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DEMONSTRATION SYSTEM DESIGN

Revision 1

**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 Revised Demonstration System Design for US DOE contract entitled, "Demonstration Testing and Evaluation of In Situ Soil Heating," Contract Number DE-AC05-93OR22160, IITRI Project Number C06787. Other related documents are: Treatability Study Work Plan, Revision 1, July 7, 1994; Health and Safety Plan, Revision 1, August 4, 1994.

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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1. INTRODUCTION

1.1 PROBLEM DISCUSSION

A number of DOE installations have soil contamination due, not only to the presence of hazardous waste materials, but also due to the co-presence of both organic, and inorganic hazardous waste as well as radioactive waste. At many installations, there is widespread contamination of soil over a large area but with low levels of both organic as well as radioactive waste. Many such sites are classified as low-level mixed-waste sites due to presence of both RCRA/CERCLA as well as radiological. Soil containing mobile organic and inorganic contaminants acts as a contaminant source for the continued future contamination of ground water. Any ground water treatment system designed to protect public health and welfare must take into account the relatively large reservoir of contaminants present in the overlaying soil which can be released to the groundwater over a period of time thus defeating the purpose of ground water treatment systems.

At low-level mixed waste sites the presence of radioactive contaminants is sometimes so low that if an economical and effective method is developed to remove or destroy the organic waste component of the contamination then the site can be effectively regarded as rehabilitated and delisted. Nevertheless, removal of the organic waste or its destruction can often permit the reclassification of the site as a radioactive waste site thus reducing the regulatory burden on the waste-site management activities. Soil remediation can allow new, economical and income producing uses of the land which otherwise would have to be kept unproductive or underutilized.

The fundamental goal of DOE's long term environmental program is to ensure that risks to human health and safety, and to the environment posed by DOE's past, present and future operations are eliminated or reduced to prescribed safe levels. In order to meet this goal DOE has set itself, as one of the objectives of long term environmental restoration, the challenging task of development of new, efficient and effective methods and technologies for the management of wastes currently being produced and the environmental restoration of contaminated sites.

In this project IITRI will demonstrate the EM Treatment Technology for the in situ remediation of soils containing organic wastes. This technology can help DOE in the following ways:

- For sites containing low-level mixed-wastes, reduce the regulatory burden by removing the hazardous organic wastes and thus change the site to a radioactive waste site.

- Many DOE sites are treated as contaminated due to the presence of the organic substances. At these sites the radioactivity levels are so low that once the organic contaminants are removed by the EM technology the site may need no further remediation for the radioactive constituents.
- For hazardous waste sites where organics are the primary contaminants of concern, the EM technology can be used for economic and effective remediation.
- The process is a true in situ process. Massive soil excavation need not be undertaken, thus preventing exposure of the general and the occupational population to fugitive emissions and dust.
- The soil is treated in situ. There is no solid residual (waste) stream that needs further disposal
- There is no on site or in situ combustion. This is expected to make permitting of the process easier than most other on site ex-situ processes.
- The process can be used for rapid clean up of soils even when they contain contaminants trapped in clayey soil of low permeability--a challenging and intractable situation for in situ venting. Medium boilers such as those boiling in the temperature range of 110° to 130°C can be rapidly removed.

1.2 DESCRIPTION OF THE TECHNOLOGY

Over the last nine years IITRI has been developing and testing 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. The vaporized contaminants, water vapor and air are recovered from the heated zone by means of a vacuum manifold system which collects gases from below surface as well as from the soil surface. A vapor barrier is used to prevent fugitive emissions of the contaminants and to control air infiltration to minimize dilution of the contaminant gases and vapors. The recovered gases and vapors are conveyed to an on site vapor treatment system for the clean up of the vent gases.

Electrical energy is applied to the soil by forming an array of electrodes in the soil which are electrically interconnected and supplied with power. The electrodes are placed in drilled bore holes which are made through the contaminated zone. There are two versions of the in situ heating and soil treatment process: the first version is called the In Situ Radio Frequency (RF) Soil Decontamination Process and the second version is called the In Situ Electromagnetic (EM) Soil Decontamination Process. The first

version, the RF Process is capable of heating the soil in a temperature range of 100° to 400°C. The soil temperature in the second version, the EM Process, is limited to the boiling point of water under native conditions. Thus the soil will be heated to a temperature of about 85° to 95°C.

In this project IITRI will demonstrate the EM Process for in situ soil decontamination at K-25 Site due to the fact that 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 in situ 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.

Figure 1 is an artist's sketch illustrating the electrode array and the vapor barrier used for the implementation of the EM soil decontamination process. The electrode array is formed by drilling multiple rows of electrodes in the soil volume which is to be heated. The tubular electrodes are made from pipe or tubing fabricated from copper, steel or aluminum. The electrodes are dropped into bore holes and electrically connected at the surface to the power source. A vapor barrier is placed on the surface to prevent fugitive emissions of gases and vapors formed upon heating of the soil. The vapors and gases formed upon heating of the soil are recovered by means of a vacuum manifold system which collects gases and vapors from the surface of the heated zone as well as from gas collection wells which have perforations to assist in the collection of the gases and vapor formed in the heated soil volume.

