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TREATABILITY STUDY WORK PLAN
(Revision 2)

DEMONSTRATION TESTING AND EVALUATION
OF IN SITU SOIL HEATING

Contract Number DE-AC05-93OR22160
IITRI Project C06787

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FOREWORD

This document is a Treatability Study Work Plan for US DOE contract entitled, "Demonstration Testing and Evaluation of In Situ Soil Heating," Contract Number DE-AC05-93OR22160, IITRI Project Number C06787. This document was previously submitted as a draft "Test Plan". Review comments on the draft Test Plan have been addressed in this revision during which the title was changed.

In this project IITRI will demonstrate its in situ soil heating and decontamination technology which uses 60 Hz AC power to heat soil to a temperature range of about 95°C. This technology is aimed at the decontamination of soil by the removal of organic hazardous constituents by the action of heat and a vacuum gas collection system.

Respectfully Submitted
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EXECUTIVE SUMMARY

A Treatability Study planned for the demonstration of the in situ electromagnetic (EM) heating process to remove organic solvents is described in this Work Plan. The treatability study will be conducted by heating subsurface vadose-zone soils in an organic plume adjacent to the Classified Burial Ground K-1070-D located at K-25 Site, Oak Ridge. The test is scheduled to start during the fourth quarter of FY94 and will be completed during the first quarter of FY95.

The EM heating process for soil decontamination is based on volumetric heating technologies developed during the '70s for the recovery of fuels from shale and tar sands by IIT Research Institute (IITRI) under a co-operative program with the U. S. Department of Energy (DoE). Additional modifications of the technology developed during the mid '80s are currently used for the production of heavy oil and waste treatment.

Over the last nine years, a number of Government agencies (EPA, Army, AF, and DoE) and industries sponsored further development and testing of the in situ heating and soil decontamination process for the remediation of soils containing hazardous organic contaminants. In this process the soil is heated in situ using electrical energy. The contaminants are removed from the soil due to enhanced vaporization, steam distillation and stripping.

IITRI will demonstrate the EM Process for in situ soil decontamination at K-25 Site under the proposed treatability study. Most of the contaminants of concern are volatile organics which can be removed by heating the soil to a temperature range of 85° to 95°C. The efficiency of the treatment will be determined by comparing the concentration of contaminants in soil samples. Samples will be obtained before and after the demonstration for a measurement of the concentration of contaminants of concern.

This document is a Treatability Study Work Plan for the demonstration program. The document contains a description of the proposed treatability study, background of the EM heating process, description of the field equipment, and demonstration test design.

1. PROJECT DESCRIPTION

The overall objective of the proposed project is to demonstrate the feasibility of the EM heating process to remove organic solvents from clayey soil at K-25 Site. A treatability test will be conducted under the project. The test will include in situ heating of relatively impermeable clayey soils to increase soil permeability and to increase vapor pressure of the contaminants. Organic contaminants will be removed using steam and air as sweep gases. Treated soil will be left in its natural surroundings.

Oak Ridge and other DoE installations have a number of sites contaminated with organic solvents. Soil vacuum extraction (SVE) is commonly used to remove such contaminants from subsurface soils. Two factors that are important for efficient use of SVE are: soil permeability to establish an air sweep and high vapor pressure of contaminants to volatilize with air sweep. Sites containing clay lenses or clayey soils and sites containing low-vapor pressure (high boiling point) contaminants such as chlorobenzenes are not good candidates for SVE. The EM heating process removes soil moisture by heating and thus increases the permeability of clayey soils. It also increases the vapor pressure of organic contaminants. As a result, the EM heating process overcomes the limitations of SVE. Successful demonstration of the proposed project will enable DoE to use the technology to remediate subsurface clayey soils contaminated with organic solvents.

1.1 DESCRIPTION OF CLASSIFIED BURIAL GROUND

The proposed project will be conducted in an organic plume area adjacent to the K-1070 C/D Classified Burial Ground. Figure 1 shows a map of the Classified Burial Ground. The K-1070-C/D Classified Burial Ground is a 22-acre tract on the east side of the K-25 Site, inside the security perimeter fence. A security-cleared escort is required for entry by uncleared personnel. The K-1070 C/D Classified Burial Ground is composed of two distinctly bounded disposal areas: the K-1070-C maintenance equipment storage area and the K-1070-D disposal area. Prior to the establishment of K-1070-C as a maintenance equipment storage site (circa early 1975), the area was used as a burial ground for classified material. The K-1070-C area is currently serving as a maintenance equipment storage area.

The K-1070-D area is mostly covered with scrub grass and small trees. Several large trees are located along the northeast and southern boundaries. The southern portion of the site, which slopes downhill, has been eroded by heavy rainfall events, and several deep gullies are present in this area. Surface water runoff in the southern portion of the burial ground is funneled

Figure 1. Map of the K-1070 C/D Classified Burial Ground Showing Burial Areas and Sampling Locations (Taken From Reference 1).

down these gullies to the drainage ditch located in the K-1070-C area. The K-1070-D disposal area is composed of multiple disposal sites, including 3 large trench burial areas, 3 earthen dike storage areas, 13 small pits, 3 glass pits, 2 land farms, and a concrete pad. Organic plume in the subsurface soils in the area south of the area is attributed to disposal of organic solvents in some of the pits. A brief description of these disposal sites is given below.

Pits

Ten pits (A-1, A-2, B-1, B-2, D-1, D-2, E-1, E-2, G-1, and G-2) are located on the west side of the K-1070-C/D Classified Burial Ground tract, and each measures ~20 x 20 x 20 ft. These pits were used from 1977 to 1979 for the disposal of various hazardous wastes, including laboratory quantities of corrosives, oxidizers, reducing agents, and chemical and pesticide containers. One of the "G" pits was used for the disposal of drum quantities of various solvents and organics including methylene chloride, freon, and trichloroethene. Liquid wastes were poured onto sand back filled into the bottom of the pits.

In addition to the pits described above, three more pits (glass pits H, I, and J) on the site were used for the disposal of plastic materials and waste glass. These three pits are located immediately adjacent to the pits listed above. All 13 pits were used from 1977 to 1979 for the disposal of hazardous wastes and are believed to be a significant source of contamination.

Landfarms

A historical investigation of landfarming operations disclosed oil treatment for dust suppression in certain areas of K-1070-C/D Classified Burial Ground. The oils were mineral oils used to lubricate cascade motor parts. Two separate landfarming operations were conducted, one in 1982 and another in 1983.

Roads within the fenced boundaries of K-1070-C/D Classified Burial Ground were treated with ~4450 gal of mineral oil in 1982 for dust suppression. The mineral oil met the specification of having less than 1% chlorinated hydrocarbon (solvent), less than 5 ppm PCBs, and no uranium. This landfarming operation was carried out on the two legs of the road "triangle" leading into dikes Area 2. No other analyses such as extraction procedure toxicity tests or toxicity characteristic leaching procedures (TCLPs) were conducted on the oils.

In 1983, about 2000 gal of oil containing a relatively high level of uranium were landfarmed in an area near the K-1070-C trench. When the soil on which the oil had been applied appeared

clean, the layer of dirt believed to have contained most of the uranium was scraped off and buried in the K-1070-C trench. This landfarming was assumed to be confined to the third leg of the approximate road triangle labeled "1983 landfarming."

1.2 DEMONSTRATION SITE

Figure 2 illustrates the general area in the vicinity of the ten pits on the west side of Burial Ground K-1070-D². Several soil borings are marked on Figure 2. Results of soil sample analysis indicate that the contaminant concentration is highest in the samples obtained from soil boring 71 which is near one of the pits. Figure 2 also indicates a fence running north south, west of Bore Hole 71. It is planned to conduct the demonstration outside the north-south fence in a general area directly opposite (west of) Bore Hole 71. In this area there are no known underground utility lines, however, there is an overhead electric line on wooden poles.

The Classified Burial Ground occupies a hilltop in the southeastern corner of the plant. The hill is underlain by siltstone, sandstone, shale, and carbonates of the Rome Formation. It is bounded on the west by a north-trending fault that plunges easterly, at a relatively low angle beneath the site. Surface runoff drains the hilltop in all directions to the plant storm-drain system and eventually to Poplar Creek.

