WHC-EP-0596
UC-630

Horizontal Drilling Workshop Summary Report for the Arid Integrated Demonstration Program

E. J. Jensen
S. P. Airhart
C. L. Edison
Bovay Northwest, Inc.

G. W. McLellan
Westinghouse Hanford Company

Date Published
October 1992

Prepared for the U.S. Department of Energy
Office of Environmental Restoration and
Waste Management

Westinghouse
Hanford Company
P.O. Box 1970
Richland, Washington 99352

Hanford Operations and Engineering Contractor for the
U.S. Department of Energy under Contract DE-AC06-87RL10930

This report has been reproduced from the best available copy. Available in paper copy and microfiche.

Available to the U.S. Department of Energy
and its contractors from
Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831
(615) 576-8401

Available to the public from the U.S. Department of Commerce
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
(703) 487-4650

Printed in the United States of America

DISCLM-1.CHP (1-91)

EXECUTIVE SUMMARY

The United States Department of Energy's (DOE) Horizontal Drilling Workshop was held at Cavanaughs Motor Inn, in Kennewick, Washington, on May 12-13, 1992. The workshop was sponsored by DOE's Arid Site Integrated Demonstration (Arid-ID) program which is administered by DOE-Richland, Pacific Northwest Laboratory (PNL), and Westinghouse Hanford Company (WHC). This workshop was one of the primary tasks for Fiscal Year 1992, of the Technical Task Plan (TTP) for Drilling Technology at Arid Sites (RL-4211103). The Arid-ID and the Drilling Technology TTP are administered through the Office of Technology Development (OTD) at the DOE-Headquarters in Washington, D.C.

The technical lead for the workshop was WHC's Environmental Field Services Group, which contracted Bovay Northwest Inc., to serve in the capacity of workshop coordinator, facilitator, and technical assistant.

The workshop was held in two sessions. The first session was open to the public and consisted of presentations from local experts on the Hanford Site and from four horizontal drilling contractors. The second was a closed door session designed to discuss the horizontal drilling needs at DOE sites. This report is organized into two parts to document both sessions of the workshop.

Part I of the document discusses information gathered from the first session of the workshop. This session, consisted of presentations on the workshop objectives, Hanford Site hydrogeology, past and current drilling practices, and mixed waste site drilling requirements. These presentations which were provided by local Hanford Site experts which were intended to provide the drilling contractors with a clear perspective of drilling conditions at Hanford and other similar arid DOE sites. These discussions were followed by presentations given by four private industry drilling contractors which were selected through a screening process described in Section 2.0. The drilling contractors represented at the workshop were Eastman Christensen Environmental Systems, Michels Pipeline Company, Cherrington Environmental, and Neyrfor-Weir Turbo Drilling (in conjunction with New Mexico Institute of

Technology). Individual presentations were given without the other three contractors in the audience to provide an atmosphere more conducive for discussing technical details of each contractor's method. At the conclusion of each presentation, a question and answer period was scheduled to allow interaction between the technical panel, the audience, and the contractor representative(s). An audio-visual recording of the proceedings was developed to assist in the preparation of this report and to provide an archived record of the workshop proceedings. These recordings will be retained internally by the DOE.

Part II of this report covers activities accomplished during the second session or "closed-door forum" which followed the two days of presentations. Participants at this session included the workshop expert panel (introduced in Section 1.1) and selected members from DOE-Richland, WHC, and PNL.

The primary objective of the closed-door forum was two-fold: 1) summarize the contractor information presented; and 2) to determine horizontal drilling needs to support characterization, monitoring, and remediation programs at DOE facilities. DOE sites not represented at the session were identified, contacted, and requested to provide horizontal drilling needs respective to their sites. Information gathered from the closed-door forum and the various site contacts was assembled into site description narratives and drilling needs matrices found in Sections 1.3 and 1.4, respectively. During the review process for this document, representatives from Savannah River, Sandia National Laboratory, and Hanford (forum attendees) involved other technical staff from their site to ensure that the information gathered represented a collective interpretation of horizontal drilling needs. Technical contacts at other DOE sites who were requested to provide the same information, were encouraged to obtain consensus information representative of their overall site needs.

Part II of this document will be separated (later in FY93) from Part I, as a stand-alone "living" document which delineates deep horizontal drilling requirements throughout the DOE complex. Annual updates will reflect changes in the Environmental Restoration (ER) program needs for each DOE site as cleanup programs progress. The end goals of this "horizontal drilling needs document" will be to achieve the

following across the DOE complex: 1) to facilitate communication among participants; 2) to promote cooperative testing activities; 3) to minimize overlapping of drilling technology efforts; and, 4) to maintain prudent use of resources for the rapid development of enhanced drilling technologies by the OTD program, and the timely transfer to the ER Program for utilization.

After reviewing the horizontal drilling methods presented at the workshop and other existing systems, it is evident that no system exists which will solely meet the complex conditions (e.g., mixed waste sites, poor drilling conditions) which occur at the Hanford Site and other arid sites in the DOE complex. As a result, the design, fabrication and testing of several supporting subsystems such as the drilling assembly, and the directional control system is necessary to develop a horizontal drilling system which is capable of meeting the program requirements. Whenever possible, existing subsystems which can be modified to fit the overall drilling system will be used to lower overall development costs.

ACKNOWLEDGMENTS

The authors wish to acknowledge Bob Bainer, Bob Galbraith, and Doug Kuhns for providing information on their respective DOE site as well as summarizing the horizontal drilling needs for that site.

In addition, the authors wish to thank Dr. George Cooper, Mr. Richard Davidson, Dr. James Dunn, Dr. Dawn Kaback, Dr. Paul Pettit, and Mr. Ben Volk for participating and assisting in the workshop, and Eastman Christensen, Michels Pipeline Construction, Neyrfor Weir Turbo Drilling, and Cherrington Environmental for providing representatives to speak at the workshop.

Finally, thanks to all the various technical personnel at each of the DOE facilities who assisted in reviewing the document.

CONTENTS

PART I HORIZONTAL DRILLING METHODS

Section

PART II HORIZONTAL DRILLING REQUIREMENTS

Section

TABLES

The following tables are located in Part II of this document

Table

PART I
HORIZONTAL DRILLING METHODS

1.0 OBJECTIVES OF THE WORKSHOP

The objective of the workshop was to obtain information about the latest deep horizontal drilling methods, that may be applicable at DOE facilities (specifically those having arid site geologic settings). Presentations included existing technologies and technologies that are currently under development. There was no attempt at the workshop or in the closed door session which followed to evaluate, rate, or select any specific drilling company who participated in the workshop.

1.1 TECHNICAL EXPERTS AND TECHNICAL ADVISORS

A technical expert panel was selected by Westinghouse Hanford Company to provide expertise and to enhance the quality and quantity of information gathered during the workshop. The panel was comprised of individuals with a broad range of expertise on drilling equipment, methods and applications. Each expert played a key role in asking questions and obtaining valuable information about each of the technologies presented. The experts also provided details on their experiences and areas of specialization which were relevant to the topic. Two of the experts were technical advisors with expertise in the installation of subsurface barriers using directional drilling equipment. Barrier installation will be a major segment of horizontal drilling at DOE programs for underground tank remediation. The experts and advisors who attended the workshop include the following:

- **Dr. George Cooper**, University of California Berkeley
  - Education - B.A., M.A., and Ph.D. Metallurgy and Materials Science University of Cambridge England
  - Expertise -Cutting and wear mechanisms of novel diamond drill bits, and design of high-angle and horizontal holes for both near-surface and deep oil recovery applications

- **Richard Davidson**, Woodward-Clyde Consultants
  - Education: Engineer Degree in Geotechnical Engineering 1977 Stanford University, M.S. Geotechnical Engineering 1976 Stanford University, B.S.E. Civil Engineering 1975 Duke University
  - Expertise: In situ testing/instrumentation, slurry walls foundation engineering, underground construction

- **Dr. James Dunn**, Sandia National Laboratories
  - Education: Ph.D Mechanical Engineering Rutgers University, M.S. Mechanical Engineering University of Minnesota
  - Expertise: Geothermal, geotechnical, environmental drilling

- **Dr. Dawn Kaback**, Westinghouse Savannah River
  - Education: Ph.D. Geological Sciences 1977 University of Colorado, M.S. Geological Sciences 1972 University of Colorado, B.S. Earth and Space Science 1970 State University of New York at Stony Brook
  - Expertise: Design of horizontal wells for environmental applications, Chairman of Technical Support Group for Drilling Technology

- **Greg W. McLellan,** Westinghouse Hanford Company, Environmental Field Services Group/Environmental Division
  - Education: B.S. Business Management, Central Washington State University
  - Expertise: Drilling technology development including enhancements to existing methods, and the design and demonstration of prototype drill rigs, and associated drilling equipment.