The collected gases are treated on site by means of conventional gas treatment unit operations which depend upon the amount concentration, and type of contaminants. In this project, because of the low concentrations and total weight of contaminants, it is proposed to release the collected gases without treatment.

This document is a System Design Report which describes the demonstration system components and how the in situ heating system will be built and placed in the ground. A soil sampling plan and system operating-data monitoring plan are also included.

In Situ Electromagnetic (EM) Heating Process for Soil Decontamination

IN SITU Radio Frequency Soil Decontamination Process

Figure 1. Artist's Sketch Illustrating the EM Process.

2. SITE DESCRIPTION

2.1 SITE HISTORY*

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. A shed and several piles of landscaping materials are located in this area. In general, the storage area is covered with gravel and serves as a parking lot. A natural drainage gully is located behind the shed; it channels surface water runoff from the K-1070-D hill. This ditch area and the boundary of the storage area are covered with vegetation.

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 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. A brief description of the pits 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.

* Taken from Reference 1.

Figure 2. Map of the K-1070 C/D Classified Burial Ground showing burial areas and sampling locations (Taken From Reference 1).

Glass 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.

Perennial Spring

A perennial spring is located about 200 ft west of K-1070-C/D Classified Burial Ground. This spring is the result of efforts to route seepage in this area to a local storm drain. In the mid-1970s, a polyvinyl chloride pipe was inserted into the K-1070 C/D Classified Burial Ground hillside. The spring water is currently collected and trucked to a groundwater treatment facility.

2.2 DEMONSTRATION SITE

Figure 3 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 3. 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 3 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.

2.2.1 Site Geology and Hydrogeology**

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 (Figure 4) 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 (Figure 4). The more shaley upper member of the Rome Formation forms the hill where sites K-1070-C and D are located.

** Material in this section taken from Reference 3.

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
- BRW-11..... BEDROCK WELL
- UNW-110..... UNCONSOLIDATED WELL
- TMW-1..... MONITORING WELL
- 16-A..... PHASE 1 SOIL BORING
- SB-025..... PHASE 2 SOIL BORING
- TMW-2..... K-1414 SOIL BORING
- SW-28..... PHASE 1 STORM WATER SAMPLE
- SW-022..... PHASE 2 STORM WATER SAMPLE
- SD-001..... PHASE 2 SEDIMENT SAMPLE
- SURVEYED BUT NOT SAMPLED

Science Applications
International Corporation

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

REVISION	DRAWN BY:	CHECKED BY:	DATE:
0	R. BEELER	D. KEEFER	02-20-84

XREFERENCES	PLOT FILES
/93043/XREF/5835513	/93043/PLOT/31311X17
/93043/XREF/5835514	
/93043/XREF/5835518	
/93043/XREF/5835519	

SHT. 1 OF 1	/94043/DWG/31311X17	N/A
DRAWING #	CAD FILE #	ROT. ANGLE

Figure 4. Geology in the Vicinity of the Oak Ridge Gaseous Diffusion Plan (Reference 3).

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.

Nine shallow test holes were drilled at this site (Figures 5 and 6). The wells and piezometers penetrate clay and weathered siltstone or silty-shale to depths ranging from 14.5 to 39 ft. Slug tests conducted in two of the piezometers, UNP-1 and UNP-13, indicated a permeability of about 10^{-5} cm/sec. A third test, conducted in UNP-2, indicated a permeability of 10^{-6} cm/sec. Table 1 summarizes the results of hydraulic conductivity measurements.

Wells BRW-9 and BRW-12 were drilled through clay residuum and penetrated dolostone and limestone, as well as siltstone and shale from about 30 ft. to the total depths of 123 and 300 ft., respectively. No permeability tests were conducted at either well. BRW-9 was pumped dry during development and recovered so slowly during the following two weeks that permeability is presumed to be extremely low. The water level in BRW-9 now stands well above levels in the shallow wells. This may not be an indication of vertical head difference between the bedrock and residuum aquifers but may simply be due to the fact that BRW-9 taps the water table at the highest point on the hilltop. BRW-11, located on the west flank of the hill, was drilled through the fault between the sandy siltstone of the Upper Rome and limestone of the underlying Chickamauga Group. No water was noted at the contact, indicating that the fault may be sealed by secondary mineralization. Well BRW-10, located a few hundred feet southeast of BRW-11, was drilled entirely in the Chickamauga indicating that the fault trace surfaces between the two wells.

Ground water is presumed to move through the unconsolidated residuum that blankets the hilltop site of K-1070-C, D, down the slopes, in a radial flow pattern. Several ephemeral springs are reported at the break in slope where the hillside becomes less steep and merges with the plain on which the plant is situated. Ground-water levels from well clusters BRW-10/UNW-17 and BRW-11/UNW-18 show a pronounced downward vertical gradient between the unconsolidated zone and the bedrock. Well cluster BRW-12/UNW-19 shows approximately equal heads between the unconsolidated zone and the bedrock.