The Rome Formation is a sequence of interbedded sandstones, siltstones, shales, and limestones of variegated olive, maroon, and drab colors. Buff-colored sandstone ledges of the lower Rome Formation form Pine Ridge along the southern border of the plant area. The more shaley upper member of the Rome Formation forms the hill where sites K-1070-C and D are located. The lower member of the Rome Formation is characterized by substantial proportions of impure carbonates ranging from limestone to dolostone. Ground-water movement in the Rome Formation is restricted to fractures in the shales and sandstones.

The main contaminants at the site are volatile hydrocarbons and chlorinated hydrocarbons. The main contaminants of concern for this demonstration are:

- Benzene, toluene, ethyl benzene, xylene (BTEX family)
- 2-Butanone
- Various chlorinated hydrocarbons derived from methane, ethane, ethylene

Figure 2. Map Showing the Location of the Demonstration.

LEGEND:

- EXISTING BUILDING
- EXISTING FENCELINE
- EXISTING CONTOUR
- EXISTING TREELINE
- EXISTING TREE
- AREA OF CONTAMINATION (AOC)
- TANK PIT
- EXIST. MANHOLE
- EXIST. CATCH BASIN
- EXIST. FIRE HYDRANT
- EXIST. POWER POLE
- EXIST. LIGHT POLE
- BEDROCK WELL
- UNCONSOLIDATED WELL
- MONITORING WELL
- PHASE 1 SOIL BORING
- PHASE 2 SOIL BORING
- K-1414 SOIL BORING
- PHASE 1 STORM WATER SAMPLE
- PHASE 2 STORM WATER SAMPLE
- PHASE 2 SEDIMENT SAMPLE
- SURVEYED* BUT NOT SAMPLED

0 50 100 200
SCALE: 1" = 100'

SAIC

Science Applications
International Corporation

K-1070 C/D CLASSIFIED
BURIAL GROUNDS
OAK RIDGE, TENNESSEE

REVISION	DRAWN BY:	CHECK BY:	DATE:
0	R. BEELER	D. KLEFFER	02-20-84

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DRAWING # CAD FILE # ROT. ANGLE

2. REMEDIAL TECHNOLOGY DESCRIPTION

2.1 INTRODUCTION

The in situ radio frequency (RF) or electromagnetic (EM) heating processes utilize electric energy to heat soil rapidly. The processes can be used to heat the soil to a wide temperature range. The contaminants are vaporized and/or boiled out along with water vapor formed by the boiling of native soil moisture. The gases and vapors formed upon heating the soil are recovered and treated on site.

In situ heating is performed by energizing an array of electrodes emplaced in bore holes drilled through the soil. The process can be used for the removal of organic chemicals which exhibit reasonable vapor pressure (about 10 mm of Hg) in the treatment temperature range. The chemical contaminants are removed from the soil as vapors along with steam and air.

The major difference between EM and RF heating processes is in the frequency of applied electric energy. When low-frequency (for example, power frequency) electrical energy is used to heat soil, the process is called EM or alternating current (AC) heating process. Presence of moisture in soil pores is necessary for low-frequency energy to propagate through the soil and to be absorbed in the soil. Since moisture evaporates at or near 100°C, the EM process can be used to heat soil to temperatures of near or below 100°C. Removal of most organic solvents can be enhanced sufficiently at these temperatures. The proposed treatability study is based on the EM heating process.

The RF heating process uses electrical energy in the radio frequency band (typically 1 to 10 MHz). Since RF energy can be absorbed by soil molecules, RF heating can continue beyond the evaporation of soil moisture. The RF heating process can be used to heat soil to temperatures of 250°C or higher. Semivolatile organic compounds (SVOCs) such as diesel and pesticides can be successfully removed at these temperatures.

All previous field applications of the heating processes required the removal of SVOCs. Hence, the RF heating process was used. A brief summary of the heating process and prior field tests is given in this section.

2.2 PROCESS DESCRIPTION

The RF or EM soil decontamination processes heat an appropriate volume of soil in situ by means of an electrode array inserted in bore holes drilled through the soil. Selected

electrodes are specially designed to permit the application of RF or EM power while collecting vapors by application of a vacuum down hole. Figure 3 is an artist's illustration of the process. The vapor collection system is an integral part of the electrode array since vapor collection points are physically integrated and embedded in the array. A vapor containment barrier is used to prevent fugitive emissions, and provides thermal insulation to prevent excessive cooling of the near surface zones. Gases and vapors rising up to the heated soil surface are also collected at the surface by means of horizontal collection lines placed below the vapor barrier. These lines are also connected to the vacuum system. Power to the electrode array is provided by means of a multi-tap transformer or a power amplifier.

Prior laboratory and field experiments ³⁻⁹ have shown that high boiling contaminants can be boiled out of the soil at much lower temperatures than their actual boiling point. This occurs due to two reasons: first, the presence of an autogenously established steam sweep helps to improve vaporization rate of such high boiling materials; second, the long residence time in situ permits significant removal, albeit at a rate which is slower than that obtainable in above ground thermal treatment systems. Another phenomenon which operates during in situ heating is the development of effective permeability to gas flow. The increase in permeability is confined to the heated zone, thus creating a preferred path of gas and vapor flow towards the soil surface or vapor collection wells.

There are several important advantages of the in situ RF soil decontamination process. These are: true in situ treatment minimizes earth removal, excavation etc., thereby minimizing attendant hazards related to odors, fugitive emissions and dust. Only 0.5 to 1 percent of the treated volume will require removal for the formation of the electrode bore holes. A concentrated gas stream containing air, water and contaminant vapors is produced which is treated on site, and the process equipment may be trailer mounted and mobile.

Some of the limitations of the process are: unable to treat metals, salts, and inorganic pollutants; if large buried metal objects are present in portions of the treatment zone then the applicability of the process may be limited to zones free of such objects. In its current state of development the process is applicable for the treatment of a contiguous volume of soil extending downward from the surface. Methods to heat selected layers of soil at depth are under development.

In Situ Electromagnetic (EM) Heating Process for Soil Decontamination

IN SITU Radio Frequency Soil Decontamination Process

Figure 3. Artist's Illustration of the EM Process.

2.3 RESULTS

Laboratory Studies

Several laboratory treatability studies on various types of soils and contaminants have been performed. These studies were done to determine the optimum temperature and treatment time for different types of contaminants found in different soil types. The treatability studies have focussed on chlorinated solvents, volatile aromatic hydrocarbons such as benzene, toluene, etc. (BTEX), petroleum hydrocarbons (TPH), phenols, chlorinated biphenyls (PCBs), and polynuclear aromatic hydrocarbons (PAHs).

The laboratory treatability studies showed that organic contaminants can be removed from soil at temperatures that are considerably below the normal boiling point of the pure contaminants. A summary of the treatability studies is published elsewhere⁷. In most instances, it was possible to reduce the concentration of the contaminants by more than 90%. Temperatures of 200°C or more were necessary to remove high boiling point compounds such as PAHs and Aroclor 1242.

Field Experiment at Volk ANGB

The first field experiment to show the feasibility of the in situ RF soil decontamination process was performed at a former fire training pit located on Volk Air National Guard Base (ANGB) in Camp Douglas, Wisconsin. In this field experiment 500 cu. ft. of sandy soil was heated to an average depth of 7 feet. The area of the heated zone was 72 sq. ft. The soil in the site was approximately 98 % silica sand which had been contaminated with JP-4 jet fuel was spilled during routine fire training exercises conducted at the site. The soil was heated to a temperature range of 150-160°C in approximately 8 days with a 40 kW RF power source. It was maintained at the treatment temperature for a period of 4 days.

Numerous soil samples were obtained from the test volume and the soil in the immediate surrounding vicinity. Pre and post test soil samples were analyzed to determine the percentage removal of the aliphatic and aromatic hydrocarbons present in the soil. It was shown that greater than 99 percent of the volatile hydrocarbons and 94 to 99 percent of the semivolatile hydrocarbons were removed from the site. Hexadecane, with a normal boiling point of 289° C, was used as a target compound to represent the semivolatile aliphatic compounds. On an average 83 percent removal of hexadecane was achieved.