- **Dr. Paul Pettit**, Halliburton NUS
  - Education: Ph.D. Chemical Engineering 1971 McMaster University, B.E. Chemical Engineering 1966 Nova Scotia Technical College
  - Expertise: Cut-off walls and environmental barriers, petroleum and geotechnical drilling

- **Ben W. Volk,** Westinghouse Hanford Company, Environmental Field Services Group/Environmental Division
  - Education: B.S. Petroleum Engineering, Montana College of Mineral Science and Technology
  - Expertise: Environmental drilling and sampling, oil and gas well drilling, groundwater hydrology, reservoir engineering

2.0 DRILLING COMPANY PRESENTATIONS

This section presents the information provided by the four drilling companies at the workshop. The presenting companies were:

- **Eastman Christensen**
- **Michels Pipeline Construction**
- **Neyrfor Weir Turbo Drilling**
- **Cherrington Environmental.**

The contractor selection process involved an initial market search to identify all horizontal drilling firms in the U.S. This study, which identified 64 companies, was performed by the University of California, Berkeley through the Drilling Technologies Technical Support Group. From this list only companies with expertise in deep (e.g., >100 ft) horizontal applications were selected. This reduced the list to approximately 30 companies, of which, only those with environmental experience were chosen. Of the remaining 21, companies with short radius capabilities and those which could potentially operate their drilling system on air, were selected reducing the list to 11. Of the 11 remaining companies six expressed an interest in making a presentation at the workshop. Finally, only four companies were able to attend the conference.

The following sections discuss the drilling operation, tools, materials, and systems associated with each technology discussed at the workshop.

2.1 EASTMAN CHRISTENSEN

Eastman Christensen Environmental Systems discussed their advance casing drilling system. This system incorporates technology primarily developed for and is being used by the oil and gas industry which is comprised of a steerable downhole fluid driven motor. The casing is pulled by the motor as drilling progresses. The motor is oriented in predetermined direction from the surface with the drill pipe which are connected to the motor inside the casing.

2.1.1 THE DRILLING OPERATION

The horizontal well is started by augering a 16 in. diameter hole to a depth of 5 to 10 ft at an angle of 15° to 75° from horizontal depending on the target and borehole proximity. Then a 14 in. diameter steel conductor pipe is cemented in place to provide a conduit for the drilling fluid. Next a 12 1/4 in. diameter auger or rock bit is used to continue drilling the hole down to the top of the curved section. At this point, the curve is drilled to 12 1/4 in. diameter using a steerable motor system and cased at the same time with a 10 3/4-in. diameter high density polyethylene (HDPE) casing. Once the curve reaches horizontal, the inner assembly is withdrawn leaving the 10 3/4-in. HDPE casing in place. The curved casing is cemented in place from the bottom up to the surface through the drill pipe. Eastman Christensen Environmental Systems has the capability of drilling a minimum radius of curvature as small as 100 ft. The radius is dependant on the casing material being used to complete the well.

Eastman Christensen Environmental Systems offers three horizontal casing advance drilling methods.

Method I - This steerable advance casing drilling method uses a patented Enviro-Screen liner. The Enviro-Screen liner is comprised of small dual layered stainless steel filtering disks mounted in the wall of the high density polyethylene liner. To avoid clogging the Enviro-Screen with drilling cuttings, and also to optimized the borehole cleaning while drilling, the screen disks are made impermeable by a paste. The paste is formed by mixing 24% MgO, 15% $MgSO_4$, 30% $CaCO_3$, and 31% water, by weight. The paste hardens to form a flexible, impermeable barrier on the screen elements. The paste is dissolved in a solution of 5% acetic acid (CH_3CO_2H) after 20 to 30 minutes. The paste neutralizes the acetic acid, avoiding damage to the formation. Small amounts of Mg^{2+} may enter the pore fluid adjacent to the well, increasing the hardness of the groundwater. Proper well development will remove the groundwater affected by the magnesium.

Method II - This method begins by drilling a 6 in. diameter pilot hole, then back reaming it to 8 1/2 in. diameter. The hole is left uncased and the advanced casing drilling method is used to drill the slotted or Enviro-Screen completion liner in place.

Due to the reaming process, most of the borehole cuttings are removed to the surface by the mud system which makes it easier to drill the production liner in place.

Method III - This method utilizes an improved fluid system and the advanced casing drilling method without the impermeable paste on the Enviro-Screen liner. According to Eastman Christensen the horizontal length would be limited to 250 ft. or less due to the marginal hole cleaning capabilities and poor liner material strength. This method is also contingent on formation structure, because drilling a long horizontal section is more difficult in a loose soft sand formation than in a tight sand formation.

Gravel packing is accomplished using polyethylene beads. First the screen is washed by circulating water in the annulus between the borehole and the screen. Then the polyethylene beads are pumped into the annulus. One of the problems with this method is that the beads cannot be sized down small enough to satisfy the filter pack requirements of the industry for fine silt formations. Eastman Christensen stated that they never use sand in horizontal wells because it would be nearly impossible to get a perfect circumference gravel pack without using material that is less dense than water.

Eastman Christensen recommends using a prepacked screen. To install a prepacked screen they case the borehole using HDPE casing during drilling. Then the casing liner is perforated and the prepacked screen placed inside. Another advantage of this method is that the prepacked screen can be pulled at any time for cleaning and inspection.

2.1.2 DRILL RIG AND DOWNHOLE TOOLS

Eastman Christensen's slant drill rig can be operated in the vertical position and slanted down to 75 degrees from vertical in 15 degree increments. It utilizes twin hydraulic top drive units which permit the independent rotation of casing and drill pipe. Their automated pipe handling system includes an hydraulically operated arm and integral make-up and breakout wrenches. The whole system requires a crew of four and is transported by three self contained trailers which include grout pumps, tanks, drill string, etc. The following are the specifications of the drill rig:

Hydraulic Hoist

- Hoisting Capacity 70,000 lbs.
- Pull Down Capacity 30,000 lbs.

Rotary Top Drive System

- Speed 160 RPM
- Torque 10,000 ft-lb

Casing Top Drive System

- Speed 20 RPM
- Torque 1,000 ft-lb

Drill Pipe

- Drill Pipe diameter 2 7/8" X 3 1/2" (G105) diameter
- Drill Pipe Length 20 ft

Power System

- 503 HP diesel engine powers hydraulic pump to drive all rig hydraulic functions.

Service Crane Rating 3 tons

Generator Capacity 113 KW

The steerable downhole drilling equipment includes an expandable bit, hydraulic motor, casing centralizers, tool face indicator, drill pipe, and stabilizers. A coring tool is also available for sampling.

The expandable bit drills a larger hole than the outside diameter of the casing and collapses inward to allow the bit to be withdrawn from the hole leaving the casing in place. The blades on the bit are operated by a hydraulic piston inside the motor which is activated by the flow of drilling fluid. This motor is a positive displacement type common to the oil industry. The bit rotates independently of the drill pipe, so the drill

pipe does not rotate. Flow rates of 150 to 400 gpm generate as much as 40 hp. Two motors are used for each well bore, one for the curved section and a smaller motor for the horizontal section.

Eccentric stabilizers are placed at the end of the casing and on the motor housing. The stabilizers on the motor housing are aligned in different positions with the stabilizers on the casing by rotating the inner drill string and holding it in position. This allows the drill hole to be directed at an angle from the center line.

There are two sets of casing centralizers attached to the outside of the first 20 ft of casing. These centralizers help center the tool string and casing in the center of the borehole.

Eastman Christensen's coring system is capable of taking samples in soft to medium formations. After the drill string is removed from the borehole the coring tool is fired into the formation with a force which can be adjusted up to 25,000 lbs. With this method, the core is taken out past the end of the borehole producing a relatively undisturbed sample in a 2-in. diameter by 5-ft long disposable plastic liner. This coring system has been field tested once by firing it into a horizontal section consisting of clay material.

2.1.3 CASING AND SCREEN MATERIAL

The preferred material is HDPE, however carbon steel or stainless steel can be used for casing, screen, or perforated sections. Stainless steel can be used if the radius of curvature is at least 150 ft. Anything less than 150 ft would permanently deform the material. PVC is not recommended because of its brittle properties. Following are the casing and screen dimensions used to produce the curve and horizontal sections.

- Curve Casing OD — 10 3/4 in. diameter
- Horizontal Casing or Screen OD — 7 1/8 in. diameter
- Pipe and Casing Length — 20 ft

2.1.4 DIRECTIONAL CONTROL DEVICES

The standard tool used for this system is the tool face indicator which is located 12 ft behind the drill bit. This tool has a nonmagnetic response for inclination (elevation), but is magnetic for azimuth, so errors may occur near pipes, tanks, etc. Single shot surveys are taken along the way and multi-shot surveys are taken at the end of the curve and horizontal sections to further confirm the data. Eastman Christensen stated that their accuracy is ± 2 ft inclination (vertically). They further explained that this enables the driller to keep the hole within a 9 ft cylinder or better.

If accuracy is critical, Eastman Christensen will use tools other than the standard tool face indicator. If drilling at 100 ft or less below ground surface they will use a steering tool by setting up a surface grid. The gyro could also be used, but it would be more costly.

The most accurate method of placing a series of parallel wells is with the use of a magnetic source. The first well is drilled and surveyed so its exact location is known. Then a magnetic source is placed in this well and followed while drilling the next. This procedure is followed for each succeeding well until all the wells have been drilled.

2.1.5 FLUID CIRCULATING SYSTEM

A closed loop fluid system is used which does not require mud pits or other excavations. When the fluid comes out of the hole it goes through a desander and is then filtered into a tank. From the tank the fluid is recirculated through the borehole. This system incorporates a linear motion shaker. When drilling is complete, the cuttings and remaining fluid can be pumped into barrels or other tanks for disposal. The following are the specifications of the system:

Drilling Fluid System

• Tank Capacity	75 bbl
• Triplex Pump Power	325 hp
• Maximum Flow	450 gpm at 15,000 psi
• Grouting Unit Capacity	25 gpm

Water-based muds that include bentonite and some polymers are used for the circulation medium. Saturated brines may be used in unconsolidated sands to keep the hole from collapsing. Eastman Christensen has started using a thick biodegradable fluid developed by Dow Chemical Corporation. The typical viscosity of the Dow mud is 35 to 40 s/qt Marsh funnel velocity (mfv). This mud reduces the fluid migration into the formation. It also turns to a pudding consistency when pumping is discontinued.