2.2.2 Soil Sample Analysis Results

Table 2 is a summary of soil sample analysis⁴ for volatile hydrocarbons. The soil samples were obtained from Bore Holes 71, 75, 76 and 80 marked on Figure 3. As the data show the highest concentration of total volatile hydrocarbons occurs in hole 71.

Figure 5. Monitor Wells and Inferred Ground Water Flow in the Unconsolidated Zone at the K-1070-C/D Site (Reference 3).

Figure 6. Monitor Wells and Inferred Ground Water Flow in the Bedrock at the K-1070-C/D Site (Reference 3).

Table 1. Hydraulic Conductivity Results From Slug Test of Wells Around K-1070-C/D

Well or Piezometer Number	Methods of Analysis		Average Permeability (cm/s Round- ed)
	Bouwer (cm/s)	Hvorslov (cm/s)	
UNP-1*	5.34×10^{-6}	7.04×10^{-6}	10^{-5}
UNP-2	5.77×10^{-7}	6.15×10^{-7}	10^{-6}
UNP-13	2.20×10^{-5}	1.08×10^{-5}	10^{-5}
UNP-17	2.60×10^{-4}	8.10×10^{-3}	10^{-4}
BRW-9 ^a			

SOURCE: Reference 3

^a The well was pumped dry during development and took several weeks to recover. From this, the hydraulic conductivity was assumed to be very low; however, this is probably a very local condition (e.g., screened interval not in proximity of water-bearing fractures, screen inadvertently blocked, or other).

The paired wells BRW-12/UNW-19 appear to exhibit nearly equal piezometric levels between the two aquifer systems, but this is probably an anomalous situation for that particular location.

Table 2. Concentration of Volatile Organics, ppb

	Hole Number 71			Hole Number 75		Hole Number 76		Hole Number 80		
	5-10 ft	10-15 ft	15-20 ft	5-10 ft	10-15 ft	5-10 ft	15-18 ft	0-5 ft	10-15 ft	15-18 ft
Total Volatiles, ppb	5271	29510	54910	6938	6560	23	383	32	5940	4209
Total Chlorinated Volatile HCs, ppb	21	1100	4190	75	712	0	212	11	115	542

(Based on Preliminary Data, Reference 4)

This hole also has the highest concentration of volatile chlorinated hydrocarbons. Due to these results the demonstration should be located as close as possible to Bore Hole 71 while satisfying other constraints as discussed in Section 2. Table 3 is a list of volatile hydrocarbons which were analyzed and found in the soil samples obtained from the four bore holes. The soil obtained from these four bore holes was also analyzed for semi-volatiles, pesticides and PCBs. Table 4 summarizes the results of these analyses. It should be noted that the concentration of the semivolatiles is low, ranging from less than 1 ppm to 7 ppm. The maximum concentration of PCB was found in Bore Hole 71 which had 6.5 ppm of Aroclor 1248 and 4.1 ppm of Aroclor 1254.

Measurement of radioactivity from the soil samples at various depths was done. Table 5 summarizes the radiation level for soil samples as a function of depth and boreholes. As the data indicate, the specific activity of various radio-isotopes in the soil is quite low.

It should be noted that the information presented in this section and in Tables 2 to 5 is based on preliminary results.

2.2.3 Geophysical Soil Characterization

Soil characterization measurements were recently done in the vicinity of the pit area. While the data are undergoing validation a brief summary of the preliminary results is provided herein. Three soil borings were made, one each in the vicinity of B-70, B-79, and B-80. Grab samples were obtained at two depth intervals from each boring. The following measurements were made:

• Bulk density	• Cation Exchange capacity
• Specific gravity	• Grain Size distribution
• Hydraulic Conductivity	• Moisture, % Sat.
• Moisture, %	• Organic carbon (<75 microns)
• Organic Carbon(bulk)	• Permeability
• pH	• Porosity
• Void Ratio	

The results of these measurements are summarized in Table 6. The range of the measured parameter and the average values are shown for shallow and deep intervals. The shallow interval data is based on four different samples, while the deep interval data are based on two samples. It should be noted that the moisture content of the soil averages 21 percent in the shallow zone while it increases to 47 percent with depth.

In the shallow zone the permeability shows a wide variation, almost by four orders of magnitude. This is probably due to the

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. Semivolatiles Found* in Bore Holes
71, 75, 76, 80**

Contaminant	Concentration Range, ppb
bis(2-ethyl hexyl) phthalate	62 - 6600
Chrysene ²	250 - 1300
Di-n-butyl phthalate ²	400 - 650
Dimethyl phthalate	49
2,4-Dimethylphenol ²	42 - 77
Fluorene	58 - 160
Isophorone ³	140
2-methylnaphthalene	320 - 770
Naphthalene	63 - 360
2-nitrophenol	73 - 84
Naphthalene	63 - 360
2-nitrophenol	73 - 84
N-nitrosodlphanylamine ³	40
Pentachlorophenol ³	38 - 130
Phenanthrene	95 - 130
Pyrene ⁴	45
PCBs and Pesticides	
Aldrin ³	1.2
Aroclor ³ 1242	1200
Aroclor 1248	200 - 6500
Aroclor ² 1254	350 - 4100

* Based on preliminary data from Reference 4.

