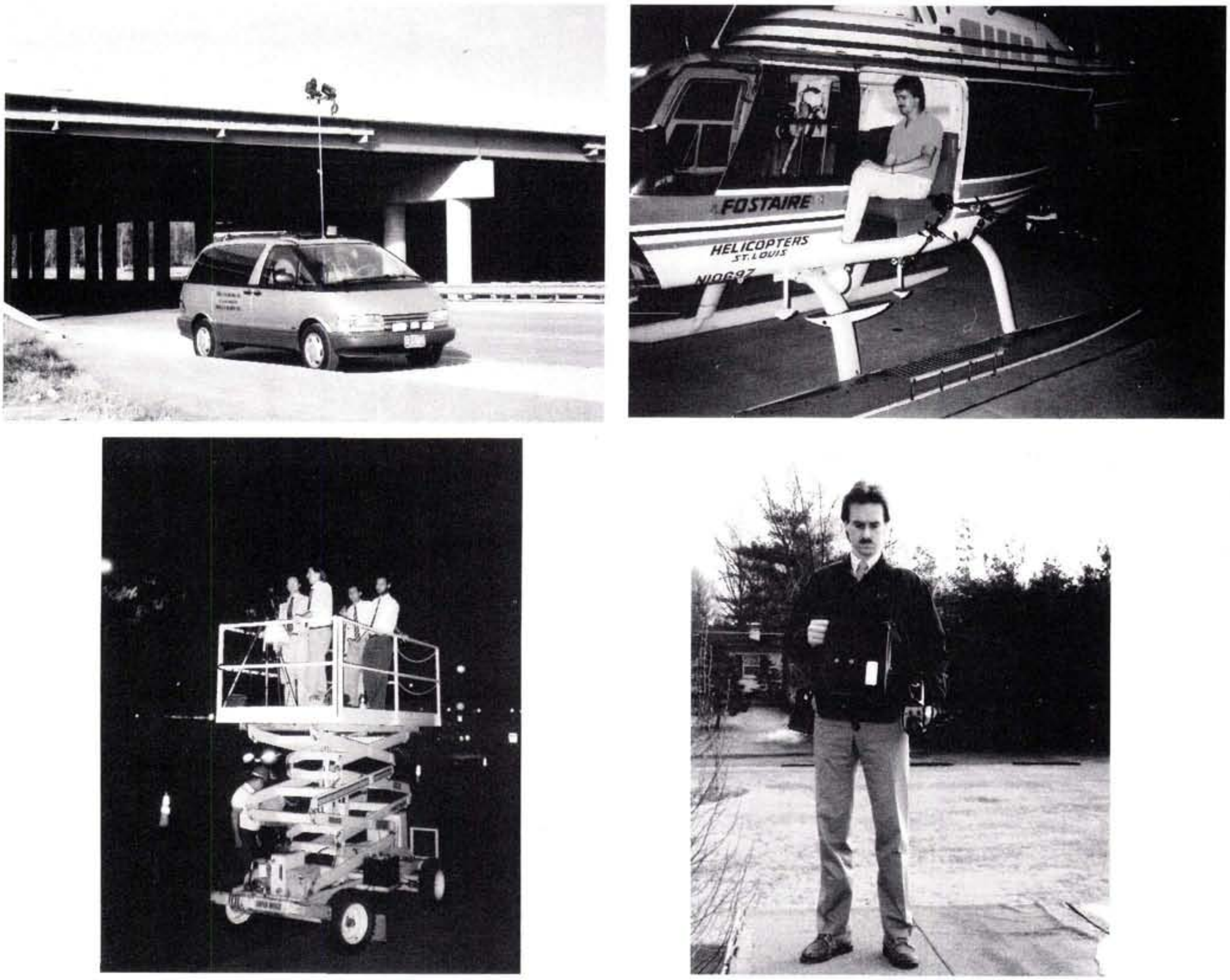

Figure 1. Various mounts for infrared scanning system.