During the course of heating, a tracer injection study was performed to determine the flow of soil fluids. Approximately 2.5 g of Halon 2402 (a liquid at ambient temperature) was injected

at a depth of 6 ft, and at a distance of 4 ft outside the heated zone. The hot gases leaving the treatment zone were sampled and analyzed for the presence of the tracer. The tracer was detected in the hot gases approximately 100 minutes after the tracer was injected into the soil.

Soil samples obtained from the immediate surrounding vicinity of the heated zone indicated a net loss of contaminants. Together with the results of the tracer study, it was concluded that no net outward migration of the contaminants occurred during the experiment.

Field Experiment at RMA

A second field experiment was successfully completed on Basin F soil at the Rocky Mountain Arsenal. The pilot test demonstrated the ability of the RF heating technology to heat Basin F soil to over 250°C, and in the process reduce organochloro pesticide (OCP) concentrations near to or below Preliminary Remediation Goals.

Table 1 compares the removal of OCPs with two proposed remediation goals which are listed in the last two columns of Table 1. The remediation goals are risk based. The column headed by 10^{-4} Biological Worker represents the final residual concentration of the various contaminants at which the excess carcinogenic risk to a "Biological Worker" at the site will be 1 in 10,000. The term "Biological Worker" refers to wildlife wardens who will be working at RMA which will become a wild life preserve after remediation. Similarly, the column with heading of 10^{-6} Biological Worker lists the residual concentration of the contaminants at which the excess carcinogenic risk to a "Biological Worker" is 1 in 1,000,000.

Aldrin and dieldrin achieved the 10^{-4} Biological Worker goal, but not the 10^{-6} worker goal. Endrin achieved both goals, but isodrin achieved neither. OCP destruction efficiencies in the soil heated to 250°C or higher were 97 to 99%, from initial concentrations which were up to 5,000 milligrams per kilogram (mg/kg).

The vapors produced during heating were treated in a vapor treatment system which removed both the semi-volatile and volatile organic contaminants, and the condensate was stored for later treatment and disposal.

A conceptual design has been prepared for treatment of Basin F by RF heating. The cost is complicated by the presence of a 5-ft deep clay cap. If this is considered to be contaminated, then it must be treated. Furthermore basin F was divided into two zones,

Table 1. Final Concentrations of Compounds Versus Soil Temperature

Parameter	200-250°C		250-300°C		>300°C		Preliminary Remediation Goals (4)	
	Concentration (mg/kg)	Standard Deviation	Concentration (mg/kg)	Standard Deviation	Concentration (mg/kg)	Standard Deviation	10 ⁻⁴ Biological Worker (mg/kg)	10 ⁻⁴ Biological Worker (mg/kg)
Aldrin	0.97	1.0	31	40	1.8	3.1	56	0.56
Dieldrin	0.59	0.35	8.0	8.0	1.1	1.5	40	0.40
Endrin	1.7	2.0	5.6	5.3	1.0	1.5	17	17
Isodrin	1.3	-	48	62	49	90	3.6	3.6
DMMP	0.0034	0.0012	0.0028	0.0016	0.0028	0.0019	-	-
DMPA	0.13	0.0	0.022	0.036	0.40	0.89	-	-
TOC	2.1%	1.8%	3.4%	1.7%	2.6%	1.5%	-	-
TOX	360	520	180	110	110	25	-	-

a deep zone (15 ft) and a shallow zone (10 ft). The present worth cost to treat the shallow zones to 250°C was \$43 million, or \$110 per ton of soil treated, or \$221/ton of contaminated soil treated. The present worth cost for the deep zone was \$19 million, or \$102/ton of soil treated, or \$153/ton of contaminated soil treated. If the cap can be scraped away before treatment, these costs will be less.

SITE Demonstration at Kelly AFB

An additional demonstration of the technology was conducted under the EPA SITE program at Kelly AFB during the summer of 1993. Approximately 100 cubic yards of clayey soil-containing cobbles and contaminated with petroleum fractions was heated to a depth of about 20 ft. Ground water level at the site was relatively shallow. Dewatering wells were used to continuously pump water and to attempt to minimize water intrusion into the test volume. Soil was heated to temperatures of more than 100°C over 60 days. Effluents containing steam, air and hydrocarbons were collected and disposed using a flare. Soils samples were obtained prior to and after the demonstration and the contaminant concentration data is currently not available.

3. TEST OBJECTIVES

The overall objective of the proposed treatability study is to demonstrate the feasibility of the EM heating process to remove organic solvents from clayey soil. The viability of the EM heating process to remove organic solvents from clayey soils at DoE facilities and elsewhere depends on the following factors:

1. Ability to enhance air sweep
2. Ability to enhance volatilization
3. Energy consumption

The proposed treatability study is designed to obtain data required to assess each of the above 3 factors. These are described below.

3.1 ABILITY TO ENHANCE AIR SWEEP

Complete and uniform sweep of soil by air or another sweep gas is an important factor to achieve in situ soil treatment. EM heating of soil removes moisture in the soil pores and increases its permeability to flow of air. This will result in the flow of a higher volume of air for a given vacuum. The volume of fluids (air, steam, and hydrocarbons) drawn from the soil volume for a given value of applied vacuum will be estimated based on the rate of production of effluents. Enhancement in fluid flow and vacuum data will be used to estimate the permeability of soil at various times and the enhancement in permeability due to heating will be determined.

3.2 ABILITY TO ENHANCE VOLATILIZATION

The rate of removal of the contaminants during SVE is directly proportional to the vapor pressure of the contaminants. Increase in temperature from 20° to 90°C increases the pure component vapor pressure of common solvents by a factor of 10 or more. Even though the vapor pressure of organic compounds mixed with each other and adsorbed on soil surfaces is considerably less than the pure component vapor pressure, vapor pressure of the contaminants will increase by about the same factor with an increase in temperature. Two factors will be used to determine ability of the EM heating process to enhance volatilization: increase in soil temperature, and concentration of the contaminants in effluents.

3.3 ENERGY CONSUMPTION

Energy consumed to increase the temperature of soil will be measured at the input to the multi-tap transformer. Energy consumption depends on soil characteristics, heat loss, and the volume of water added to maintain ohmic contact between soil and

the electrodes. Design calculations indicate that energy consumption will be between 160 and 220 kW per cu. yd. of soil. Actual values of energy consumption will be compared with calculated data.

4. DEMONSTRATION TEST DESCRIPTION

4.1 DESIGN BASIS

The design of the demonstration is based on the following:

- The demonstration site is located outside the Q cleared fence in an area opposite Bore Hole 71. Bore Hole 71 is inside the Q fence.
- Dimensions of the heated volume: 25 ft. length
16 ft. width
20 ft. depth
- Heated Volume: 8000 ft³
- Average Bulk Density 98 lb/ft³
- Target treatment temperature range of soil 85 to 95°C
- The demonstration will be performed with a 200 kW AC power source supplied with utility power.
- As far as possible, the soil cuttings generated during drilling will be spread over the heated area and compacted so that they are also heated along with the soil

4.2 CONCEPTUAL SITE LAYOUT

The demonstration will be conducted outside the Q fence on the shoulder of the road between Bore Holes 74 and 75 which are marked on Figure 2. Figure 4 shows a conceptual site lay out. The shaded area shows the approximate location of the heated zone. This area was picked so as to keep the long dimension of the electrode array parallel to the Q fence and also to maximize the distance between the array and the overhead power line. In addition, previous sampling has indicated that the high concentration plume lies between the two Bore Holes 74 and 75.

4.3 ELECTRODE ARRAY DESIGN

The design of the electrode array which is to be emplaced in drilled bore holes located in the shaded rectangle of Figure 4 is described in this section. The electrode array will be formed by drilling three rows of electrodes. Figure 5 is a plan view illustrating the electrode array dimensions, row spacing, electrode spacing and the size of the vapor barrier. The length of each of the two outer rows is 25 ft, the outer row separation is 16 ft and

Figure 4. Conceptual Site Layout

Figure 5. Plan View of the Electrode Array
(Water injection, instrumentation and power lines not shown)

the electrode separation within any row is 2.5 ft. The outer rows are longer than the center row. Each outer row has 11 electrodes, while the center row has 9 electrodes. This configuration was selected in order to better control the fringing electrical fields near the ends of the array. There are four gas collection wells in the approximate center of each quadrant of the array. These wells are connected to a manifold by means of steel pipes. In addition there are two perforated horizontal gas collection lines placed on the surface of the soil. These are also used for collection of vapors. All vapor collection lines run under the vapor barrier until they clear the perimeter of the barrier. All the lines are heat traced to prevent condensation of steam. Electrical insulators are installed in each metal pipe leaving the array to prevent accidental personnel injury when power is applied.