Any circulating media must range between 3 to 5 ft/s to be effective. This can be achieved at 180 to 200 gpm in a 6-in. diameter hole. Anything less than 3 to 5 ft/s and the hole will not be cleaned, dunes will form and eventually the tools will become stuck.

Large amounts of fluid loss were experienced while drilling the curved section of the vadose zone at Savannah River. The same problem occurred while drilling vertical wells in the saturated zone in this area. Large amounts of fluid loss has also been observed while drilling in the vadose zone at Hanford.

2.1.6 SUMMARY

Eastman Christensen stated this system would not be practical for drilling in the unconsolidated gravel and boulder formation at Hanford. Rather, they recommended developing an alternative system which they have done some research on. The alternate system would include the development of a steerable air index hammer. The hammer would turn the bit 1/4 turn every time it made a percussion. The drill string would not turn and steel casing would be used. An expandable bit would be used so the drill hole would be larger than the outside diameter of the casing and still be able to withdraw the bit through the casing.

A positive displacement air system or standard mud system could be used for the horizontal section. The radius of curvature would be extended to 150 to 200 ft to accommodate the steel casing according to the Eastman Environmental systems.

2.2 MICHELS PIPELINE CONSTRUCTION

Michels presented two different technologies which they have been using for pipeline construction and environmental work. These technologies are the river crossing and micro tunneling systems.

2.2.1 RIVER CROSSING SYSTEM

The main characteristics of the river crossing system are 1) the drill pipe is rotated during drilling, 2) mud is used, and 3) an exit hole is usually produced.

A. **The Drilling Operation** - A comprehensive land survey is the first step for most holes drilled using the river crossing method. The survey includes a detailed profile and plan drawing which contain accurate horizontal distances. Survey hubs are then placed at appropriate entrance and exit points. These points were used to derive the directional calculations for azimuth and inclinations.

Once the azimuth has been established on the proposed alignment, the drill rig is then set up on the same alignment using a transit. The next step is to begin drilling the pilot hole at the entrance point hub. Drilling is accomplished by pumping bentonite down at a maximum of 3,000 psi through the drill stem to the drill head. At the drill head the bit jets the formation while the bentonite erodes the material and carries it to the surface. The hole is advanced through the first radius of curvature, then the horizontal section is drilled followed by another curve back to the surface.

As the drill string begins ascending towards the surface a hole is dug at the designated point of exit. Once the steering tool exits the hole it is removed leaving the drill string in place. Depending on the use of the bore the steering tool is then

replaced with a reaming device which may be rotatively pulled back through the pilot hole to the entry hole to create a larger hole. The reamer can then be pushed back through the hole to the exit side. Depending on the diameter of the final product, incrementally larger reaming devices are used. The size of the hole is dependent on the desired size of the casing and screen.

When reaming is completed the reaming device is removed at the exit side and a coupler is attached to the specified casing and screen. The pipe is then pulled back to create the well. Gravel packing was not mentioned during the workshop, however that does not necessarily mean it is not done.

B. Drill Rig and Downhole Tools - The drilling rig is manufactured by Michels Pipeline Company. It is a trailer mounted slant rig with the following specifications.

Torque	30,000 ft. lbs
Thrust	225,000 lbs.

Power System

- 400 HP diesel engine powers hydraulic pump to drive all rig hydraulic functions.

Drill Pipe

• Drill Pipe diameter	5 in. diameter
• Drill Pipe Length	30 ft

Service Crane Rating	35 tons
Generator Capacity	160 KW

The downhole tools consist of the steering tool, reamer, and drill pipe. The maximum diameter of reamer is 36 in. The pilot hole is drilled by rotating the drill pipe and jetting with mud. With this system there are no downhole motors.

C. **Casing and Screen Material** - Any casing and screen material could be used that can be pulled through the hole without breaking. Carbon steel, stainless steel, HDPE, or fiberglass are examples of material that would work. The screen is simply attached to the casing and pulled into place.

D. **Directional Measurement Devices** - A steering tool located at the drill head is used to guide the direction of the borehole. The steering tool is a sensoring unit that consists of magnetic and gravitational sensors. There are six sensors positioned inside of the probe reading each of the X, Y, and Z coordinates. Three sensors are magnetometers reading the azimuth. The other three are accelerometers which read the various angles, the sum of which equals the force gravity. Borehole surveys are taken every 30 ft. Various tools are used for degree or depth changes that may be required.

E. **Fluid Circulating System** - The entry side bore pit is excavated to a dimension of 6 ft W x 6 ft L x 4 ft deep and lined with an impermeable vinyl membrane. Bentonite returns come back to the lined sump hole where they are then pumped to the mud recovery system. The mud recovery system is comprised of a mud tank and shaker with screens, which will recycle drilling fluids (Bentonite) pumped from the receiving pit by way of sump and hose. The bentonite cutting returns are then displaced through the screen and shaker where the non-reusable solids are sifted out and separated from the useable Bentonite returns. The solids are containerized for disposal and the recycled bentonite is pumped back into the mud tanks on the drilling system for reuse. A viscosity of 35 to 37 s/qt mfv is maintained.

The drilling rig and mud recovery equipment are positioned over a heavy duty rubber containment vessel with inflatable sides. If spillage should occur it is contained by this special rubber matting and pumped back into the mud recovery system.

On the exit side a receiving pit, also lined with an impermeable vinyl membrane, is excavated to similar dimensions as stated for the entry side pit. As bentonite returns collect, a second mud recovery system is set up and maintained. As the bentonite attains the appropriate viscosity it will be pumped back through the drill stem and be reused.

The following are the specifications for the fluid circulating system:

■ Maximum Drilling Fluid Pressure	3000 psi
■ Normal Operating Pressure	1500 psi
■ Maximum Flow Rate	450 gpm
■ Normal Drilling Flow	330 gpm
■ Normal Backream Flow	450 gpm
■ Bentonite Mixing Tank	5,000 gal

F. **Summary** - Michels Pipeline Construction has drilled a large number of holes using the river crossing method for pipeline construction projects. They have also drilled a few holes for environmental applications.

According to the vendor, the river crossing method may be effective in cobbles and boulders. It would not be that difficult to drill the pilot hole through the cobbles, but it is very difficult to ream the hole or pull casing back depending on the length, depth, and diameter of the hole.

Michels has drilled wells at Tinker and Williams Air Force Bases for environmental applications. Revert polymer was used for these holes instead of bentonite and the holes were drilled without an exit hole. The problem with drilling and not using an exit hole is that there are times when the hole is left

uncased. This is not a problem in solid rock, clay, or other semi-cemented formations, but it may be a big problem in unconsolidated sediments. An exit hole would be a necessity in the unconsolidated gravels, according to the vendor.

2.2.2 MICRO TUNNELING SYSTEM

The main characteristic of the micro tunneling system is the use of a large vertical shaft from which a smaller horizontal hole is drilled. This system uses a laser guided directional measurement device and a rock crushing bit that make the boreholes extremely accurate.

A. **The Drilling Operation** - The first step in the micro tunneling process is to excavate a shaft down to the depth where the horizontal section is to begin. The standard shaft is 17 ft wide, although the shaft can be built to whatever width is needed. Michels provided an example of a 38 ft wide shaft they had built. Shaft construction material can included any of the following depending on depth and other conditions.

- Ribbon Lagging
- Steel Ribs
- Wood Lagging
- Liner Plate
- Steel Sheet (limited to 70 ft or less).

After the shaft is completed a drilling machine called a mole is lowered into the shaft. Drilling machines are available to drill holes with a minimum of 16 in. and a maximum of 36 in. in diameter.

As the drilling machine drills the hole the cuttings are removed by either an auger or a fluid system. The casing is jacked into place behind the drilling machine. A T-bar hydraulic jack system is used to give a greater advantage with the hydraulics. The rams are capable of 300 ton of thrust. Using intermediate jacking stations can increase the length of the horizontal bore to 1,000 to 1,500 ft

depending on the soil conditions. Without the intermediate jacking stations lengths of 500 to 600 ft can be attained.

A laser system is used in the head of the drilling machine for directional guidance. There is also a monitor in the drilling machine for detecting methane, combustible gases and depleted oxygen. These parameters are monitored 24 hrs a day both in the drilling machine and in the shaft. There is room in the drilling machine for additional instrumentation such as a scintillation probe for measuring gamma radiation.

When the hole is complete an exit hole is required to retrieve the drilling machine. There was no any mention of installing screen or gravel packing material.

B. **Drill Rig and Downhole Tools** - No drill rig is required for micro tunneling. However, a crane and earthmoving equipment are necessary.

The downhole tools consist of the casing and the drilling machine. The head of the drilling machine has rock crushing capabilities that can take in cobbles and boulders up to 30% of the diameter of the machine. After the material is taken in and ground up, it is transported by either an auger or slurry system. The slurry removal has a greater range than the auger. The auger system available today drives the head with the auger flights, so the longer the length the more torque is required to turn the head. A German company is developing a hydraulic head which will solve this problem, but it will not be available for at least another year. The present auger system will reach a maximum of 300 to 350 ft.