¹ Only those found at or above detection limit.

² Found in Blanks also.

³ In Bore hole 80 only.

⁴ In Bore hole 76 only.

Table 5. Measurement of Radioactivity in Soil Samples, pCi/gm

Radio-Isotope	Units	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
Co-60	pCi/g	0.31	0.35	0.3	0.32	0.27	0.28	0.22	0.23	0.27	0.28
Cs-137	pCi/g	0.22	0.06	0.16	0.3	0.26	0.17	0.27	0.3	0.31	0.28
Gross Alpha	pCi/g	28±10	36±9.5	26±8.5	20±7.3	31±9.3	21±9.7	19±7.8	24±9.1	25±8.2	37±9.8
Gross Beta	pCi/g	28±5	35±5.7	35±5.3	20±4.7N	42±5.7	35±5.6	26±5	27±5	25±5	48±5.9
Sr-90	pCi/g	0.53±0.73	1.50±0.54	0.49±0.86	-0.98±1.2	-1.80±4.5	2±2.6	-0.23±0.5	0.09±0.93	0.51±1.4	-1.20±1.3
Tc-99	pCi/g	0.06±1.2	0.73±1.2	0.72±1.2	0.70±1.2	1.70±1.2	0.80±1.2	1±1.2	1.30±1.2	0.86±1.2	0.99±0.28
U-234	pCi/g	1.30±0.32	1.0±0.33	0.90±0.27	0.68±0.24	0.78±0.26	1.30±0.35	0.03±0.32	1.70±0.4	1.30±0.35	0.80±0.28
U-235	pCi/g	0.07±0.08	0.02±0.05	-0.01±0.01	0.05±0.07	0.01±0.05	0.11±0.1	0.11±0.1	0.15±0.12	0.08±0.09	0.10±0.1
U-236	pCi/g	1.2±0.3	1.40±0.38	0.83±0.27	0.77±0.25	0.86±0.26	1.10±0.32	0.87±0.3	1.80±0.41	1.20±0.35	0.64±0.25

Based on Preliminary Data, Reference 3

Table 6. Soil Characteristics

Parameter, units	Shallow, 0-8 ft (n=4)		Deep, 13 to 18 ft (n=2)	
	Range	Average	Range	Average
Bulk Density, lb/cu. ft.	84-109	98.3	73-80	76
Cation Exchange Capacity, MEQ/L	7.5-16	10.3	12-32	22
Specific Gravity	2.66-2.79	2.71	2.68-2.75	2.72
Hydraulic Conductivity, cm/sec, $\times 10^{-9}$	0.2-1200	302	0.3-2.72	1.51
Permeability, cm/sec, $\times 10^{-6}$	2.7-12500	3145	3-39	21
Porosity, %	34-57	42	52-58	55
Void Ratio	0.5-1.07	0.74	1.1-1.4	1.23
Moisture, % sat.	62-91	78	100	100
Moisture, wt %	15-35	21.4	44-50	47
Organic Carbon, (<75 microns), %	0.14-0.88	0.46	0.12-0.17	0.14
Organic Carbon (Bulk), %	0.15-0.70	0.38	0.1	0.1
pH	4.8-6.6		4.7-6.1	
Grain Size, (Clay), %	28-55	36	52-74	63
Grain Size, (Silt), %	25-47	34	24-33	29
Grain Size, (Sand), %	20-36	28	2-15	8
Grain Size, (Gravel), %	0-4	2	0	0

presence of gravel which varies from 0 to 4 percent in the shallow zone, but is absent at depth. Due to the wide variation in the observed permeability and also due to limited data at depth the above conclusion should be used carefully. The soil particle size distribution indicates that in the shallow region the soil is clay or clay-loam, in texture, whereas at depth the soil is all clayey.

2.3 Contaminants of Concern

The main contaminants of concern are the volatile hydrocarbons and chlorinated hydrocarbons present at the site. Based on the concentration ranges given in Table 3 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

3. SYSTEM DESIGN

3.1 Demonstration Objective

The objective of the demonstration is to heat soil in situ, using 60-Hz electrical energy to a temperature range of 85° to 95°C in order to demonstrate average removal of the contaminants of concern in the range of 90 to 95 percent.

The percent removal will be determined through a comparison of soil sample analyses performed on samples obtained before and after the demonstration. Table 7 gives the vapor pressure of the contaminants of concern in the temperature range of 85° to 95°C. As the table shows, even the least volatile compound has a vapor pressure of 106 mm Hg at 85°C and 155.5 mm Hg at 95°C. This compound is tetrachloroethane. The vapor pressure of tetrachloroethane is sufficiently high to allow removal at the target treatment temperature.