There are 7 thermowells marked by filled triangles and labelled MW01 through MW07. Wells MW01 through MW06 are located within the heated array, while MW07 is outside the array. In each of these wells, two Teflon tubes, plugged at the bottom end will be inserted to a depth of 20 ft. During operations, thermocouples will be inserted in these tubes to measure the temperature of the soil at various depths.

4.4 GAS COLLECTION AND TREATMENT SYSTEM

A vapor barrier covers the entire area of the heated zone and extends outward a distance of 10 ft. all around the array. The purpose of the vapor barrier is to control fugitive emissions, control air infiltration and minimize heat losses from the soil surface. The vapor barrier is made in a single piece. It will be made from Seaman Corporation's 8130 XR-5 SP Geomembrane.

The hot gas and steam will be collected from the gas recovery wells and conveyed through the vapor collection system by means of a blower or a compressed air ejector. Figure 6 illustrates the blower option. If a blower is used, it will be necessary to adjust the humidity at the entrance to the blower. It is proposed to adjust the humidity by adding dilution air. The air will warm up as it mixes with the hot gases recovered from the soil. As a result of this, some water in the hot gas stream will condense to provide the energy necessary to heat up the air. It is estimated that the amount of water condensing will be less than 0.5 lb. per min. The amount of dilution air added will be up to 8 lbs/min.

Figure 7 illustrates the compressed air ejector option in which air at high pressure is supplied to a venturi which creates a vacuum at its throat. The process gas line where the vacuum is desired is connected to the throat of the venturi. In this scheme,

Figure 6. Flow Diagram of the Gas Collection System

Figure 7. Flow Diagram of the Gas Collection System-Ejector Option

dilution of the hot gas stream by the motive fluid occurs in the ejector.

Temperature, relative humidity, and flow rate of the gas stream will be measured at selected points. These are indicated on the flow sheets. At two points the gas stream will be sampled. These are marked S1 and S2.

4.5 THERMAL INSTRUMENTATION

The progress of in situ heating and control of the power input will be based on the measurement of the temperature (among other parameters) of the soil as a function of time and location within the array. For this purpose a number of thermocouples will be attached to the inner walls of selected electrodes. In addition, thermocouples will be inserted into Teflon-tube thermowells inserted in bore holes drilled through the heated soil.

Measurement of thermocouple or thermowell temperature data will be performed by temporarily shutting down the power to the electrode array. When the power is down, the thermocouple wire bundle will be plugged into a multiplexer connected to a data logger controlled by a PC. The data from the thermowells will be manually acquired by inserting a long thin stainless steel sheathed thermocouple into the individual thermowells. The data will be manually recorded by connecting the thermocouple to a hand held digital thermometer. It is planned to acquire the thermocouple data at least once every 12 hours. The data from the electrode thermocouples may be acquired more frequently (once every 8 hours) should it be needed to control and adjust the input AC power or water injection rate to the electrodes.

4.6 DESCRIPTION OF THE AC POWER SOURCE

AC power from the 480V supply will be provided to IITRI's multi-tap isolation transformer which in turn will supply power to the electrode array. The area immediately surrounding the array will be cordoned off to prevent entry while the power is on. Interlocks will be provided on the fence gate and along the perimeter of the fence. The purpose of these will be to interrupt power to the array in case of unauthorized entry or an entry made without proper lock-out, tag-out precautions.

Table 2 summarizes the various tap settings, voltages, current and the load impedance necessary to deliver the maximum 200 KVA rated power into the load. At a given voltage tap setting, the resistance of the load should be equal to or greater than the values listed in the last column in order to stay within the current capacity of the transformer.

Table 2. Voltage Taps on the AC Power Transformer

Tap No.	Voltage, V	Current, A	Load Resistance for Full 200 KVA power, Ohm
1	200	1000	0.2
2	400	500	0.8
3	600	333	1.8
4	800	250	3.2
5	1000	200	5
6	1500	133	11.3
7	2000	100	20
8	2500	80	31.3
9	3000	67	44.6
10	4000	50	80

The multi-tap transformer and all the associated controls will be installed in a 20 ft long trailer. This trailer will be parked outside the L fence and AC power lines will run through the fence into the array.

4.7 ESTIMATE OF CONTAMINANT CONCENTRATION, WEIGHT, AND EMISSIONS

Table 3 presents the concentration range of volatile hydrocarbons and chlorinated volatile hydrocarbons found in the analyses of samples of soil obtained from bore holes 71, 75, 76 and 80. Table 4 provides the concentration of total volatile hydrocarbons found in various sampling depth intervals for Bore holes 71, 75, 76, and 80. The concentrations presented in Table 4 is the sum of the concentrations of volatiles which were above the detection limit. Thus in the depth interval of 15-20 ft of Bore hole 71, the total concentration of volatiles above the detection limit was 54,900 ppb. Of this the total chlorinated volatiles were 4190 ppb.

Using the data presented in Table 4, an estimate of the weight of contaminants in the heated volume of soil was made. These calculations are summarized in Table 5. Line 1 of Table 5 gives the maximum concentration of total volatiles found in any sampled

Table 3. Volatile Hydrocarbons Found* in Bore Holes
71,75,76,80

Contaminants	Concentration Range, ppb
<u>Hydrocarbons:</u>	
Acetone	15-26,000
2-Butanone	10-16,000
Ethyl Benzene	15-180
Toluene	140-2200
2-methyl-2-pentanone	15-25
Benzene	up to 6
Carbon disulfide	up to 7
<u>Chlorinated Hydrocarbons:</u>	
Methylene Chloride	5-40
Tetrachloroethene	25-130
1,1,1-Trichloroethane	5-25
1,1,2-Trichloroethane	10-90
Trichloroethene	20-400
1,1-dichloroethane	15-60
1,2-dichloroethane	5-30
1,1,2,2-trichloroethane	up to 15

* Only those found at or above detection limit.
Based on preliminary data, Reference 4.

Table 4. Concentration of Volatile Organics, ppb
(J: Estimated Value; E: Concentration Exceeded Calibration Range;
X: Undefined Flag)

	Hole Number 71			Hole Number 75		Hole Number 76		Hole Number 80		
	5-10ft	10-15ft	15-20ft	5-10ft	10-15ft	5-10ft	15-18ft	0-5ft	10-15ft	15-18FT
Total Volatile HCs, ppb	371 4900 E	27400 2110 J	44200 5910 J 4800 X	42 6 J 0 6890 E	371 14 J 55 X 6120 E	17 6 J	364 19 J	32	670 770 X 4500 E	1024 85 J 3100 E
Total Volatiles, ppb	5271	29510	54910	6938	6560	23	383	32	5940	4209
Total Chlorinated Volatile HCs, ppb	21	1100 J	4190 J	75	306 6 J 400 E		199 13 J	11	115	494 48 J
Total Chlorinated Volatile HCs, ppb	21	1100	4190	75	712	0	212	11	115	542

depth interval for each of the four bore holes. Line 2 gives the average concentration of total volatiles in each of the four bore holes. This represents a simple arithmetic average of the concentration found in all sampled depth intervals for any given bore hole. For example, the average for Bore hole 71 was computed thus: $(5271+29510+54910)/3 = 29,897$ ppb or approximately 30 ppm.

An estimate of the mass of total volatile contaminants in the heated volume was made on the basis of average and maximum concentrations found in the four bore holes. These results are summarized in line 3 of Table 5. The total weight of soil was multiplied by the concentration of total volatiles to estimate the weight of volatiles. The mass of soil was estimated to be approximately 392 tons which was rounded up to 400 tons. This was based on a treatment volume of 8,000 cu. ft. and soil bulk density of approximately 98 lbs/cu. ft. For example, the maximum weight of the volatiles in the treatment volume, assuming that the concentration is 55 ppm uniformly distributed in 8,000 cu. ft. is: $(400 \times 2000 \times 55 \times 10^{-6}) = 44$ lbs. Similarly, the mass of volatile contaminants can be estimated based on the use of average concentrations. Lines 6, 7, and 8 of Table 5 provide the maximum concentration, average concentration and an estimate of the mass of chlorinated volatile contaminants, respectively. It should be noted that chlorinated volatiles are a sub-set of total volatiles and have been included in the concentration and mass estimates of total volatiles.