The head of the drilling machine is driven by both electrical motor and hydraulic pump. An electric motor drives a hydraulic pump in the head which is gear mounted. A bull gear is located around the internal periphery of the machine.

Also located in the head of the drilling machine is a TV camera and laser. Behind the drilling machine is the casing which contains the following:

- Discharge line
- Intake line
- Bentonite slurry line
- Electrical wire
- Hydraulic line
- Methane monitor line
- TV cable.

The discharge and intake lines circulate water to the face where the cuttings are picked up in a slurry and carried out of the hole. The bentonite line supplies bentonite to the face for lubricating the rock crushing and helping the casing slide in as it is being jacked form the shaft. Each time a new piece of casing is added, the lines are disconnected and reconnected.

C. **Casing and Screen Material** - The recommended casing material includes reinforced concrete, steel, and fiberglass. The fiberglass is a new material that has the compressive strengths necessary for jacking. During the workshop there was no mention of screen material or methods of screening the hole. However this does not necessarily mean it is not done.

D. **Directional Measurement Devices** - The guidance system utilizes a laser which projects a beam onto a target on the drill head. A TV camera views the target and transmits the image to the operators counsel at the surface. The operator is able to keep the borehole at the desired depth and direction by keeping the laser on target. The drill head is articulated so the operator can steer it to make corrections. This is a very accurate system with tolerances of 1 to 1/2 in. on both line and grade.

E. **Fluid Circulating System** - The circulating system is a closed loop system with tanks for slurry. Material is brought into the face of the machine and mixed with water. The water is then used to transmit the cuttings to the surface. At the surface a cyclone is used to separate the solids from the liquid. The solids are taken out and deposited in a separate container and the liquid is reused.

F. **Summary** - According to the vendor, the two most important attributes of micro tunneling are its ability to go through unconsolidated sediments and its accuracy. The rock crushing ability of the drilling machine enables it to penetrate through cobbles and boulders up to 30% of the diameter of the machine. The laser guided system makes this an extremely accurate technology that is unaffected by magnetic interference. This is essential when drilling in high risk contaminated areas and/or locations where pipelines, utilities, or other subsurface structures exist.

The minimum diameter of the hole is 16 in. which could be a problem in highly contaminated soil, where disposal of large volumes of waste is not practical. Another factor is that personnel are required to work in the shaft and the environment inside the shaft may be too hazardous. However, this could be overcome with the use of robotics or placing the shaft far enough back in clean soil.

2.3 NEYRFOR WEIR TURBO DRILLING

Neyrfor Weir Turbo Drilling discussed the Air Turbine Directional Drilling System which is in the initial stages of downhole tool development at New Mexico Institute of Mining and Technology located in Socorro, New Mexico. This system utilizes air or gas to power a downhole motor and clean out the cuttings in the horizontal section. Although the concept has been field tested, further system refinements are necessary to meet Hanford and other Arid-site requirements.

2.3.1 THE DRILLING OPERATION

An auger is used to drill the first section down to the beginning of the curve if the soil will permit. At this point a steel casing is set and cemented in place. The curve section is drilled on a 50 ft radius, either open hole or cased.

The curve is drilled using short radius curved drill guide technology. The curved drill guide is a pre-curved drill pipe that is heat-treated to a 50 ft arc. This pre-curved section of pipe is fitted inside the hole with an articulated shaft that transfers torque from the top end to the lower end of the pipe. This entire assembly is called the curved drill guide. When this curved section is placed in the hole, it pushes against the side of the borehole so that the bit works its way out of the hole and cuts a 50 ft arc. Essentially the pipe relaxes itself back into its original shape. This action is very predictable and robust, states Neyrfor Weir. If the hole starts at 45 degrees, roughly 40 ft later it will produce a 90 degree angle at the bottom with a 50 ft radius. The curved drill guide is 20 ft long so standard drill pipe only needs to go around a 20 ft long curve. Most drill pipe will withstand that radius of curvature without any undue stress.

Drill pipe with a mule shoe is used to orient the curve in the desired direction. A reference is taken on the mule shoe prior to going into the hole. A J-clutch system is used to rotate the outer shell by pulling up on the drill string, thus orienting the mule shoe in whatever direction is needed. The inner drill pipe is then rotated at the top through a clutch system to turn the drill bit. The outer pipe is held stationary while riding on a bearing package.

If the depth is shallow (20 to 30 ft) before making the turn, then manual methods can be used by marking the pipe as it goes in the hole and making sure it stays correct. These manual techniques for keeping the outer shell aligned are easy to understand and use.

The horizontal section is drilled at the end of the curve while pulling the casing into the hole using a downhole motor. Either a pneumatic vane or a pneumatic turbine type motor would be used in this section. The motor and drill string would be removable so coring could be performed at any time.

Pre-slotted casing or screen would not be used, instead the casing would be slotted after it was put in place. There are many good tools available for slotting both steel and plastic casing.

The reasons for not using pre-slotted casing or screen include potential separation and poor drilling dynamics. Return air flow would occur in the annular space between the drill pipe and casing and would contain the cuttings and formation water. If reverse circulation were utilized, return air would be through the drill pipe. The reverse circulation situation would be better for cleaning the borehole.

2.3.2 DRILL RIG AND DOWNHOLE TOOLS

The system is being developed to operate from most standard geotechnical layover rigs. This system takes advantage of existing drilling equipment and should reduce the overall cost of drilling.

The two types of downhole air motors being considered for use with this system are the pneumatic vane and pneumatic turbine motors. The vane motor presently being manufactured in Houston is 24-in. long by 4-in. in diameter and operates at 10 hp. This motor is available commercially.

To drill horizontally, the system requires three to four times as much air as it does to drill vertically. The vane motor is a positive displacement type, so the volume of air that can be run through it is dependant on the length of the motor. If more air is needed, more chambers are added which increases the length. This increased length makes it difficult to get the motor through short radius curves. To overcome the problem, the hole can be drilled in stages. The hole is advanced 2 to 3 ft then backed off so a bypass can be run to clean out the hole. This procedure is repeated throughout the horizontal section.

Vane motors are at a disadvantage because the sliding vane that works on an eccentric shaft requires lubrication. The lubricant can be vegetable oil or some other substance that would not have the potential to affect analytical samples. The turbine motor does not require any lubrication and can be run totally dry.

The downhole pneumatic turbine motor was developed in the late 1980's. A prototype was tested at Farmington, New Mexico in a non-geothermal environment and then in a geothermal environment at the Geysers Area in Northern California. Nearly any volume of air can be run through this motor, so it can be constructed in a short overall length. Reverse circulation techniques are being considered, because they would allow the advantage of reducing the total volume of air needed. This would also create less air to be filtered.

The torque produced by the motor causes the drill pipe to flip over when the motor is turned on. A tremendous amount of flip over would occur when hitting cobbles, followed by very little flip over activity in the matrix material. This causes the bit to flip back and forth making directional control difficult. The use of a counter rotating bit could be used to alleviate this problem. The inner part of the bit would be rotated one direction and the outer part rotated the other direction. This would produce canceling torques back to the drill string, which would make directional control much easier. However, there are some drawbacks with this idea. Since a counter rotating bit has yet to be built a significant expense will occur to develop the bit and design a means to lubricate it. The biggest problem might occur in unconsolidated cobbles where the counter rotating part would have the potential at times to produce more torque and unscrewed the drill string. According to the Neyrfor, this could be alleviated by referencing the counter-rotating gear system to the welded casing.

The specifications for the present pneumatic turbine motor include the following. It is a single-stage turbine device, with a 4-stage gear box having a 168:1 gear reduction. The turbine device section is 7 1/2-in. in diameter, 8-in. long, and produces 60 hp. However, only 13 hp was used when drilling in the Geysers Area. The motor uses a side entry turbine rotary wheel and stader in an aerodynamic chambered system which orients the air as it comes into the turbine from the side. It essentially orients the air around the

periphery of the turbine, then dumps the air down into the chamber and past the gear box. The pneumatic turbine motor runs at about 13,000 rpm and the pneumatic vane motors run at about 4,000 rpm. This is why the pneumatic vane motor uses a small grease packed gear box with a 20:1 gear reduction.

The pneumatic turbine motor tested at the Geysers area was heavily built to withstand the geothermal environment. The motor was 9-in. in diameter, 16-ft long, used 2,400 to 3,600 cfm of air, and drilled a 10 5/8-in. diameter hole to depths up to 9,000 ft. A much smaller pneumatic turbine or vane motor would be use for shallow horizontal environmental applications. The dimensions of these motors would be 5 in. in diameter and 4 ft long.

The drill bit developed for this system would be a two piece system. The outer piece would run on the casing. The inner piece would be splined into place so it could easily be removed with the motor to allow coring at any location.

2.3.3 CASING AND SCREEN MATERIAL

Casing material would include stainless steel, teflon, various plastics, or schedule 40 welded mild steel. Neyrfor Weir suggested that the mild steel casing would work best in unconsolidated gravels. Screen material would include any of these casing materials mechanically perforated in place. It would not be possible to use pre-perforated casing or screen with this drilling system.