Areas in excess of half an acre, with resolution approaching 1 inch (2.54 centimetres), can be investigated in one single image, making this testing method highly efficient as well as cost effective. The system may be man-carried, vehicle mounted, and/or aerial mounted, depending on the size of the area to be investigated (Figure 1). TIR systems are available at costs ranging from $20,000 to $2,000,000, depending upon system capabilities and options.

The use of thermal imaging for mapping minute surface temperature variations makes this investigation technique a useful method for locating surface and subsurface anomalies related to waste deposits, buried tanks, buried pits, moisture differences, voids, density differences, or any other anomalies that would cause a difference in thermal capacity or thermal conductivity. As with most forms of non-destructive testing, this technique only tells the operator of areas that are different from the surrounding property; it does not determine what is causing the difference.

In order for the TIR operator and equipment to obtain data, energy movement must be established in the areas under evaluation. Solar heating is an even and thorough energy source to measure the thermal loading and unloading characteristics of the pavement and soil areas in question. The basis for differences in the infrared radiation of soil is caused by differences in its absorption, storage, and emittance of energy. As the sun's energy radiates upon the ground surfaces, all similar surface material will absorb and store this energy in the same manner, according to their thermal properties, i.e., specific heat, thermal conductivity, emissivity, etc.

This energy will then be transferred to the subsurface materials by means of conduction. If subsurface differences are present in the soil, the rate at which the energy is received, stored, and released will also differ. A thermal anomaly can be indicative of changes within the subsurface. These changes could include voids, USTs, and deteriorated backfill because of their looser packing and higher insulation values, as well as soil with leak plumes caused by fluids with thermal properties different from the dry soil materials.

Normally, the multitude of different materials and their differing thermal properties encountered in pavements and

SUPPORT ELECTRONICS & RECORDING DEVICES: RADAR ANTENNA MANUAL TOW SYSTEM:

Figure 2. GPR data collection.

subsurface materials makes establishing accurate models of the heat transfer process extremely difficult. A general model of the heat transfer process would have to include the three modes of heat transfer: conduction, convection, and radiation. Because this paper will use empirical evidence to support its propositions, the author will leave a detailed discussion of constructing mathematical models to others.

Instead of using mathematical models to test our original theories, EnTech Engineering, Inc. worked with the Sverdrup Corporation, under the sponsorship of the St. Louis Metropolitan Sewer District, to construct a field test to determine the TIR process effectiveness to identify subsurface voids and leaks. This test program, performed in 1983, encompassed three repetitive tests at two separate locations. It proved that TIR could locate voids (representative of partially empty tanks), to a depth of 38 feet (12 metres) below typical city street surfaces, with an accuracy of 80 percent. The test also proved that TIR could locate an eight inch (20 centimetres) water main leak (representative of a potentially hazardous waste leak plume) at a depth of 12 feet (4 metres) below the same city street surfaces.

Typically, anomalous areas are marked with paint in the field at the time of data collection. When extraneous variables, such as surface debris, uneven ground cover, and solar shading of the site are present, post processing may be required. This post processing may consist of image averaging, image subtraction, typical leak/UST signature recognition, histogram equalization, and other image manipulation techniques as well as manual input from the operator, in order to enhance the thermal imagery.

With this type of investigative technique, there are many variables that combine with divergent environmental conditions that must be recognized. Care must be taken when analyzing apparent thermal differences to insure that they are not caused by surface emissivity changes, such as caused by surface grass, ponded moisture, or varying pavement materials. It should also be emphasized that thermographic testing techniques can only reveal surface thermal characteristics created by subsurface anomalies. Depth, construction type, or other characteristics of subsurface objects must be determined by other complementary techniques such as ground penetrating radar.