As discussed in Section 4.2, the demonstration will be done outside the Q fence near Bore Hole 71. This distance is estimated to be approximately 40 to 65 ft from Bore Hole 71. Other nearby Bore Holes are 75 and 74. It is estimated that Bore Hole 75 will be within 25 to 40 ft of the heated volume. As the data of Table 5 show, the concentration of contaminants in soil obtained from Bore Hole 75 is less than that of Bore Hole 71 by a factor of 4 to 8. Concentration data for Bore Hole 74 was not available.

Assuming that the concentration of the total volatiles in the treatment volume will be in the same range as those found in bore holes 71 and 75, the estimated weight of total volatile hydrocarbons is in the range of 5 lbs. (based on smallest average concentration) to 45 lbs. (based on maximum concentration) And the estimated weight of chlorinated hydrocarbons is in the range of 0.3 lbs (based on smallest average concentration) to 3.2 lbs. (based on maximum concentration)

It is estimated that the soil heating will take 18 to 25 days. Thus the average rate of total volatile hydrocarbon removal from the heated zone will be in the range of 0.2 to 2.5 lb/day, and 0.01 to 0.2 lb/day for the volatile chlorinated hydrocarbons. This

Table 5.

Estimated Weight of Volatile Contaminants in the Treatment Volume
 (All Concentrations are in ppm, all masses are in lb.)
 (Assumes: 8000 cu. ft heated, equivalent to 400 tons)

	BORE HOLE NUMBER			
	71	75	76	80
Max. Volatile Concentration Encountered in any depth interval	55	6.9	0.39	5.9
Average Volatile Concentration encountered averaged over all depth intervals	30	6.8	0.2	3.4
Mass of Volatile Contaminants				
based on max. conc.	44	5.5	0.31	4.8
based on average conc.	24	5.4	0.16	2.7
Max. Chlorinated Volatile Concentration in any depth interval	4	0.71	0.21	0.54
Average Chlorinated Volatile Concentration averaged over all depth intervals	1.8	0.37	0.1	0.22
Mass of Chlorinated Volatile Contaminants				
based on max. conc.	3.2	0.57	0.17	0.43
based on average conc.	1.4	0.3	0.09	0.2

assumes 100 percent recovery of the contaminants and uniform rate of recovery over time.

The above calculations show that the total weight of contaminants as well as their average rate of recovery will be quite small. In fact, these rates may be small enough to justify open release to the atmosphere without treatment, as long as there is no steam condensation at the outlet of the vent stack.

4.8 ESTIMATE OF HEATING TIME

An estimate of heating time was prepared to heat approximately 8,000 cu. ft. of soil from an initial temperature of 18°C (65°F) to a final temperature of 95°C (203°F). It was assumed that the average input power was 150 kW (75 percent of the power source capacity) and the daily operating factor was 95 percent. Table 6 summarizes the basis and assumptions used for the calculation of the heat load and heat up time. The heating time ranges from 18 to 25 days as the native soil moisture varies from 20 to 30 percent. During this test, 14,000 to 21,000 gal. of moisture present in the soil will be evaporated.

Table 6. Basis and Assumptions for Estimating Heating Time.

Parameter	
Volume of Soil, cu. ft	8000
Bulk Density of Soil, lb/cu. ft	98
Specific heat of dry soil, Btu/lb F	0.2
Specific heat of water, Btu/lb F	1
Latent Heat of water, Btu/lb	970
Final Temperature, F	203
Initial Soil Temperature, F	65
Initial Soil Moisture , %	20 to 30
Percent of Native water boiled, %	75
Water injected, lb	16000
Average Power Input, kW	150
Daily Operating Factor, %	95%
<u>Assumptions:</u>	
Neglect Heat Load of Contaminants because of low concentration	
All the injected water is boiled out.	
The heated volume is well above the water table.	

5. EQUIPMENT AND MATERIALS

A listing of all equipment and materials required for the treatability study is unduly long. A summary of major items and their purpose is given below.

1. **AC Power Source.** A 200 KVA multi-tap transformer will be used to provide AC power to the electrode array.
2. **Electrode Array.** An electrode array consisting of 31 electrodes placed in the soil is used to provide power to soil.
3. **Instrumentation Trailer.** A 40-ft. trailer is used to distribute power to auxiliary equipment and to monitor process performance.
4. **Power Trailer.** A 20-ft. trailer is used to house the power source and associated equipment.
5. **Data Acquisition System.** A personal computer system with appropriate software to monitor and record necessary parameters.

6. SAMPLING AND ANALYSIS

6.1 PRE-TEST AND POST-TEST SOIL SAMPLING

The decontamination of the soil will be determined by analyzing soil core samples for the contaminants of concern. Pre-demonstration samples will be taken when the bore holes are being drilled for the installation of electrodes. Post-demonstration soil samples will be taken after the soil has cooled down. New bore holes will be made for the post demonstration soil sampling plan.

The soil samples will be obtained in split core barrels which will be driven into the soil while drilling for electrode bore-holes. Soil samples will be obtained in metal sleeves which will be sealed in the field and iced for shipment to the laboratory for analysis. Detailed sampling procedures, handling, QA/QC, analytical methods will be documented in the project QA/QC plan.

The pre-demonstration soil sampling plan is illustrated in Figure 8. Bore holes marked with numbers such as S101, S102, etc., will be sampled. From each bore hole three samples will be obtained, spaced approximately equally along the depth of the hole. There will be a total of 9 bore holes sampled for obtaining 27 pre-demonstration soil samples.

The post demonstration soil sampling plan is illustrated in Figure 9. Locations marked as S201, S202, etc., will be drilled to obtain post demonstration soil samples. Again, from each bore hole 3 samples will be obtained as a function of depth. Many of the post demonstration samples have been selected to correspond to the pre-demonstration samples such as numbers S201, S202 and so on. However, some samples have been added to determine the effect of the temperature profile as it develops across the array in the transverse and longitudinal directions. For this reason samples S209, S211, S212, and S205 have been selected.

The efficiency of decontamination will be assessed in three ways: first the average concentration of the pre-demonstration samples will be compared against the average post demonstration concentration. Second, if the pre-demonstration samples showed any stratification, then the corresponding locations from the post demonstration samples will be examined to see the effect of treatment on stratification. Lastly, the effect of any temperature profile generated within the soil will be evaluated by comparing the post-demo concentration at various locations with the maximum temperature attained there to assess the effect of temperature.

Figure 8. Pre-Demonstration Soil Sampling Plan

Figure 9. Post-Demonstration Soil Sampling Plan

6.2 DATA MONITORING

6.2.1 System Operating Data

The progress of in situ demonstration and the operation of the gas collection system will be monitored by measuring the following data:

Electrode Array Performance:

- Initial resistance
- Initial temperature at all measurement points
- Initial measurement of step potential at low power levels (discussed further in the Health and Safety Plan)
- Applied voltage and current during operation
- Plot of soil electrical resistance as a function of time
- Rate and amount of water injected into the array.

Thermal Data:

- Initial Temperature in all electrodes and monitoring thermowells
- Temperature data from all points once every 8 to 12 hrs. At this time AC power to the soil will be switched off for safety reasons.

Vapor Collection System Data:

- Vacuum or pressure at all measurement points.
- Gas stream humidity
- Gas stream flow rate
- Temperature of the gas stream
- Gas samples for total volatiles; and effluent composition by the use of on-line ITMS system to be provided by ORNL.

The above data will be collected once every 4 to 8 hours. Data collection frequency will be adjusted in an appropriate manner during normal and critical portions of the test.

7. DATA MANAGEMENT

All data obtained during the demonstration will be reviewed, analyzed, and summarized in the final report. The data to be obtained, their measurement method and purpose are shown in Table 6. Other project related documents such as planning documents, design reports, trip reports will be provided to DoE Project Manager. Photographs will be taken at various critical times to document site preparation and equipment installation procedures. A continuous log of site activities will also be made in a project logbook.