Table 8 is a summary of treatability studies⁵ that were done by IITRI in which sandy soil was spiked with tetrachloroethene and chlorobenzene at a concentration of approximately 10 ppm. The results clearly show the desired removal in the temperature range of 90°C. Additional soil treatability studies are summarized in Reference 6.

The above results show that in situ heating to a temperature range of 85° to 95°C should be adequate to obtain the desired degree of removal of the contaminants from the soil.

3.2 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° - 95°C

Table 7. Vapor Pressure and Boiling Points of Contaminants of Concern

Contaminant	Normal Boiling Point °C	Vapor Pressure, mmHg	
		85°C	95°C
Benzene	80.1	881.8	1177
2-Butanone	79.6	897.3	1206
Ethyl Benzene	136.2	151.8	216.8
Toluene	110.6	345.1	476.8
Methylene dichloride	39.6		
Tetrachloroethene	121.1	246.8	345.9
1,1,1-Trichloroethane	74.1	1052	1389
1,1,2-Trichloroethane	113.9	303	425.2
1,1-dichloroethane	57.3		
1,2-dichloroethane	83.4	797.2	1059
1,1,2,2-Tetrachloroethane	145.1	106.2	155.5
Trichloroethylene	189°F		
Chloroethane	12.3	6338	7890
Chloroform	61.2	1554	2031
1,1-dichloroethene	31.6		

Table 8. Removal of Tetrachloroethene (PCE) and Chlorobenzene (CBZ) from Soil

Treatment Temperature C	Time at Temperature hr.	Residual Conc ¹ . ppb		Percent Removal %	
		PCE	CBZ	PCE	CBZ
89	4	121	191	98.8	98.1
88	4	155	246	98.5	97.5
134	4	320	315	96.8	96.8
129	4	287	273	97.1	93.9
25	4	9360	8710	-9.1	-1.6

(Initial Concentration: PCE 9.53 ppm², CBZ 9.33 ppm²)
 (Last experiment: PCE 8.78 ppm², CBZ 8.58 ppm²)
 (All experiments with sandy soil)

¹ On Dry basis

² On Wet basis

- 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

3.3 Assumptions

The following assumptions were made in the preparation of the demonstration system design. Many of these assumptions are based on field observations, or on the results of soil core characterization studies.

- There is no bed rock in the depth interval of 0 to 20 ft. so that all the drilling activities can be accomplished with an auger. If bedrock is encountered, depth will be decreased.
- The water table is at least five feet below the bottom of the heated zone, that is the water table is at a depth in excess of 25 ft. Heating will be confined to a region in which there is no water table.
- Average moisture content of the heated zone is 30 % by wt.
- Initial average permeability to gas flow is 30 millidarcies.
- The soil formation is stable so that the bore holes needed for electrode emplacement can be left unsupported for a period of 2 hours while the electrodes are being installed. This will allow smaller diameter holes to be drilled and will minimize the soil cuttings.
- As it will be shown in section 3.4, the total mass of contaminants of concern is quite low. Due to this reason it was assumed that the gases and vapor collected from the site may be freely vented to the atmosphere, without treatment or separation from the vent gas stream.
- There are no radioactive contaminants of concern. This will be verified in the field by means of monitors.
- It will be necessary to inject water inside the electrodes to keep the soil surrounding the electrodes moist. It was assumed that drinking water or water from a hydrant may be injected into the electrodes without restriction.

3.4 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 9 summarizes the basis and assumptions used for the calculation of the heat load and heat up time. Table 10 summarizes the energy load calculation. The heating time ranges from 18 to 25 days as the native soil moisture varies from 20 to 30 percent.

Table 9. 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.	

Table 10. Estimate of Energy Required and Heating Time

Load	Energy Required, BTU		
	Soil Moisture, % wt, wet basis		
	20%	25%	30%
Sensible Heat required to raise dry soil to a Temperature of 95C	17,310,720	16,228,800	15,146,880
Sensible Heat required to raise native moisture to a Temperature of 95C	21,638,400	27,048,000	32,457,600
Latent Heat to Boil 75% of Native moisture	114,072,000	142,590,000	171,108,000
Energy to Raise native soil temp., no heat loss	153,021,120	185,866,800	218,712,480
Heat losses, 25 percent of above	38,255,280	46,466,700	54,678,120
Total Energy to raise soil temp. to 95C	191,276,400	232,333,500	273,390,600
Sensible Heat required to raise injected water to a Temperature of 95C	2,208,000	2,208,000	2,208,000
Latent Heat to vaporize 100% of the injected water	15,520,000	15,520,000	15,520,000
Total Heat Load for Injected water	17,728,000	17,728,000	17,728,000
Total Process Energy Requirement for heating	209,004,400	250,061,500	291,118,600
Total Process Energy Requirement for heating, kW-Hr	61,238	73,267	85,297
Energy Available Per Day, kW-Hr	3,420	3,420	3,420
Heating time, Days	18	21	25
Weight of Native water boiled, lb	117,600	147,000	176,400

Table 10 also shows that approximately 118,000 to 177,000 lbs (14,000 to 21,000 gallons) of native water will be boiled out of the soil as steam or water vapor.