Ground Penetrating Radar

The ground penetrating radar (GPR) system uses an antenna to transmit controlled electromagnetic pulses that are transmitted into the subsurface areas in question. The pulses penetrate the subsurface and are reflected back to a receiving antenna. The radar system amplifies and enhances the pulses, which are then recorded on data tape and simultaneously displayed in real-time on a color monitor (Figure 2).

Although GPR employs an EM process, it differs from a magnetometer because it uses a sharply focused, narrow band width, microwave spectrum signal to locate subsurface objects rather than an obtuse, omnidirectional sensor tuned to a magnetic resonance. It reflects or refracts its signals off all subsurface objects in the specific direction of the focused sensor. The GPR also has a time measurement capability which allows measuring the time for a signal to travel from the transmitter, bounce off a target, and return to the receiver. This time function can then be calibrated to the velocity of a specific subsurface condition in order to measure distance to a subsurface object or horizon. Calculations can be used to convert this time value to a distance measurement that represents the depth of the target based upon field determined values for soil properties such as dielectric and wave velocity in a medium. A simplified technique that can be used when calibrating the depth measurement abilities of a particular GPR system involves coring a sample target, measuring its depth, and relating it to the number of nanoseconds it takes a wave to propagate.

Once the time function ability of the equipment gives the operator depth information, the equipment is moved laterally in the horizontal direction, thus allowing the construction of a two-dimensional (2D) profile of the subsurface. By scanning in a series of parallel lines over a site, a 3D image of the subsurface can be constructed.

A wide range of GPR antennae are available and normally operate over a range of frequencies from 80 Mhz to 2.5 GHz. Each has its own advantages and disadvantages, and the frequency selection should take into consideration individual project criteria. For example, the lower frequency antennae generate signals which have the ability to penetrate deeper into the ground, but provide less resolution, whereas the higher frequency antennae generate signals with greater resolution, but do not obtain the depth necessary for some investigations. With the proper antenna selection and ideal soil and subsurface conditions, such as deep ground water table, low material conductivity, etc., GPR testing can accurately characterize subsurface objects at depths in excess of seventy-five feet (23 metres).

The data collected by GPR systems can be interpreted immediately for large subsurface objects. At other times, it may be necessary to use post processing techniques to enhance data in order to improve subsurface resolution and interpretations. These techniques may include special data filters for eliminating background noise, for waveform manipulation, and for various methods of displaying the waveforms.

Although GPR is an excellent tool for pinpointing and characterizing subsurface waste sites, this testing method is considered impractical for measuring information over large areas for the location of subsurface contaminants because of its need to use a sampling grid system for data collection.

By using infrared thermography as the primary screening method with its ability to view large areas with 100 percent site coverage, and GPR as a complementary, secondary testing method for characterizing documented thermal abnormalities, in-depth characterization of sites suspected of containing hazardous waste can be economically and efficiently performed. The following case studies illustrate how these two technologies are used together.

Case Studies

Case Study 1: West Coast Air Force Base

An Air Force base located in California is working to remediate 89 suspected UST locations that have been out of service for many years.

The first step in this remediation process was to examine records and documentation concerning the existence, placement, size, and possible removal of the 89 suspected USTs. By reviewing available records, it was determined that the previous location and removal of 40 USTs could be confirmed. Documents for the remaining 49 USTs gave approximate information as to their location; however, no information was available that referenced size, construction type, or depth. Conversations with base personnel and further documentation review left unresolved whether a number of the remaining USTs had been removed at an earlier date, or if all still remained buried.

In order to confirm the existence of the USTs, base personnel performed electromagnetic investigations, using metal detector type magnetometers, of numerous suspected UST site locations. The data from this testing method were inconclusive due to the large amount of metallic objects within the soil. In addition, the electromagnetic investigation was time consuming and was unable to indicate potentially contaminated soils created by leaking USTs.

An investigation program that would confirm and characterize, or deny the existence of, the suspected USTs located at the 49 separate sites throughout the base was begun in 1992. The parameters of the investigation were set up based upon vague documentation of the suspected UST locations. The investigation would cover an area of approximately 10,000 square feet (1000 square metres) surrounding each of the suspected UST locations.