Table 7. Data Monitoring During Demonstration			
Measurement	Method	Frequency	Purpose
Electrode Temperature	Thermocouples using digital thermometers and data acquisition system	4 to 12 h	Determine soil and electrode temperatures.
Soil Temperature	Thermowells using digital thermometers and data acquisition system	4 to 12 h	Monitor the progress of the test.
Array Impedance	Voltage and current data at power source	4 to 12 h	Determine changes in soil impedance
Cumulative Energy Consumption	Wattmeter at power source	Daily	Determine energy consumption
Volume of Water Injected	Water level at injection system. Volume of water added to reservoir	4 to 8 h during injection	Determine water requirements
Effluent Production	Flowmeter	4 to 12 h	Rate and total volume of effluent production
Steam Production	Slip stream sampling	4 to 12 h	Fraction of energy used for evaporation
Manifold pressure	Magnahelic gauge	4 to 12 h	Soil permeability changes
Contaminant concentration in effluents	- Bubblers/GC - ITMS (Done by ORNL)	Daily Semi-Continuous	Progress of soil decontamination; Determine composition of volatile HCs in the effluent

8. DATA ANALYSIS AND INTERPRETATION

Data obtained during the demonstration test will be analyzed to determine the extent of contaminant removal and to assess the viability of the EM heating process for soil treatment at similar sites.

Soil samples obtained both prior to and after the treatment will be analyzed to determine the concentration of target contaminants. The total quantity of contaminants present in the test volume will be estimated using concentration data obtained for discrete locations. It is anticipated that contaminant concentrations will vary significantly from one location to another. Average values or interpolated values will be used to estimate total quantity of contaminants before and after the test. The percentage removal will be calculated based on the pre-test and post-test data.

Soil samples obtained from outside the test volume will be analyzed to determine pre-test and post-test concentrations of contaminants. The data will be used to determine net migration of contaminants from outside the test volume into the test volume.

Temperature data, effluent production data, power data, and other parameters measured will be plotted appropriately and presented in a Final Report. Data will be analyzed to correlate important parameters such as water evaporated, soil temperature increase, permeability enhancement, contaminant concentrations, total power input and array impedance with each other. The results will be used to draw conclusions on the success of the demonstration test and the viability of the EM heating process to treat similar sites at Oak Ridge and elsewhere.

8.1 TECHNOLOGY ASSESSMENT

Operational and performance data obtained (please see Sections 6 and 7) from the demonstration test will be used to assess the viability of the EM heating process. Data will be used to determine anticipated removal of the contaminants, capital and operating costs.

8.1.1 Removal of Contaminants

In situ removal of contaminants using the EM heating process depends on two factors: 1. increase in soil temperature to increase vapor pressure of the contaminants; and 2. increase in soil permeability which will enhance soil sweep with air.

A number of thermocouples are placed within the electrodes and the soil to monitor the temperatures within the test volume.

Actual temperature data and the variation in the temperatures within the volume will aid in the assessment of the EM heating process to heat soil to temperatures close to the boiling point of water. Increase in soil permeability will be monitored by measuring the manifold pressure and effluent production rate during the test period.

The combined effect of increase in vapor pressure and permeability will be monitored by measuring the concentration of contaminants in the effluents as a function of time, and the concentration of the contaminants in pre- and post-test soil samples. In addition to determining the residual concentrations of contaminants, the data will be used to assess percentage removal of contaminants within the soil volume at selected locations, and correlation of the contaminant removal data with soil temperatures and other factors.

8.1.2 Capital Costs

The capital costs of the EM heating process will depend on the complexity of the equipment. The only unique capital equipment for the EM heating process in comparison to soil vacuum extraction is the variable-tap transformer. Impedance data obtained during the demonstration test will be assessed to determine if any changes to the design of the existing transformer are necessary. Other operating data such as the rate of water injection will be used to design auxiliary equipment. Conceptual designs of the effluent treatment system available at IITRI from an earlier program will be modified, if necessary, based the range of effluent production, steam production, and contaminant concentration data. Capital cost of effluent treatment system will be updated. The total estimated capital cost of the equipment required for the EM heating process will be developed.

8.1.3 Operating Costs

The major components of operating costs for soil remediation using the EM heating process are the cost of labor for site preparation and operation, cost of electrical energy, cost of drilling and electrode installation, and cost of effluent treatment. The experience gained during the demonstration will provide data on each of the above factors. An additional important factor to be monitored is the amount of water injected to achieve successful soil heating. Addition of larger than anticipated quantity of water will increase energy consumption. Operating cost of each component will be assessed based on the data obtained during the demonstration test. Total operating costs for the EM heating process will be developed.

9. HEALTH AND SAFETY PLAN

In this section a summary of the Health and Safety Plan is presented. This is based on the project Health and Safety Plan, which is a separate document, Reference 10.

9.1 PROJECT ORGANIZATION AND RESPONSIBILITIES

IITRI's project manager is Mr. Guggilam Sresty. He will be assisted by the project team comprising of engineers, chemists, and technicians in ensuring that the demonstration project health and safety plan is implemented and that all project activities are conducted in a safe manner. It is the personal responsibility of each and every project personnel to ensure that they as well as their co-workers follow the health and safety rules and guidance provided in this document. The responsibilities of the various project team members (see Figure 10) with respect to the administration of the HSP are described below.

9.1.1 Project Manager

The Project Manager is responsible for overall project execution. The responsibilities of the Project Manager include:

- coordinating with DoE personnel, including, project manager and field coordinator manager;
- ensuring implementation of the HASP;
- ensuring that a qualified SHSO is designated; and
- maintaining a current copy of the HASP.

9.1.2 Site Operations Manager

The site operations manager will oversee the installation of the EM technology demonstration system, soil sample collection and related QA/QC activities, and the implementation of HSP. He will delegate further responsibilities to other members of the sampling team. He/she is ultimately responsible for implementation of this HASP. Specific responsibilities of the site operations manager are listed below:

- ensuring that all personnel on site follow the requirements of the HASP;
- coordinating on-site operations, including logistics;
- interfacing with plant and project personnel;

Figure 10. Project Organization Chart

- assisting the SHSO when necessary;
- participating in on-site system installation activities;
- maintaining project activities and data logs; and
- maintaining a current copy of the HASP.

9.1.3 SHSO

The SHSO is responsible for making health and safety decisions and for specific health and safety activities. The SHSO as well as all project personnel have stop work authority for all personnel on site. The SHSO has primary responsibility for the following:

- Ensuring that personnel receive the HSP and are aware of its provisions, are instructed in safe work practices, and are familiar with potential hazards and planned emergency procedures prior to initiation of site activities.
- Confirming that all on-site personnel have received the training listed in the Training Requirements section of this HASP.
- Issuing respirators, as necessary, and ensuring that respirator users have been properly trained and fitted for respiratory protection. Note that this requires training to comply with 29 CFR 1910.134.
- Establish site work zones and the level of protection required. In addition, establishing personal decontamination stations and instructing personnel in their use.
- Establishing and making available at the site an emergency action plan, with telephone numbers and appropriate radio communication information.
- Field checking the calibration of all monitoring equipment that will be used daily and recording results in the field logbook.
- Ensuring that all monitoring equipment is operating according to the manufacturer's specifications and instructions and providing minor maintenance if warranted.

- Ensuring monitoring for potential on-site contaminants during field operations is conducted.
- Conducting a site-specific pre-entry health and safety briefing and appropriate follow-on briefings covering known or suspected hazard precautions, emergency actions, etc. including this HASP.
- Remaining on site at all times during hazardous waste operations and activities.
- Documenting field changes to the HASP.
- Controlling visitor access to the site.

9.2 SITE OPERATING PROCEDURES

This section presents those general safety rules that apply to the entire project.