3.5 Estimate of Contaminant Weight and Emissions

The concentration of volatile and chlorinated hydrocarbons was presented in Section 2.2.2, Table 2. The concentrations presented in Table 2 are 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 that table, an estimate of the weight of contaminants in the heated volume of soil was made. These calculations are summarized in Table 11. Line 1 of Table 11 gives the maximum concentration of total volatiles found in any sampled 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 11. 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 11 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 2.2, 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 (concentration data in Table 11) and 74. It is

Table 11. 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

estimated that Bore Hole 75 will be within 25 to 40 ft of the heated volume. As the data of Table 11 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)

In Table 10 it was 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 assumes 100 percent recovery of the hydrocarbons 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 (as proposed in this design) without treatment, as long as there is no steam condensation at the outlet of the vent stack.

3.6 Conceptual Site Layout

As it was mentioned in Section 2.2 it is planned to conduct the demonstration outside the Q fence on the shoulder of the road between Bore Holes 74 and 75 which are marked on Figure 3. Figure 7 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. Figure 7 does not show the location of new transformer poles, a power distribution panel, light poles, etc. These details can be decided upon once the design of the power supply line for the site has been finalized. It is IITRI's understanding that the overhead line will be de-energized for the duration of this demonstration project.

Figure 7 Conceptual Site Layout

3.7 Electrode Array Design

3.7.1 Plan

The design of the electrode array which is to be emplaced in drilled bore holes located in the shaded rectangle of Figure 7 is described in this section. The electrode array will be formed by drilling three rows of electrodes. Figure 8 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 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 is 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 as specified in the temperature monitoring plan described in Section 3.7.7.

The 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.

3.7.2 Typical Transverse Section

A central transverse section of the array is shown in Figure 9. This figure illustrates the depth of the outer and the central electrodes, the depth of the temperature monitoring wells, the thickness of the soil overpack and the location of the gas collection lines in a sectional view. The electrodes in the outer rows will be 20 ft deep while those in the central row will be 18

Figure 1. Plan View of the Electrode Array
(Water injection, instrumentation and power lines not shown)

Figure 9. Central Transverse Section of the Electrode Array

ft deep. It is estimated that the soil cuttings obtained from the drilling of the holes will form an overpack with a depth of 10 to 18 in. This is based on the assumption that the soil can be compacted to an average density of 50 to 100 lb/cu. ft., and that the soil in the area is stable so that empty bore holes will not collapse for a period of 1 to 2 hours while the electrodes are placed. In stable soil smaller bore holes can be drilled because a hollow stem auger will not be needed to provide support to the bore hole wall.

If the soil is stable, then it is estimated that approximately 175 to 200 cu. ft. of soil cuttings will be produced. It is planned to pack these on top of the treatment zone, in an area of 25 ft. by 16 ft. If the soil is unstable, then the soil cutting volume could increase to 470 cu. ft.

3.7.3 Typical Electrode Design and Bore Hole Completion

The electrode design and the completion of the electrode bore holes is illustrated in Figure 10. All electrodes will be made from 2 in. diameter Schedule 40 steel or black iron pipes. The electrodes will be capped at both ends. The electrodes will be perforated or slotted with openings of dimensions 0.020 in. The interior of the electrodes will be filled with medium to coarse sand. A water injection tubing will be installed inside each electrode which will release water into the sand pack at three discrete depth intervals. The water injection tubing will be made from Teflon. Water injection will be used only when the soil surrounding the electrode is drying out. Water injection will be necessary to keep the soil moist and to provide a conductive path for the electric current to reach the electrode. To assist in this and to measure the soil temperature, thermocouples will be installed inside selected electrodes. Details of water injection system are presented in Section 3.7.4. Details of the temperature measurement plan are presented in Section 3.7.7.

All bore holes will be made by means of an auger. The ID of all bore holes will be 5 in. except for those holes from which soil samples will be taken. For such holes the bore hole ID will be 7.25 in. The annular space of the bore hole is filled with a clay slurry. The clay slurry will be made by mixing water with bentonite. The slurry will be pumped into the annular space by means of a tremie pipe or else the hole will be filled with the slurry before forcing the electrode into the partially filled hole.

The electrical current will be carried by means of three 350MCM cables routed through plastic conduit attached to the top cap of the electrode by means of a solderless lug. Cables will electrically connect all electrodes within an electrode row. The top outer surface of the cap will be machined smooth and flat

Figure 10. Typical Electrode Design and Bore Hole Completion

before welding of the an iron section used to mechanically attach the cable connector lugs.