2.3.4 DIRECTIONAL MEASUREMENT DEVICES

Drilling control would use proven technologies used in mud drilling which should work well for air drilling. The standard tools used would be the single- or multi-shot tools where accuracy is not critical. A Steering Tool would be used in high risk areas. The tool would be located 4 to 6 ft behind the bit. The orientation of the bit would be changed based on the data from the directional measurement devices using a bent sub and rotating the pipe a few degrees. Both the pneumatic turbine and vane motors operate at low torque and high speed which makes it easier to maintain directional control.

2.3.5 FLUID CIRCULATING SYSTEM

The circulation system would be a closed loop system using negative pressure on the return side. A slight vacuum would be created either by returning the circulation system back to the compressor suction or to an axillary fan or compressor. In the event that a hole was accidently punched in the return side, the hose would not spray the cuttings out; instead it would simply suck more air into the system. The vacuum would also increase the velocity of the air coming out of the drill hole which would increase the efficiency of cleaning out the cuttings. Another advantage is that it would be unlikely that air flow would occur into the formation, because the pressure in the bottom of the borehole would be near one atmosphere.

All of the components for the circulation system are off-the-shelf items so there would be no need for development. The system combines a complete cuttings recovery cyclone separator with a reverse jet bag filtration system. The filter will take out 98% of 50 micron particles. The filter is not very efficient for small particles around 1 micron. However 99% of the cuttings from air and gas drilling are larger than the 50 micron size. The reverse jet bag filter consists of multiple socks with air jets at the top which emits an occasional puff of air that knocks the dirt off and into a hopper. A High Efficiency Particulate Air filter (HEPA) can be used down stream of the jet bag for a final clean up before the air enters the atmosphere.

2.3.6 SUMMARY

According to the vendor, air drilling would be a good system for waste minimization and control of contamination. No liquid would be introduced to the formation to transport toxic materials. Also a large amount of mud would not be produced for later disposal.

The vendor states that this is a simple system based on existing technologies. It should be easy to teach most rig operators how to use it in a couple of days. Further, the design of the downhole equipment would make it easy to guide the hole in the right direction. These design features also appear to be capable of overcoming some of the problems encountered when drilling in unconsolidated gravels.

2.4 CHERRINGTON ENVIRONMENTAL

Cherrington Environmental discussed an adaptation to the River Crossing System. The main features of this system are 1) the drill pipe is rotated only during over reaming, 2) mud is used, and 3) a jet or positive displacement motor is used. However, Cherrington has developed a process of gravel packing, and setting screen and casing without using an exit hole.

2.4.1 THE DRILLING OPERATION

The operation begins by drilling a 3 1/4 to 3 1/2 in. diameter pilot hole with a 2 3/16 to 2 7/8 in. diameter drill string. The curve and horizontal sections are drilled with the same drill string and the hole is left uncased. The curve section is generally drilled on a 200 to 240 ft radius. The hole is terminated in the ground so no exit hole is produced for environmental work. Either jetting or a rotary bit are used with mud to drill the hole and clean out the cuttings. A biodegradable drilling mud is used to reduce mud caking on the borehole walls.

After the pilot hole has been drilled, a second larger diameter drill pipe is used to ream out a larger diameter borehole and instal a casing behind it. The casing is called a washover pipe. The pilot string is left in the hole while the larger drill string and casing work over the top of it. This process stops fracturing and lost circulation, and prevents the pilot string, and the jet or bit from sticking. A tungsten carbide tipped overreamer would be used to break up the rocks much like a Barber vertical rig does. The hole can be opened to just about any size, but the common environmental borehole is 9- to 12-in. in diameter.

After the reaming has been completed, the hole is cleaned out from top to bottom using a vacuum to remove as much mud and cuttings as possible. Next the drill string used to drill the pilot hole is removed and the permanent casing and screen is placed inside the washover pipe to total depth. Through a patent pending filter packing process, the washover pipe is withdrawn as the sand filter pack is placed in the annulus with a tremmie pipe leaving a snugly packed filter around the screen. This is a dry process

which requires no liquid introduction. As the washover pipe moves up the hole past the screen section, the annulus is filled with a bentonite slurry and then cemented at the surface according to the regulations of the particular state or country.

The drillhead is guided by a downhole steering tool which is hardwired to a computer at the surface. A bent sub near the drill head allows the operator to make adjustments from this data in combination with surveys taken from a directional surface system (TruTracker™). This tool is simply a verification tool to make sure the steering tool is not being influenced by magnetic interferences.

2.4.2 DRILL RIG AND DOWNHOLE TOOLS

Cherrington designs and manufactures their own drill rigs in two different sizes The smaller rig has 50,000 pounds of pull and the larger rig has over 500,000 pounds. They are currently constructing two intermediate size rigs which should be ready for use in the near future. The rigs are equipped with rubber tracks to prevent breaking up concrete and paved areas and low decibel engines for hearing protection and sensitive public areas.

The downhole tools consists of either a hydraulic spud jet or a conventional drilling bit driven by a downhole positive displacement motor. The use of a bit or jetting is dependant on the type of soil. Cherrington is investigating air motors, but it is more likely that they will attempt to use air in a mud motor sometime in the future. A bent sub, steering tool, various size reamers, and drill pipe are also used. Coring can be performed for characterization needs.

2.4.3 CASING AND SCREEN MATERIAL

Cherrington can use PVC, HDPE, or steel casing and screen. They are currently studying a composite material for screens that would combine the handling qualities of PVC with the flexibility of HDPE and the strength of steel.

Pre-slotted casing or wire wrap screens can be used during the completion process. The screen is centered in the borehole with the filter sand packed around it. A pre-packed

screen can be used. This would be an added expense if stainless steel is used. However pre-packed PVC screens are now available and would not be more expensive than the filter packing process. Cherrington believes their filter packing process which provides 2 to 4 in. of sand is better than the 1/2 in. provided by pre-packed screens. Also the larger borehole diameter with more surface areas exposed to the formation would give better production results.

2.4.4 DIRECTIONAL MEASUREMENT DEVICES

Cherrington uses a variety of guidance systems for determining the location and direction of travel of the drill bit. The following is a description of three of these systems.

A. **Sharewell Magnetic Guidance System (M.G.S)** - This magnetic guidance system is designed to be used for a wide range of applications from normal oil and gas drilling to drainhole and pipeline river crossing drilling.

The system permits guidance of the bit while directional drilling with either a downhole motor or jetting operation. Data is transmitted to the surface via a single conductor wireline. Useful features include the ability to monitor the magnetic moments, perform probe operational diagnostics, and verify probe calibration during drilling.

The operator has the option to use either the magnetic tool face or gravity tool face during drilling. The hole direction and inclination are updated and displayed on a continuous basis. The surface processing unit also displays voltage and temperature. A printed record of the data is available at selected intervals by the operator. The M.G.S. downhole probe incorporates the latest technology in accelerometers, magnetometers, calibration, and modeling techniques to provide a rugged and reliable tool.

The tool consists of three axis accelerometers and three axis magnetometers. They have all angle capability. The probe is 47.25-in. long and 1.38-in. in diameter and the protective housing is 6 ft long and 1.75 in. in diameter. The maximum

operating temperature is 125°C with a repeatability of 0.2 degrees at horizontal and 0.5 degrees at 4 degrees or less.

B. **TruTracker™** - The Sharewell TruTracker™ System will provide accurate non-magnetically influenced bit location data during drilling operations. The TruTracker™ is a series of nonintrusive magnetic coils which are placed in such a way as to triangulate the head of the drill string.

The location of the drill bit is independent of the driller's survey calculations. Information provided is not affected by the drillstring or outside magnetic interference. The TruTracker™ is a surface monitoring and signal-induced system which communicates with the downhole M.G.S. probe to determine its position.

TruTracker™ is accurate to ± 2% of the vertical depth at sensing position when operated according to the manufactures instructions. It can be operated at depths in excess of 100 feet.

C. **Combination High Accuracy Magnetic Probe (CHAMP)** - Sharewell offers an all angle, solid state electronic magnetic surveying instrument with Data Verification ability known as CHAMP. The CHAMP's design uses the latest technology in accelerometers, magnetometers, calibration, and modeling in combination with new software programs.

The tool will produce an accurate survey of uncased boreholes. The following are some of the capabilities of the CHAMP probe:

- Single-shot survey instrument
- Continuous survey instrument for surveying on the trip-out
- Continuous core orienting without the need to stop to obtain survey data.

The probe and power pack are contained within a 1.75 in. O.D. x 8 ft protective housing and weighs 8 pounds. The probe has the following accuracies:

■ Inclination	± 0.1° All Angles
■ Azimuth	± 0.1° at > 3°
■ Tool Face	± 0.1° at > 3°

The probe has a survey accuracy of 1.4 ft per 1,000 ft and it resolves inclination, azimuth and tool face to the nearest 0.01 degree.

2.4.5 FLUID CIRCULATING SYSTEM

Drilling fluid is circulated through a closed loop system utilizing a steel return tank. This eliminates drilling fluid contact with the ground surface. The system is capable of 100 to 300 psi at 150 to 200 gpm.

Cherrington's standard drilling fluid consists of a natural biodegradable polymer additive called "Revert". If the use of a naturally biodegradable drilling fluid additive is not acceptable for some reason, there are a number of alternatives including other polymers which can be degraded with citric acid washes to leave an uncaked hole. A bentonite type material would only be used in unusual circumstances or while drilling the pilot hole prior to reaming the borehole.