- The provisions of the plan are mandatory for all on-site employees and visitors.
- "Tailgate" meetings may periodically be called during field activities to apprise on-site personnel of any potential health and safety concerns that may change because of unplanned field conditions.
- Spills will be prevented to the extent possible. In the event that a spill occurs, contain the material, if possible, and notify the site operations manager and the SHSO.
- Splashing of contaminated materials should be prevented.
- Good housekeeping will be practiced. Everything will be kept orderly and out of potentially harmful situation.
- All waste generated during the demonstration project will be disposed of in accordance with the Waste Management Plan.
- All injuries will be reported, no matter how minor.
- emergency procedures to follow if they are exposed to chemicals; how to read labels and review MSDSs to obtain appropriate hazard information; and location of MSDS file and location of hazardous chemical list.

- Emergency telephone numbers and how to obtain help in an emergency.

9.3 CONTINGENCY PLAN

The K-25 emergency response organization will be contacted for response to all emergencies at the site and will utilize the K-25 Site Emergency Plan. The site Shift Superintendent at K-25 coordinates 24-h emergency response coverage from the Plant Protection and Shift Operations Division. The Shift Superintendent on duty is assisted by a well-trained plant emergency squad and is the overall coordinator responsible for directing the response to emergencies such as fires, major equipment failure, hazardous materials releases or spills, natural disasters, sabotage, etc. All personnel working on site will be trained to the awareness level and will be instructed to notify the K-25 emergency response organization for assistance. The K-25 Facility Emergency Procedure for Building K-1414 will be applicable to the demonstration site.

9.4 HEALTH AND SAFETY HAZARD ANALYSIS AND CONTROLS

The purpose of the hazard analysis is to identify potential health and safety concerns that may be encountered by site personnel and the hazard controls required for each site task. The SHSO may raise or lower the level of PPE worn by the teams, depending upon the site-specific hazards encountered in the field. Whenever a conflict exists with the PPE requirements, the more restrictive will apply.

The scheduled tasks include soil boring, soil sampling, decontamination system installation, check-out, operation, system demobilization, etc. In this demonstration project the soil will be energized with electrical energy. Up to 150 kW of power may be applied to the electrode array at voltages in the range of 120 to 4,000 V. There is a risk of electrical shock to personnel. It is planned to monitor the site for step-and touch potentials to assure that there is no risk of electrical shock. Similarly, process equipment will require testing, protection and mitigation of spurious electric potential. The exclusion zone will be based on chemical as well as electric shock hazard considerations.

There are overhead electrical transmission lines that cross portions of the sampling locations of K-1070 C/D Classified Burial Ground. Prior to placing the sampling equipment at an auger hole location, the Field Operations Manager or his designee will verify that the sampling equipment will not be placed where any part of the drill rig mast enters within a minimal radial distance of 10 ft. from electrical transmission lines or as specified in Table 7. All personnel should stay out from under overhead work and temporarily suspended or moving equipment.

Table 8. Safe Working Distances From Electrical Transmission Lines for Equipment

Normal Voltage, Phase-to-Phase (kV)	Minimum Required Clearance (ft)
<i>When operating near high-voltage power lines</i>	
0 to 50	10
51 to 200	17
201 to 350	22
351 to 500	27
501 to 750	35
751 to 1000	44
<i>While in transit with mast, boom, shovel, etc. lowered and secured</i>	
All voltages	10

Source: 20 CFR 1910.180j(1).

9.4.1 System Operation

The following are major guidelines to be followed by all site personnel during the operational phase, which includes system check-out, debug and operation.

- All site operational personnel will be instructed as to possible electrical hazards associated with operation of the EM heating array.
- No personnel are permitted to enter the area delineated by the "exclusion zone fence" while the EM heating array power is energized.
- The exclusion zone fence incorporates an electrical interlock, which will remove electrical power to the EM heating array in the event a person attempts to breach the fence. EM heating array power will not be re-energized by clearing the fence fault.

9.4.2 Step Potential And Touch Voltage Measurements

In order to make step potential and touch voltage measurements, it is necessary to energize the EM heating array. The following are some of the major guidelines to be followed by all site personnel while making either step potential or touch voltage measurements. Figure 11 shows a conceptual site layout and the electrical exclusion zone.

- Only persons trained in making step potential/touch voltage measurements will be permitted to perform step potential and touch voltage measurements. IITRI will be responsible for training the necessary persons.
- All trained personnel will be instructed as to possible electrical hazards associated with performing step potential and touch voltage measurements.
- All trained personnel performing step potential and/or touch voltage measurements are responsible for wearing fully encompassing clothes and double sole work boots.
- Step and touch potential measurements must be performed at each level of input power level applied to the array.
- While performing step potential measurements, the trained person(s) must not come in physical contact with any structure or other person.
- Step potential measurements are to be performed utilizing a step potential measurement device manufactured by IITRI and consists of 2 rods separated by 1 meter. The rods are connected to a portable digital voltmeter via insulated test leads.

9.5 SITE CONTROL MEASURES

The following sections will be used to determine work zones for the K-1070 C/D Classified Burial Ground site. Figure 12 shows site work zones.

Exclusion Zone: The exclusion zone is the area where the greatest potential exists for exposure to contamination and/or electrical shock. The electrical exclusion zone will be such that it encloses within it the step potential contour of 2 Volts/meter under all operating conditions of the array.

Contamination Reduction Zone: A contamination reduction zone is established outside the exclusion zone to provide a transition

Figure 11. Conceptual Site Layout Showing Electrical Exclusion Zone

Figure 12. Site Work Zones

from and a buffer between the exclusion zone (potentially contaminated zone) and the support zone (clean zone).

Support Zone: The support zone (clean zone) will be marked and protected against contamination from the work site. Primary functions of the support zone are:

- entry area for personnel, material, and equipment;
- exit area for decontaminated personnel, materials, and equipment;
- a clean storage area for safety and work equipment; and
- an area for rest breaks, consumption of food and beverage, and all other activities.
- an area for office trailer and communications equipment.

9.6 PERSONAL PROTECTIVE EQUIPMENT

All Personal Protective Equipment (PPE) for site activities, tasks, and work zones is based upon potential site-specific contaminants and may involve conservative additions to personnel protection by the Field Operations Manager. Protective equipment may be selected for chemical and electrical hazards.

10. RESIDUALS MANAGEMENT

The waste management plan is attached in the table below.

WASTE MANAGEMENT PLAN	
1. Project Name:	Demonstration, Testing and Evaluation of In Situ Soil Heating and Decontamination
Plant:	K-25 Site
Organization:	Site Programs Organization
2. Responsible Manager:	Frank R. Van Ryn, 4-1907, MS 7328, K-303-7
3. Expected Start/Completion Dates:	Start 11/1/94 Complete 6/1/95
4. Project Description:	<p>The Department of Energy proposed action is to conduct a remediation demonstration to evaluate a technology that has the potential for the remediation of vadose zone soil contaminated with organic solvents at DOE facilities. The demonstration project would be conducted on contaminated soil located just outside the western boundary of the K-1070-D Burial ground located at the K-25 Site, Oak Ridge. The demonstration project would be established near the vicinity of soil borings 74 and 75 which are located approximately 100 yards north-north east of the K-1414 building. <u>The site is currently a CERCLA site and is listed in Appendix E of the Federal Facilities Agreement.</u> This site was selected because of the ease of access, the types of contaminants in the soil and appropriate site characteristics such as moisture content, depth of contamination, permeability, etc.</p> <p>The Technology demonstration will be conducted by IIT Research Institute (IITRI), Chicago, IL. The In Situ Electromagnetic (EM) Heating Process will be demonstrated. The purpose of this demonstration is to show in situ decontamination of soil by heating of the contaminated test volume with 60 Hz electrical power. The contaminants are removed from the soil by raising its temperature and vaporizing and/or boiling the organic solvents. The resultant organic vapors and steam are removed by collection wells connected to a vacuum system. Figure 6 and 7 show two alternative means of generating the required vacuum. One of these will be used at the site. The collected gases will be vented to the atmosphere due to the low concentration, discharge rate and total weight of the contaminants. The soil will be heated to a temperature range of 85 to 95° C by this technology. A list of contaminants and their concentration ranges found in the near vicinity of the site is presented in Table 3, Section 4.7 of this document.</p> <p>In situ heating of soil is conducted by inserting an array of electrodes in the soil which are then energized with 60 Hz power. The electrodes are placed in vertical bore holes drilled through the contaminated zone. The hot air, steam and contaminant vapors will be collected by applying a vacuum to gas collection wells placed in side the heated area. A vapor barrier will be placed on top of the soil surface to prevent fugitive emissions and to control the vacuum. Approximately 400 tons of soil will be heated. The total concentration of volatile organic hydrocarbons in the soil at the site is estimated to be in the range of 6 to 55 ppm. The efficacy of the demonstration will be determined by comparing the results of contaminant concentration analysis performed on numerous soil core samples taken before and after the treatment.</p> <p>Soil heating will be conducted over a 3 week period.</p> <p>Fieldwork would consist of site preparation (clear weeds, install fences, install power drop poles and a power distribution panel), installation of electrical power supply, installation of the heating system in drilled bore holes, installation of the gas collection wells, the vapor barrier and the vacuum system. Prior to heating of the soil there will be a safety and readiness review and prior to application of full power there will be electrical safety checks performed at low power.</p> <p>Soil cuttings will be generated during installation of the electrodes and during post-demo sampling. The soil cuttings generated during installation of the electrodes will be used as over-pack for the array. This over-packed soil will also be heated as part of the in situ treatment. This soil will remain on-site.</p>