3.7.4 Water Injection System

The flow diagram for the water injection system is illustrated in Figure 11. In Figure 10 a water distribution header was illustrated near the top of the electrode. There will be three such headers, one for each of the three electrode rows. Each header will supply water to 9 to 11 electrode by means of branches connected to the header. Distilled, drinking, or fire hydrant water will be injected inside the electrodes when the soil temperature around the electrodes approaches 85°C in order to replenish the water evaporated from around the electrodes. It is necessary to keep the soil moist around the electrodes in order to maintain a conductive current path. Figure 11 shows the water injection system flow diagram. Water will be stored in a reservoir and pumped into three separate header systems, each with its own rotameter and a pressure gauge. The portion of the header below the vapor barrier and buried in the soil over pack will be made from 0.5 in OD copper tubing. All other parts of the header which are outside the heated zone will be made from plastic tubing or pipe. A peristaltic pump will be used to ensure that there is complete electrical isolation between the fluid and the pump. The water will be stored in a plastic tank. The flow rate to each of the three electrode rows will be independently set and measured.

3.7.5 Gas Collection and Treatment System

Gas collection lines were shown in Figure 7 and 8. These lines are connected to four gas collection wells and to two horizontal perforated gas collection lines placed near the top surface of the soil, in the overpack. Figure 12 illustrates the completion of a typical gas collection well. The gas collection well will be made from slotted steel casing having opening in the range of 0.018 to 0.020 in. The depth of the casing will be 20 ft below the original ground surface. The interval 2 to 20 ft will be slotted. There will be a bentonite surface seal from surface to a depth of 2 ft. The casing will be placed through a hollow stem auger and the annular space will be filled with a medium to coarse sand by means of a tremie pipe. The ID of the bore hole will be 10.25 in. An elbow will be connected to the top of the casing inside the overpack as schematically illustrated in the flow diagram shown in Figures 13 and 14.

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 13 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

Figure 11. Water Injection System Flow Diagram

Figure 12. Typical Gas Collection Well Completion
Below Ground

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

The system shown in Figure 14 is safer because it does not use any large electric powered equipment. Both types of vapor collection systems have been safely used in the past during in situ heating demonstrations performed with radio frequency energy.

The heat tracing for the gas lines will be a constant wattage type designed to maintain the pipe temperature at 100°C. The cable will be rated for Class 1, Division 2 hazardous areas. A local temperature controller will be used which will also be rated for Class 1, Division 2 hazardous area. A humidity sensor and flow meter will also be used. These will also be rated for hazardous location service.

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.

3.7.6 Vapor Barrier and Thermal Insulation

A vapor barrier will be used to cover the heated zone. It will extend approximately 10 ft outside the dimensions of the heated area. The plan view of the vapor barrier is illustrated in Figure 7. Figure 15 illustrates a cross sectional view of the vapor barrier. The vapor barrier will be made from a Geomembrane manufactured by the Seaman Corporation. The membrane is made by coating a base fabric with ethylene interpolymer alloy (EIA). The base fabric is made from polyester fibers. The catalogue number of the membrane is 8130 XR-5 SP. The SP designation specifies the use of material suitable for solar pond applications. This grade was selected due to improved temperature resistance. The 8130 designation specifies the finished coated weight of the membrane.

A 2 in. thick thermal insulation blanket will be rolled out on top of the geomembrane. The thermal insulation will be covered with a single sheet of nylon cord reinforced HDPE. The HDPE cover

Figure 14. Flow Diagram of the Gas Collection System-Ejector Option

Figure 15. Vapor Barrier Construction Detail

is needed to protect the thermal insulation from rainfall. The thermal insulation will cover the heated area and extend out by 3 ft, all around the array. The HDPE sheet will cover the heated area and extend 10 ft all around, outside the array.

3.7.7 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. The distribution of the thermocouples and the temperature measurement points in the thermowells are presented in this section.

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 per 12 hours. The data from the electrode thermocouples may be acquired more frequently (once per 8 hours) should it be needed to control and adjust the input AC power or water injection rate to the electrodes.

The thermocouple distribution is shown in the next five figures. Figures 16, 17, and 18 show the location of the thermocouples attached to the inner walls of the electrodes. Figure 16 illustrates the location of thermocouples in the outer row of electrodes, Row EA. There will be a total of 12 thermocouples in this row. They will be located at depth of 1, 9, 18 and 20 ft. Figure 17 illustrates the thermocouple distribution in the center row of electrodes, Row EB. In this row there will be 13 thermocouples located at a depth of 1, 9 and 18 ft. Thermocouples in the second outer row of electrodes, Row EC, are illustrated in Figure 18. In this row there will be 7 thermocouples located at a depth of 1, 9, 18, and 20 ft.

All thermocouples will be Type K, ungrounded junction with a 12 in. long, 1/16 in. stainless steel (SS304) sheath.