Revert has the following advantages over conventional bentonite slurries.

- Formation damage is minimized, because Revert's viscosity can be reduced to nearly that of water for efficient removal during well development.

- Revert's lower gel strength allows cuttings to settle out in the return tank at a faster rate.

- Penetration rates are increased. The lower density Revert reduces fluid friction in the circulating system. This makes available increased energy in the drilling fluid at the drill bit where it is needed.

- Less Revert is needed to do the job. Revert has 8 to 10 times the viscosity-building capacity of bentonite. This means that a Revert fluid has only one eighth to one tenth the amount of solids as conventional muds of the same viscosity thus resulting in a lighter weight drilling fluid.

Revert is as easy to mix as any conventional drilling fluid. A jet-type mixer is typically used for on-site preparation of the fluid. As with bentonite materials, Revert cannot be dumped unmixed into the mud tank or fed too fast into the mixer or it will tend to "gumball" in lumps because of incomplete hydration. A typical feeding rate of 250 lb/hr with a standard jet-type mixer should produce complete wetting of all Revert particles. The viscosity produced by a given amount of Revert in water can be affected by several conditions such as the temperature, Ph and salinity of the mix water. The higher the temperature of the water, the more Revert is needed to achieve a given viscosity. Similarly, the higher the water's Ph (more alkaline) the longer the hydration time and the lower the viscosity will be from a given amount of Revert. Mixing with saline water rather than fresh water will also result in a lower viscosity Revert fluid.

Note: It should be noted that at the present time the Washington State Department of Ecology is opposed to the use of revert, because of the potential bacterial complications which can develop during the degradation of the revert.

2.4.6 SUMMARY

This company has drilled numerous horizontal wells for environmental applications which include pump and treat, and vapor extraction wells at service stations, bulk plants, and commercial property developments.

The river crossing method was originally designed to exit the ground for pulling back pipe, conduit, screens, etc. However, the technology has been developed so an exit hole is not required and has never been used by Cherrington for environmental work.

Screens and gravel packs are standard practice in most formations. According to Cherrington, drilling in unconsolidated gravels can be accomplished using a rock crushing reaming device, however it may be a little slower than in other formations.

PART II
HORIZONTAL DRILLING REQUIREMENTS

1.0 TECHNICAL FORUM

Following the completion of the first session of the horizontal drilling workshop, a technical forum was held to discuss the information provided from the drilling companies. In attendance at the forum were the expert panel, selected technical and management representatives from DOE-Richland, various subcontractor representatives, and technical experts from the Hanford Site, Savannah River, and Sandia National Laboratory.

The purpose of the technical forum was to summarize the information provided by the drilling companies to assess potential horizontal drilling technologies for meeting the characterization, monitoring, and remediation requirements at the various DOE locations. The technical forum did not rate, evaluate, critique, or select the horizontal drilling companies or their capabilities; rather, the technologies were discussed in a generic applications format.

The following was conducted in order to meet the objectives of the technical forum:

- Potential applications of horizontal drilling at the various DOE Arid Sites were defined.
- Subsystems which comprise the horizontal drilling system were defined.
- DOE site specific conditions and remediation, monitoring, and characterization needs were defined.
- A matrix for each DOE site which specifies the subsystem equipment recommended for each defined application was constructed.

- Information on geologic conditions, predicted contaminants, and contaminant concentrations for each DOE site was compiled. This information was compiled into narratives which were used to supplement the matrices constructed for each DOE site.

The following subsections summarize the information associated with each part of the technical forum. The site specific information for the Hanford Site was discussed in detail at the workshop. The information for the other DOE sites was obtained from technical representatives from each site.

1.1 POTENTIAL APPLICATIONS OF HORIZONTAL DRILLING AT DOE SITES

The first part of the forum was to identify the potential applications for horizontal drilling at the various DOE sites.

The equipment requirements of a horizontal drilling system differ significantly depending on the specific application. In order to identify the optimum horizontal drilling configuration which might be used, it was first necessary to identify the potential applications related to characterization, remediation, and monitoring at DOE sites. Potential horizontal drilling applications included:

- In situ bioremediation
- Vapor extraction
- Leak detection monitoring of treatment storage and disposal (TSD) facilities
- Barrier emplacement
- Characterization
- Pump and inject hydrologic control systems.

Each of these applications are described below.

1.1.1 IN SITU BIOREMEDIATION

In situ bioremediation refers to a process of biologically degrading contaminants in place. This process is accomplished by two methods: 1) stimulating indigenous microorganisms using nutrients and or oxygen, and 2) placing synthesized or grown microbes into the contaminated media to accelerate and improve the degradation process.

Currently, Battelle Pacific Northwest Laboratory and Westinghouse Hanford Company are designing a large-scale in situ bioremediation system for degrading a carbon tetrachloride plume beneath the Hanford Site. Initial studies associated with this project have identified the use of horizontal wells for the placement of nutrients into the subsurface. The geometry of the horizontal well will provide a much larger area of influence for a single well application.

1.1.2 VAPOR EXTRACTION

Vapor extraction is a process of concurrently removing volatile organic contaminants (VOC) from soils and groundwater. The Savannah River site has demonstrated a large-scale vapor extraction system for removing elevated concentrations of trichloroethylene and tetrachloroethylene from the groundwater and unsaturated sediments (Kaback, et al. 1991). Two parallel horizontal wells were positioned in a vertical plane. One well was used for air injection while the other one was used as a vacuum or vapor extraction well. Horizontal wells were used primarily because their geometry maximized efficiency of the remediation system. Based on the success of this innovative large-scale remediation effort, it is thought that a similar system would be useful for cleaning up VOCs such as carbon tetrachloride at Hanford and various contaminants at other DOE sites.

1.1.3 LEAK DETECTION MONITORING

TSD facilities reaching or exceeding their design life or placed in a corrosive environment are highly suspect of potentially leaking into the surrounding geologic media. A strategically placed leak detection system would effectively alert monitoring personnel to a leak before the contaminants are transported beyond control. Like vapor extraction, the geometry of horizontal wells would allow for maximum efficiency in detecting leaks

beneath a facility. In addition, horizontal wells can be emplaced with minimum disturbance to the integrity of the structure being monitored.

1.1.4 SUBSURFACE HORIZONTAL BARRIER EMPLACEMENT

Horizontal barriers emplaced beneath leaking or potentially leaking TSD facilities may be an effective way of controlling contaminant migration. There are a number of barrier emplacement technologies; however, the basic concept involves placement of a low permeable material (e.g., grout, bentonite) in a laterally continuous pattern beneath the facility. Horizontal barriers would be placed in conjunction with vertical barriers to provide a total subsurface barrier system.

As part of DOE's Underground Storage Tank Integrated Demonstration Program, a workshop was held on February 25-27, 1992 in Tucson, Arizona to identify a subsurface barriers technology for application to the 241-C-106 high-level, mixed-waste, storage tank on the Hanford Site (McLaughlin, et al. 1992). Regardless of the technology presented, it was evident that a directional drilling technology would be required to emplace or provide a conduit for emplacement of barrier materials beneath the tank structure.

1.1.5 CHARACTERIZATION

Characterization refers to the collection of subsurface data which is used to direct emplacement of monitoring networks, direct remediation activities, map contaminant migration, etc. Characterization requirements may include determining the hydrogeologic conditions through aquifer testing; defining the contaminant species and distribution; and determining the geotechnical properties of the geologic media through sediment sampling or geophysical logging. The geometry of horizontal wells provides an advantage over characterization using vertical wells when the target of investigation is 1) known to extend laterally and is confined to a relatively thin vertical thickness, 2) lies beneath a storage facility or building, or 3) laterally very large, otherwise requiring many vertical wells.

It is likely that dual purpose (e.g., characterization and barrier installation) horizontal wells will be installed to minimize costs. An exception might be the emplacement of a conduit for long term monitoring of contaminant migration using geophysical logging or geochemical methods.

1.1.6 HYDROLOGIC CONTROL

Hydrologic control refers to a large-scale well network designed to alter the normal pathflow of groundwater and contamination migration. This network would be comprised of a grid of injection and withdrawal wells of proper spacing and size to effectively perform the desired control. Horizontal wells offer a much larger zone of influence and would therefore be much more efficient and less costly than installation of multiple vertical wells.

1.2 HORIZONTAL DRILLING SUBSYSTEMS

The second part of the technical forum was designed to define the subsystems which comprise the horizontal drilling system. The technical forum determined that because of the varying conditions and applications which exist at the various DOE facilities, it is not likely that one existing drilling system will meet all the requirements. Instead, drilling systems will be developed using various existing and developmental subsystems to most efficiently meet the application and site requirements.

The technical forum determined the following subsystems to be the most critical in defining a total horizontal drilling system:

- Directional control equipment
- Circulation media
- Drilling tools
- Cuttings containment
- Completion design

The following subsections discuss each of the above mentioned systems.

1.2.1 DIRECTIONAL CONTROL EQUIPMENT

Directional control systems monitor and record directional parameters such as inclination (angle), direction (azimuth), and tool face orientation, either during or after the installation of a borehole. This data informs the drill operator whether the prescribed hole alignment is on course or whether corrective action is necessary. Directional control

systems include the downhole survey (sensor) equipment and the data transmission (communication) equipment (e.g., mud telemetry, wireline, electromagnetic). The combinations of survey equipment and communications equipment often dictates the accuracy of the directional control equipment. The following is a short description of the various off-the-shelf methods for determining borehole azimuth, inclination, and tool face orientation.