WASTE MANAGEMENT PLAN

Soil cuttings generated during the post-demo. sampling activities will be left on a plastic sheet placed on the ground near the demonstration area. The cuttings will be covered. Final disposition of this material will be made after the soil sample results become available.

5. Project Participants (for Waste Management Interface only):

Waste Generator - Site Programs Organization
 Waste Handler - Site Programs Organization
 Waste Transporter - K-25 WTD0
 Waste Treatment - Central Neutralization Facility

6. Waste Generation:

Waste Stream	Type	Category	Volume	Contaminants	Process Knowledge	Sample Analyses
Soil Borings from post-demo. sampling activities	Solid		100 cu. ft.	see Table 3		✓
Auger washing fluids and soil cuttings in water	solid/liq uid mix		1000 gal	see Table 3		
Solvent Waste	Liquid		5 gal	Acetone, methylene chloride, isopropyl alcohol		
Metal scrap: iron pipe & fittings	Solid		4000 lbs	Table 3		
Vapor Barrier	Solid		500 lbs	Table 3		
Process Condensate as per Figure 6 alternative	Liquid		600-1000 gal	Table 3		✓
Waste gas stream	Gas		50 to 200 cfm	Table 3		✓
Paper, work gloves, etc	sanitary trash	non-hazardous	1 yd ³	none	✓	

7. Waste Analysis and Characterization: See attached data

8. Waste Staging Area: NA

Location:
 Special Requirements:

9. Transportation Across Public Roads: No

Road(s) Involved:
 DOT Regulations to be applied:
 Reportable quantities of anticipated DOT-regulated hazardous materials (if required):

WASTE MANAGEMENT PLAN

10. Waste Storage Requirements: None

Field Staging Area:

Location:

Responsible Organization:

90-Day Storage Area: Yes

Location: K-33 Bldg., KA019

Capacity: NA

Waste Acceptance Criteria Requirements: NA

Responsible Organization: Site Programs Organization

Permitted (or Interim Status) Storage:

Location:

Capacity:

Waste Acceptance Criteria Requirements:

Responsible Organization:

11. Identification of Potential Treatment Options:

12. Identification of Potential Disposal Options: Central Neutralization Facility

13 Waste Minimization and Reduction Techniques to be Implemented:

Segregation:

In-field pretreatment:

Decontamination:

Waste handling (spill control):

Compaction:

Material recycle (solvents, containers);

Solvent substitution:

Materials reuse (solvents, wash waters);

Sludge dewatering:

Cutting fluids recovery:

Selection of PPE:

Selection of Equipment:

Other: Minimize the amount of auger washing fluids generated during soil sampling. Treat the soil drillings made prior to the demonstration by incorporating them within the treated soil volume.

Description of Special Techniques and Expected Effectiveness: NA

Prepared by: Harsh Dev, IIT Research Institute

Approvals:

K-25 Waste Management Division:

Date:

11. COMMUNITY RELATIONS PLAN

Prior to initiating field activities at the K-25 Site, a four-page flier will be prepared describing the site needs, EM heating technology and its capabilities, and the goals for the treatability study; the flier will be oriented for a nontechnical audience. In addition to making these flyers available at various technical meetings, they will be made available during public meetings conducted by DoE's Environmental Restoration and Waste Management Division when remedial actions are proposed for public comment. The fliers will also be made available, along with sample materials, at the Information Resource Center (IRC) in Oak Ridge. Previously published materials will be made available to individuals upon request, and their availability will be advertised in the flier; group briefings will be made to interested organizations or groups upon request.

12. REPORTS

Several reporting milestones will be established over the multiyear effort of this treatability study. The treatability study report will be prepared at the end of 1994 as indicated in the project schedule. A number of additional reports will be prepared during the project for submission to DOE. These are listed below:

- Management Plan
- Design Report
- Health and Safety Plan
- Project AQ/QC Plan
- Monthly Progress Reports

13. SCHEDULE

The proposed schedule for the treatability study is presented below. It is anticipated that the demonstration test will be conducted during late summer/early fall of 1994.

14. MANAGEMENT AND STAFFING

IITRI staff will be responsible for all major tasks. The project organization chart is presented in Figure 10, Section 9. Mr. Guggilam Sresty will serve as IITRI Project Manager and will report to Mr. Johnny Moore, DoE-ORO COTR. He will be assisted by Messrs Kloempken, Dev, Jones, and Miller to manage various aspects of the program. Mr. Frank VanRyn of MMES will provide required assistance to co-ordinate site activities. MMES will provide required site utilities and field support.

15. BUDGET

The estimated costs for the treatability study are \$863,764.

16. REFERENCES

- 1 Phase 2 Remedial Investigation Work Plan for the K-1070-C/D Classified Burial Ground at Oak Ridge K-25 Site, Oak Ridge, TN, Vol. 3: Health and Safety Plan, DoE/OR-1025/V3&D3, July 1993.
- 2 Personal Communication, Mr. Johnny Moore, U.S.DoE.
- 3 Dev, H., Enk, J., Sresty, G., Bridges, J. In Situ Decontamination by Radio Frequency Heating--Field Test. IIT Research Institute. Final Report C06666/C06676. Prepared for USAF, HQ AFESC/RDV, Tyndall AFB, FL, May 1989.
- 4 Snow, R. H., Sresty, G. C., Conroy, C., Collins, R., and Kilgannon, T. Test of Radio Frequency In Situ Heating for Treatment of Soil at RMA, Proc. of the XIV Superfund Conference, HMCRI, Greenbelt, MD, 1993
- 5 Dev, H., J. Bridges, G. Sresty, J. Enk, N. Mshaiel, and M. Love. Radio Frequency Enhanced Decontamination of Soils Contaminated with Halogenated Hydrocarbons. EPA/600-2-89/008. U.S. Environmental Protection Agency, Cincinnati, Ohio, 1989
- 6 Dev, H., and G. Dubiel. Optimization of Radio Frequency (RF) In Situ Soil Decontamination Process. Draft Final Report, IITRI Project No. C06691. ANL Contract No. 83482402. June 1990.
- 7 Sresty, G.C., Dev, H., Gordon, S. M., and Chang, J. Methodology for Minimizing Emissions by Remediation of Environmental Samples Containing Wood Preserving Chemicals, Draft Final Report, IIT Research Institute. US EPA Contract No. 69-D8-0002, Work Assignment No. 22, IITRI Project No. C06693C022.
- 8 Sresty, G., Dev, H., Chang, J., and Houthoofd, J. In Situ Treatment of Soil Contaminated with PAHs and Phenols. Presented at and to be published in the proceedings of the International Symposium on In Situ Treatment of Contaminated Soil and Water, Air and Waste Management Association, February 4-6, 1992, Cincinnati, Ohio.
- 9 Dev, H., Sresty, G. C., and Carpenter, P. In Situ Decontamination by Radio Frequency Heating. Presented and published in the 18th Environmental Symposium and Exhibition; ADPA, Alexandria, VA, February 1992.

- 10 Demonstration Testing and Evaluation of In Situ Soil Heating,
Oak Ridge, TN, Draft Health and Safety Plan, IITRI Project
No. C06787, DE-AC05-93OR22160, April, 1994.