The initial investigation was conducted using infrared thermographic imaging during both nighttime and daytime hours with weather conditions being 50 to 80°F (10 to 27°C), no precipitation, and no standing water on the surface. In order to gain a wide field of view, the thermographic equipment and operator were placed in a self-propelled lift truck, elevated to a height of fifty feet (15 metres). By combining 40°, wide field-of-view optics and a wideband HgCdTe detector in the 2- to 14-µm band, with the elevated height of approximately 30 feet (9 metres), a 10,000 square foot (1000 square metres) area could be viewed in one image, from a single vantage point. Determination of surface temperature anomalies, which could be indicative of subsurface targets, was performed in real-time and locations were marked on the ground surfaces with paint. The time required for the TIR investigation and ground marking process at the 49 different sites was a total of 15 hours.

Of the 49 suspected UST locations, thermographic imaging documented 38 sites as containing subsurface anomalies that could be indicative of USTs. The remaining 11 sites displayed no subsurface anomalies and were considered to contain no USTs. As confirmation, two of the "clean" sites were further investigated using backhoes, but no USTs were found.

A ground penetrating radar investigation was made for the 38 sites where thermal imaging documented subsurface anomalies. As a result of locating the subsurface anomalies by thermal imaging, the GPR investigations were only required to test approximately 400 square feet (36 square metres) of area per site, rather than the initial 10,000 square feet (1000 square metres). The GPR antenna was manually guided over a five-foot grid system placed on the investigation site to facilitate data collection. The GPR data was analyzed in real-time with a total investigation time of approximately 12 hours for all 38 sites.

The combined data results from both the TIR and GPR investigations confirmed the location, horizontal size, depth to the top surface of the anomaly, and construction type, metal or non-metal, of 36 USTs (Plate 1). In addition, two of the 36 sites were found to contain contaminated soils surrounding the UST location. The contamination evidenced itself in both the TIR and the GPR tests. In the TIR test, the plumes thermal characteristics differed from those of the surrounding materials. This difference caused a warmer surface temperature in the areas covering the plume. In the GPR tests, the contamination showed up as obvious differences in the dielectric value of the subsurface materials. The remaining two locations identified by thermal imaging as containing subsurface anomalies were confirmed by GPR, and minor soil disturbance, to be the location of an abandoned utility line and a buried automobile tire, both of which were located under a dust covering near the ground surface. The above results were confirmed by independent government contractors during their site rehabilitation program.

Case Study 2: U.S. Government Testing Laboratory

In the Cold War era, many firms designed, tested, and constructed numerous types of military weaponry for the government. During the process of design and construction, highly toxic waste materials were produced, with the responsibility of disposal left to the discretion of the manufacturer. It later became apparent to these manufacturers that hazardous waste was an unwanted bi-product and difficult to dispose of.

Several factors surrounding these past events contributed to the current problem of undocumented waste sites. Oftentimes the waste was buried on the manufacturers' own property without documentation or proper disposal techniques. Sometimes the waste material produced in the past was not considered hazardous at the time of production, but later was found to be a potential threat to groundwater supplies, animals, and humans.

As a result, there are presently thousands of acres of land scattered with man-made waste sites that contain a variety of hazardous waste products. The current owners of these sites vary in their knowledge of the location, size, or type of debris in the waste sites. Many of the trenches, pits, and barrels of known waste sites are being found to leach contaminants into surrounding soils and have penetrated, or will eventually penetrate, the water table.

Until recently, the only way of pinpointing and characterizing these sites was with records, which at times unintentionally or intentionally contained inaccurate information which could disguise the dumping of toxic wastes. The following case study illustrates the use of TIR and GPR studies to successfully characterize a 33-year-old waste site located in New Mexico.