A. **Single Shot** - The single shot system is considered the most basic directional control equipment. The system incorporates photographic film, a flash bulb on a timer, a pendulum, and a compass. The system takes one picture of the compass rose and pendulum at some point along the borehole. Calibration of a single shot system is difficult and the necessary tools and skills are not usually found within companies who exclusively use this type of equipment. Instrument accuracy, at best is ± 1 degree inclination and ± 1 degree azimuth. With this instrument there is no way to back out other system level inaccuracies that may add to instrument errors. These system level inaccuracies include bottom hole assembly misalignment, offset center (the single shot tool may not be in line with the center of the borehole), instrument misalignment, drillstring (magnetic) interference, formation (magnetic) interference, earth's field (reference field) variations, and physical structure interferences such as underground tanks, pipelines, etc.

B. **Multi Shot Film System** - The multi shot system is essentially the same as a single shot system except that the multi shot takes continuous pictures on 8mm film at prescribed time intervals (e.g., every 2 minutes). Instrument inaccuracies are the same as the single shot, however, in a skilled operator's hands, one can eliminate offset center error.

C. **Steering Tool** - Steering tool systems use solid state instrumentation (e.g., fluxgate magnetometer) for azimuth sensing, and anything from a straingage pendulometer to bubble levels to accelerometer for inclination. The steering tool data is transmitted to the surface via a wireline. Depending upon the number of fluxgate magnetometers (two or three) in the tool, the skill of the operator and the capability of the software, an accuracy of ± 0.25 degrees in some orientations (north-south orientations are inaccurate for azimuth solutions using fluxgates) may be achieved. Depending on the inclination sensing means, a ± 0.05 degree

accuracy may be obtained. With these instruments, and in the hands of a skilled operator, one should be able to eliminate or at least define most if not all of the inclination and magnetic errors.

D. **Monitoring While Drilling** - MWD systems consist of three main components; a suite of downhole sensors, a data transmission device, and surface equipment to receive and manipulate the data. Essentially the MWD is a steering tool which uses mud pulse (pulse or continuous wave) or electromagnetic telemetry to communicate to the surface equipment. Typically the surface MWD components include a signal detection pressure transducer, analog pressure recorder, electronic signal decoding equipment, and various digital and analog readouts and plotters. The type and sophistication of downhole sensor combinations (i.e., tools measuring both directional drilling parameters and formational parameters) employed by MWD systems varies widely and is changing rapidly. The inaccuracies associated with the MWD system are related more to the communication limits between the downhole transmitters and the surface equipment rather than the downhole sensor instrumentation.

E. **Gyros** - There are several different types of gyros available which vary in accuracy and application. Most gyros will not work in horizontal boreholes. However, recent developments have redesigned the gyro to work in horizontal applications (e.g., Humphrey Horizontal gyro and the dual mode gyro). The following is a description of some of the gyros available for drilling applications.

- **Free Gyro (Humphrey Gyro)** - Although many varieties of conventional free gyros exist, they essentially fall into two categories; film system and surface readout. Gyros operate by remembering an orientation line which is inputted by the operator using a magnetic compass. Error occurs as the gyro drifts from this line in space. Film systems take a picture of an inclinometer superimposed over the compass rose. Accuracies of ± 1 degree + 1 degree per hour azimuth, and ± 1 degree inclination at best. Surface read-out units typically use accelerometers for inclination but generally are not temperature compensated. Accuracy of the readout units is ± 0.5 degree + 1 degree per hour, azimuth and ± 0.25 degree inclination, at best. No conventional oilfield directional gyro can go

horizontal, however, Humphrey has recently introduced a "horizontal" gyro that will go horizontal. This horizontal gyro has the same accuracy as conventional gyros.

- **Rate Gyro** - There are various types of rate gyro systems which use either of two types of strapdown gyros; 1) co-planar for determining the earth's rate in four orthogonal positions, or 2) gyrocompassing to determine the azimuthal direction of tilt. Information is accurate to ± 0.25 degree azimuth and ± 0.05 degree inclination up to 30 degree inclination and 60 degree north/south latitude. Like the conventional gyros, the azimuth reading using the rate gyro is no longer reliable, as the borehole approaches horizontal. Therefore the rate gyro is not useful in horizontal applications.

- **Dual Mode Gyro** - The dual mode gyro system uses a strapdown gyro to determine azimuth at near vertical orientations, and integrates the gyro rate output as it follows the high side of the hole while traversing the borehole. Gyro compass accuracy is the same as the rate gyro. The second mode is typically called inertial dead reckoning and is accurate to ± the accuracy of the initial alignment given (can be as good as ± 0.05 degree) + 0.05 degree per hour azimuth and 0.10 degree inclination.

1.2.2 CIRCULATION MEDIA

Circulation media are media used to circulate cuttings from the borehole (i.e., facilitate bottom-hole cleaning), maintain the integrity of the borehole wall, lubricate the casing and drill bit, cool the drill bit, and erode the formation when jetting during the drilling operation. The type of circulation media used is based primarily on the intended use of the well (i.e., if a well is used for hydrologic testing, an air/mist media would be preferred) and the characteristics of the geology (i.e., in unconsolidated open framework gravels a mud circulation media is most effective). Table 1 shows the different types of circulation media and their application.

Table 1. Drilling Media and Potential Applications

Circulation Media	Composition/Application	Reason for Use
Air	Air/ Used in rock, consolidated formations or cased boreholes where borehole wall integrity is not a problem	Minimize impacting natural chemical hydraulic conditions
Air-Mist	Air and water mixture/ Used in rock, consolidated formations or cased boreholes where borehole wall integrity is not a problem	Minimize impacting natural chemical hydraulic conditions
Fluid (Environmentally Acceptable)	Clay or polymer-based mud. May be used in any geologic formation. Composition of mud must meet regulatory standards.	Maximize borehole wall integrity and minimize alteration or contamination of the natural chemical environment
Fluid (Biodegradable)	Clay or polymer-based mud, or mixture. May be used in any geologic formation. Composition of mud must meet regulatory standards and must sustain biological growth.	Maximize borehole wall integrity and minimize alteration or contamination of the natural chemical environment. Also minimize toxicity to microorganisms.

1.2.3 DRILLING METHODS, TOOLS, AND TECHNIQUES

The directional drilling method most suited for a particular application is dependant primarily on the: 1) site geology; 2) presence and type of contamination; 3) intended use of the well; 4) the required precision; and, 5) physical constraints in the area of investigation. The general drilling methods categories identified by the technical forum are listed and defined as follows:

A. **Downhole Motor (Air/Fluid)** - Downhole motors generally are positive displacement motors which use the energy of the drilling media (fluid or air) to provide mechanical energy to the rotor. Unlike conventional rotary systems, the drill pipe in a downhole system does not rotate; instead it provides downward pressure to aid in the advancement of the drill motor.

The downhole motor assembly is located directly behind the drill bit. Fluid-driven motors (especially mud) are most common due to the lubricating capabilities of the fluid and the ability of the fluid to support the borehole wall. The deviation of directional drilling motors is accomplished by bottom hole assemblies which may include a bent sub, an offset stabilizer, bent housing, jetting assemblies, or

whipstocking assemblies. MWD directional control systems are generally located behind the drill motor.

B. **River Crossing** - The river crossing method uses a downhole motor, water jet, and rotation. This system utilizes a conventional angle-derrick rotary drill rig with a conventional rotary bit. A typical pilot hole is initially drilled through the first curve to horizontal then through another curve to an exit hole at the surface (mid-hole directional changes are achievable). The exit hole is not required, but is generally used to allow placement of the well completion materials. The hole is then reamed to a maximum diameter of 36 in. In addition, during the backpull process, casing and screen can be installed in the borehole. Bentonite mud is most frequently used as a drilling media for this drilling process.

C. **Micro Tunneling** - The micro tunneling method employs the use of a large-diameter vertical shaft from which a horizontal tunnel is drilled. The tunneling device consists of a rock crushing rotating bit which is guided and tracked using laser survey equipment. Casing is pushed or jacked behind the tunneling bit as it advances. Casing materials may include, concrete, steel, or fiberglass that have sufficient compressive strengths.

Micro tunnels are effective in boring through large gravels due to the size of the bit and its rock crushing capability. Micro tunneling is also useful in applications requiring a high degree of accuracy. Cuttings are removed from the boring via mud or an auger. Micro tunneling is a popular boring method used for constructing pipe lines through rock and sediment.

D. **Sonic** - The sonic method uses sonic (resonant) energy waves (up to 150 hertz) generated by two, high-speed, counter bearings in the drill head. The energy is transmitted through the drill rod and bit to the formation. Concurrent with the resonant energy, the drill head rotates the pipe at a slow speed and applies downward pressure. Continuous core samples are obtained using a wireline system. No circulation media is normally required during the drilling process, and the only secondary waste products from drilling are core samples and fluid from equipment decontamination.

To date, sonic drilling has only been applied to drilling vertical boreholes, although Sandia National Laboratory is currently performing a demonstration for its use in angled and horizontal borings.

E. **Water Jet** - A water jet system effectively bores through the formation using high hydraulic pressure which is dispersed at the tip of the bit. As with most fluid drilling systems, circulation return during the boring operation is dependant on the permeability of the formation. In unconsolidated formations, a temporary casing is emplaced as the jet nozzle advances.