The temperature monitoring points in the thermowells are illustrated in Figures 19 and 20. Figure 19 is a central transverse view of the array showing the location of the

Figure 16. Thermocouples in Electrode Row A

Figure 17. Thermocouples in Electrode Row B and Thermowell MW04

Figure 18. Thermocouples in Electrode Row C

Figure 19. Temperature Measurement Points in Thermowells

Figure 20. Temperature Monitoring Points in Section BB'

temperature monitoring points in the thermowells. These thermowells will be made from 0.25 in ID Teflon tubing which will be plugged at the bottom end. A thin, 1/16 in. long thermocouple will be inserted to the desired depth to read the temperature. Thermowells which are located under the vapor barrier will be passed through the barrier so that the thermocouples may be inserted through them. Every pass-through will be sealed to prevent gas leakage.

Figure 21 illustrates a block diagram of the thermocouple wiring and data acquisition system. A bundle of thermocouple wires will exit each of the three electrode rows. The three bundles will enter the disconnect box located outside the fences. In this box the thermocouple leads will be connected to other cables which lead to the multiplexer from where the temperature signal will be sent to the data logger. The disconnect box is needed to ensure that the thermocouples can be disconnected while AC power is on.

3.7.8 Description of the AC Power Source

Figure 22 is a block diagram of the power supply to the electrode array. 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 12 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.

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 safety exclusion zone and AC power lines will run through the safety fence into the array.

3.7.9 Removal of Below Ground Equipment

At the end of the experiment, when the soil has cooled, all equipment at or below the ground surface level will be removed. The major items are: electrodes and associated cables, gas collection wells and associated piping, thermowells, the vapor barrier and the thermal insulation. The electrodes and the gas collection wells will be withdrawn by means of the drill rig which

Figure 21. Block Diagram of Thermocouple Wiring and Data Acquisition System

Figure 22. Block Diagram of Power Supply to the Electrode Array

Table 12. 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

will be mobilized at the end of the experiment to drill for soil samples. All of these materials can be disposed off unless some need for performing another similar experiment is foreseen. Prior to disposal, the below ground equipment may have to be cleaned depending on its condition. Cleaning shall be done by one or more of the following methods: steam cleaning, wiping with dry rags, wiping with acetone or alcohol soaked rag, etc.

The lower surface of the vapor barrier which was in contact with the soil may need to be cleaned prior to disposal. Cleaning will be done by wiping the surface with a rag soaked with acetone or iso-propyl alcohol. The thermal insulation will be disposed off as debris.

The open electrode holes and gas collection wells will be backfilled with bentonite. Bore holes which collapse upon the removal of the electrode or the casing will not be re-drilled.

4. SOIL SAMPLING PLAN

The decontamination of the soil will be determined by analyzing soil core samples for the contaminants of concern. Pre-demonstration samples will be taken during when the bore holes are 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. In this section the location of soil samples to be obtained from the site is presented.

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 are presented in the project QA/QC plan.

The pre-demonstration soil sampling plan is illustrated in Figure 23. 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 24. 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 two 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 23. Pre-Demonstration Soil Sampling Plan

5. UTILITY REQUIREMENTS

AC power is needed to heat the soil, collect vapors and gases, and run the instrumentation. It is estimated that for in situ heating 200 KVA of single phase AC power at 480V will be required. For other electrical loads, 208V, 3-phase, 50 KVA will be required.

Figure 25 is a schematic figure of the electric power distribution panel that is needed in the field. Power from this panel will be distributed to the various loads as indicated in Figure 25.

In addition to AC power, drinking water or equivalent will be needed for injection into the electrodes. It is estimated that 2,000 gallons of water will be needed over the duration of the demonstration. Daily water requirements will be approximately 100 gallons.

Figure 25. Electrical Distribution Panel

6. SYSTEM OPERATING DATA MONITORING PLAN

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 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 at sample points S1 and S2 in Figures 13 and 14.

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. In addition to the above measurements, ORNL's Chemical and Analytical Sciences Division will collect gas samples from points S1 and S2 for on line analysis in their direct sampling ion trap mass spectrometer (DSITMS)

Safety Related Data (more in the Health and Safety Plan)

- Initial and continuing measurement of step and touch potentials at the site
- Total organic hydrocarbons at the gas vent pipe using an OVA.

- Measurement of total organic hydrocarbons in the general area of the demonstration site and the trailers

7. 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 PRDA No. DE-RA05-910R22000, Modification No. 002, Appendix to Attachment 3.
- 4 Personal Communications, dated 1-14-94. Mr. Frank VanRyn, Martin Marietta Energy Systems, Inc., Site Programs Organization.
- 5 Dev, Harsh and Bajzek, Tom. Hydrocarbon Removal by In Situ Heating of Soil by Electrical Energy, Presented at Environmental Restoration Technology Transfer Symposium, U. S. Air Force for Environmental Excellence, San Antonio, TX, January 26-27, 1993.
- 6 Dev, Harsh, Sresty, Guggilam, and Carpenter, Paul. In Situ Soil Decontamination by Radio Frequency Heating Presented at the 18th Environmental Symposium and Exhibition, American Defense Preparedness Association, Alexandria, VA, February 1992.

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