The waste deposit site was established in approximately 1959 and encompassed approximately 1.6 acres (0.65 hectares) of land. The history of the site revealed that hazardous radioactive and mixed waste, possibly consisting of radioactive tracers, contaminated oils, fuel drums, and concrete, was placed in lined trenches and pits from 1959 through 1992. The area was fenced in 1992 based upon available written records of waste deposited at the site, a 1960 aerial photograph that depicted the waste site before backfill was placed over the waste, and a two-year ground-based search using conventional techniques.

The investigation began with an aerial thermographic survey of the 1.6 acre (0.65 hectare) site. The aerial reconnaissance, taken from a 100-foot extended basket truck, allowed for single image data collection of the entire site. The advantage of this method of data collection is its ability to capture the data with a single image, allowing for immediate and accurate comparison of surface thermal characteristics. The thermal data were also recorded on instrumentation videotape for later office playback, enhancement, and analysis. From the interpreted thermal data, a drawing was created that displayed the location of potential subsurface anomalies indicative of waste pits, trenches, and the horizontal delineation of waste plumes created by leaking pits and trenches thought to contain liquids. Within the 1.6 acre (0.65 hectare) site, 14 suspect areas were documented, including one suspect waste deposit that was located outside the fenced waste site boundaries.

Upon completion of the thermal analysis, the GPR investigation was conducted by manually towing the antenna across suspected anomaly areas that were plotted on the thermographic drawing. The results were analyzed in real-time, based upon patterns observed in the GPR data, with pit boundaries, trench locations, and plume locations marked on the site surface.

The combined data results from both the TIR and GPR investigations documented all of the trenches and pits to be within the boundaries of the waste site, with the exception of a 50-gallon drum which was located 13 feet outside of the quarantined area. Numerous pits and trenches displayed nonlinear spatial border temperature signatures (sometimes hotter and sometimes colder than surrounding areas, depending upon the time of day data were collected) which could indicate leaching of contaminated material from the lined pits and trenches (Plate 2). The data results were utilized to accurately pinpoint specific waste sites for ease of remediation, as well as to depict soil areas that will require extensive rehabilitation.

All of the suspected areas identified by using the TIR and GPR technologies over a 2-day field program were confirmed by additional digging and sampling tests performed by another engineering firm under the administration of the site managers, except for the drum of material located adjacent to the fence delineating the area. This drum was confirmed using nuclear radiation sensors by the site managers. The traditional tests took a period of approximately 2 years to complete the field data collection process.

Case Study 3: Rehabilitated Gasoline Station

The third case study illustrates the use of thermographic infrared imaging and ground penetrating radar for the confirmation of underground storage tanks at a retail property for sale. Record searches performed indicated that the property was used as a gasoline station in 1962. The records also indicated that two 10,000-gallon (37,843-litre) gasoline tanks and a 100-gallon waste oil tank were once in active use at the site; however, the records did not indicate that the tanks had been removed.

The thermographic investigation was conducted at night from an adjacent rooftop, and the resulting data indicated four subsurface anomalies. The first anomaly was approximately 2 feet in diameter, circular in shape, and cooler in temperature than the surrounding areas. The other was triangular in shape, approximately 4 feet across at its widest point, and also cooler than the surrounding areas. The other two anomalies were rectangular in shape, approximately 5 feet wide and 10 feet long, and had cooler temperature signatures. The following day, ground penetrating radar was utilized to further characterize the thermographic anomalies. Using a 5-ft by 5-ft grid system to pull the antenna over the investigation site, the GPR data uncovered the location of the filled 100-gallon waste oil tank (Plate 3); a second anomaly was documented as a subsurface void created by a nearby cracked 28-inch sewer main. The two largest TIR anomalies were confirmed by locating previously hidden vent/fill pipes. The two 10,000-gallon tanks were not found. All results were confirmed by independent client rehabilitation contractors.

The data results aided the client in two ways: first, by locating the existing 100-gallon tank, and second, by having the cost of its removal paid for by the current property owner. In addition, the client was able to convince the sewer department to repair the damaged sewer, as well as fill the void that was present beneath the property.

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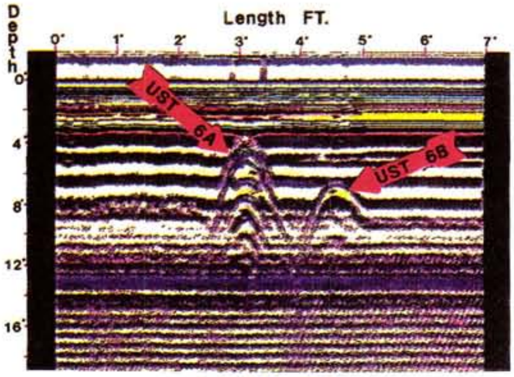

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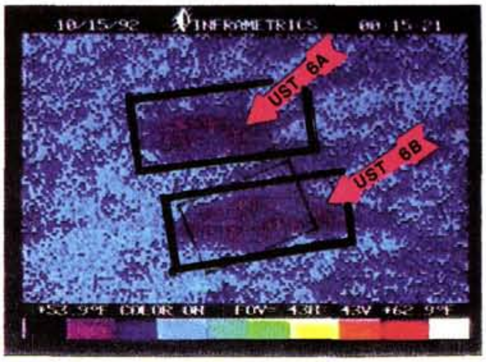


INFRARED THERMOGRAM:

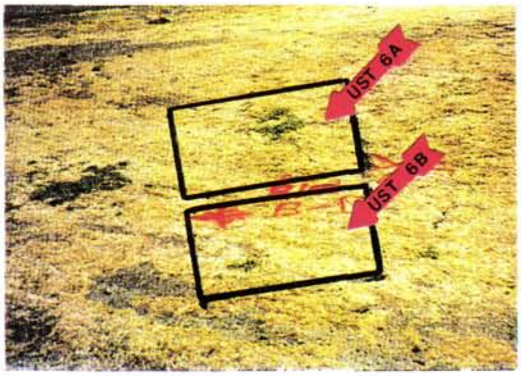
UST 6A& 6B

LOCATION: US. Air Force Base
California
35 feet SE of building 87C

DEPTH: UST 6A - 4 feet
UST 6B - 7 feet

SIZE: UST 6A - 500 Gallon Approx.
UST 6B - 500 Gallon Approx.

NOTE: See Drawing , Items 6A & 6B for tank location



VISUAL IMAGE:

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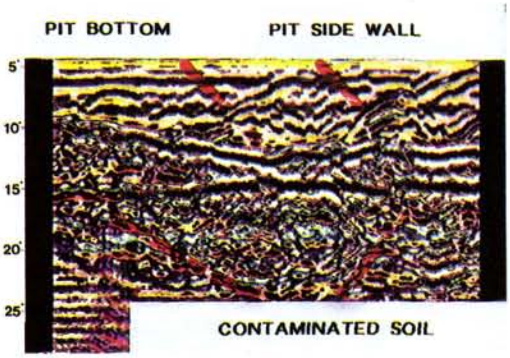
Plate 1. Combined visual, IR, and GPR data of UST.



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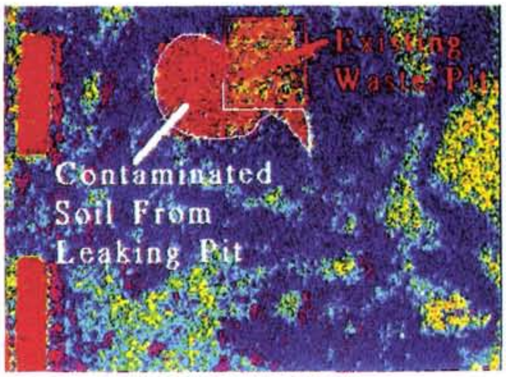


INFRARED THERMOGRAM:

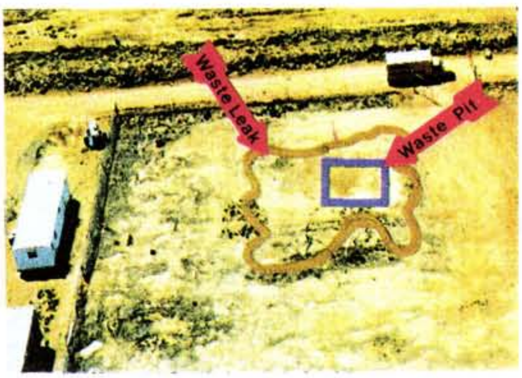
WASTE SITE INVESTIGATION

LOCATION: Testing lab toxic mixed waste site
New Mexico
Location of individual waste pit

PIT DEPTH: 10 feet from surface
PIT SIZE: 25' X 25' & extends 5 feet deep

NOTE: See Drawing for tank location
Analysis of surrounding pit area displays
A plume of contaminated soil

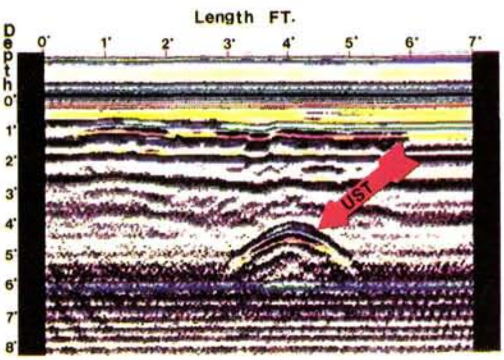
PLUME DEPTH: Maximum of 20 feet
PLUME SIZE: 750 sq. ft. Approx.



VISUAL IMAGE:

EnTech Engineering, Inc.

Plate 2. Visual, IR, and GPR data of contaminated soil plume.



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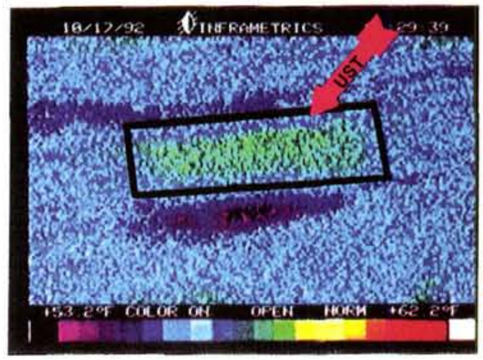

INFRARED THERMOGRAM:

UST INVESTIGATION

LOCATION:	Retail Store St. Louis Missouri 5 feet South of Broadway
DEPTH:	4 feet
SIZE:	100 Gallon Approx.
NOTE:	See Drawing for tank location UST suspected of containing waste oil

VISUAL IMAGE:

EnTech Engineering, Inc.

Plate 3. Visual, IR, and GPR data of UST location in St. Louis, Missouri.

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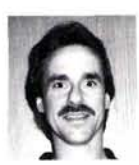
Gary J. Weil

Gary Weil has a BSME degree in Plant Engineering and an MBA in Business Management. He is the Principal and Vice President of Technical Services at EnTech Engineering, Inc. He has been involved in nondestructive testing for 22 years. As a member of ASTM, he has helped write several standards used for infrared thermographic testing throughout the world. He has authored sections of the *CRC Handbook on the Nondestructive Testing of Concrete*, as well as over 25 international technical papers on nondestructive testing of pipelines.



Richard J. Graf

Richard Graf, a Project Manager with EnTech Engineering, Inc., has a degree in Business Administration and is a Certified Thermographer. He is the co-developer of a patented mobile thermographic scanning system used for the detection of highway subsurface voids; delaminations and cracks in concrete bridge decks; and utility pipe leaks in buried sewer water, and gas lines. He has developed the use of ground penetrating radar to incorporate current infrared thermographic techniques for the enhancement of pavement analysis.