F. **Air Turbine Motor** - Recently, a pneumatic turbine motor was designed and constructed for geothermal operations, however, the motor may have other applications especially in environments where minimum formation damage is desirable. This motor is an impulse-type turbine combining a rotor-driven rock bit with a thrust assembly using surface compressed air. The motor gearbox is a sealed unit with its own internal, oil lubrication system.

1.2.4 DRILLING CONTAINMENT SYSTEMS

Drilling containment systems refers to the equipment used for containing drilling media and cuttings during the drilling operation. The containment system is very critical, especially while drilling in contaminated materials. The degree of containment (e.g., total or none) is primarily dependant on the type and amount of contaminant which is known or suspected to be encountered during the drilling operation. Three types of containment systems were identified:

- Sealed Containment. This refers to a total air and liquid containment system including a negative air pressure containment tank, a de-mister, and a High Efficiency Particulate Air (HEPA) filtration system. This system would be designed for use in locations where radioactive and chemical contaminants are known or are likely to exist in the substrate.

- Liquid Containment. Refers to the containment of the liquid spoils and drilling media during the drilling operation. Liquid containment equipment may include a lined trench or pond, tanks, or 55 gallon drums. Liquid containment equipment

would be designed for locations where minimal or no chemical contamination is present or suspected in the substrate. No HEPA filtration is employed with this system.

- Air Containment. This refers to the containment of air emitted from the drilling operation. The use of this equipment would pertain to drilling operations using air or air/mist as a drilling medium. Air containment equipment may include a HEPA filtration system where chemical and radiological contaminants are of concern, or a baghouse when the objective is to minimize nuisance dust.

1.2.5 COMPLETION DESIGN

The completion design of a horizontal well is dependant on the application of the well, the geologic materials, and the chemical environment of the sediments. The completion design refers to the open interval of the well (if any) and the type of material (e.g., gravel pack) placed around the open interval. There are three primary components of the well completion design: 1) type of open interval; 2) the packing materials; and, 3) the completion materials. The primary variations included in each of the well completion design components are as follows:

- **Type of Open Interval**
  - Blank Casing (no openings)
  - Slotted or wirewrap (openings present in the screen before placement)
  - Perforated [slots placed in casing after emplacement using perforation tool (e.g., Mills Knife)]

- **Packing Material**
  - Natural Pack: allows the formation to cave around the open interval
  - Gravel/Sand Pack: emplaced around open interval during completion of the well
  - Pre-pack screen: open interval, factory-packed with a filter material before emplacement of the open interval

- **Completion Material**
  - Carbon Steel
  - Stainless Steel
  - Plastics - (e.g., HDPE or PVC)

1.3 DOE SITE DESCRIPTIONS, CONSTRAINTS, HORIZONTAL DRILLING NEEDS

Part of the technical forum was designed to define the horizontal drilling needs for performing characterization, monitoring, and remediation activities at the various DOE facilities. Since each DOE facility has unique contaminant problems and site constraints (e.g., regulatory, physical, and institutional), it was important to identify these basic site parameters which will influence the development of a horizontal drilling system which is capable of meeting the DOE Environmental Restoration program requirements. The DOE sites evaluated include: Hanford, Idaho National Engineering Laboratory, Lawrence Livermore National Laboratory, Nevada Test Site, Sandia National Laboratory, Savannah River, Rocky Flats, Los Alamos National Laboratory, Oak Ridge Reservation, and Fernald Environmental Management Project. Matrices identifying the potential horizontal drilling needs for each site are included in Section 1.4.

There are some constraints on drilling which must be considered by a drilling contractor prior to performing drilling activities at DOE sites. Three of these constraints include: 1) regulatory; 2) institutional; and, 3) physical. These constraints are mentioned only to point out potential impacts to the project schedule and budget. The following brief discussion includes the regulatory and institutional constraints that are common to all DOE sites. The regulatory constraints differ from site to site according to the interpretation of the federal regulations by the state government where the site is located. These differences are discussed in the next section on site specific details. Institutional constraints differ from site to site, but are generalized below for all DOE sites with no further discussion in the site specific section. Physical constraints are unique to each site and are presented only in the next section.

The following federal regulations govern the environmental activities (including drilling) at DOE sites:

- **Comprehensive Environmental Response Compensation Liability Act (CERCLA)** - CERCLA establishes a ranking system to prioritize cleanup of hazardous waste sites under the National Priority List (NPL). It also provides rules concerning methods for cleanup and creates a mechanism for deciding "how clean is clean."

- **Superfund Amendments and Reauthorization Act (SARA)** - This act is enforced by the EPA which reauthorizes and amends CERCLA. It establishes a list of hazardous substances that must be reported if released to the environment and contains emergency planning and community right-to-know provisions.

- **Resource Conservation and Recovery Act (RCRA)** - This act is enforced by the EPA and includes management of hazardous wastes from "cradle to grave" as stated in Subtitle C. RCRA also establishes the requirements for permitting TSD facilities.

- **Hazardous Materials Transportation Act (HMTA)** - Enforced by the Department of Transportation to govern the transportation of hazardous materials which can include samples taken during drilling (packaging, labeling, shipping papers, etc.)

- **Occupational Safety and Health Act (OSHA)** - Worker safety at hazardous waste operations (including drilling locations) are governed under the 29 CFR 1910.120 regulations. At a minimum, waste site workers are required to have 40 hours of hazardous waste worker training.

- **Endangered Species Act** - This Act requires that site activities must not impact rare species of native plants and animals which are known to occur on the site.

- **National Historic Preservation Act, Archaeological Resources Protection Act, and American Indian Religious Freedom Act** - This Act requires that the site location must be surveyed to ensure the protection of valuable cultural resources.

- **National Environmental Policy Act (NEPA)** - This Act requires that the project must be carefully reviewed to ensure that activities associated with the project will not damage the environment.

- **Clean Water Act (CWA)** - This regulation requires a National Pollutant Discharge Elimination System (NPDES) permit for nonradioactive discharges to navigable waters.

- **Safe Drinking Water Act (SDWA)** - This regulation applies to drinking water supplies.

Institutional constraints also effect drilling activities at DOE sites. Institutional constraints refers to requirements placed on the contractor by the company managing the project and also restrictions placed on the contracted firms working within the boundaries of a DOE facility. Most companies familiar with working for private industry will find requirements on government locations more stringent. These requirements include quality assurance and quality control of all project activities, strict safety oversight and enforcement, and strict adherence to defined data quality objectives. In addition, the national security concerns still prevalent at many DOE sites mandates security badges and property passes for site access.

1.3.1 HANFORD SITE DESCRIPTION

The Hanford Site is a 560 mi^2 DOE facility located in southcentral Washington State. The Hanford Site has been the location of plutonium processing and production since the early 1940's. Recently, the Hanford Site has undergone a major mission change from defense activities to environmental restoration, research and development, and technology development. The restoration activities are focused on decontamination and decommissioning of facilities and clean up of contaminated soil and groundwater near inactive waste sites.

Soil and groundwater contamination occurs on the Hanford Site as a result of past waste disposal practices to tanks, trenches, cribs, and ponds. The Hanford Site contains a wide variety of chemical and radioactive contaminants. Table 2 shows the major chemical and radiological groundwater contaminants as related to the Hanford Site operations.

Table 2. Major Chemical and Radiological Groundwater Contaminants and Their Link to Hanford Site Operations (Taken from Woodruff and Hanf, 1991)

Facilities Type	Area	Constituents
Reactor Operations SO_4^{2-}	100	^{3}H, ^{60}Co, ^{90}Sr, Cr^{6+},
Irradiated Fuel Processing ^{99}Tc, NO_3^-, Cr^{6+}, CN^-,	200	^{3}H, ^{137}Cs, ^{90}Sr, ^{129}I, F^-, Uranium, Plutonium
Plutonium Purification	200	CCl_4, $CHCl_3$
Fuel Fabrication Trichloroethylene	300	Uranium, ^{99}Tc, Cr^{6+},

A. Site Specific Constraints at Hanford

(1) **Regulatory** - One of the key elements to Hanford's compliance with the CERCLA, SARA, and RCRA is the establishment of the Hanford Federal Facility Agreement and Consent Order (Tri-Party Agreement). The Tri-Party Agreement is an agreement among the U. S. Environmental Protection Agency (EPA), Washington State Department of Ecology (WDOE), and the DOE. The agreement establishes schedules for the characterization, cleanup, and management of mixed and hazardous wastes at Hanford over the next 30 years.

(2) **Physical** - Physical constraints refer to conditions which might effect the progress of the excavation activities. These include the following.

- **Geology** - There are very coarse, unconsolidated gravels present beneath the Hanford Site. These geologic conditions have often significantly reduced the excavation and drilling rate in some locations. In addition, the heterogeneity of the geology makes it difficult to anticipate the location of very large cobbles or boulders. Drilling methods requiring the use of a circulation fluid may encounter problems with lost circulation zones, especially in the coarse horizons of the Hanford Formation.

- **Subsurface Piping** - Many of the locations requiring use of horizontal drilling methods contain a dense network of underground piping including numerous vertical wells (e.g., the tank farms area). In some instances the piping is poorly mapped due to the age of the plumbing and the frequency of modifications. In addition, piping which served or serves as waste transfer lines, is likely to be highly contaminated with radionuclides and hazardous chemicals. Therefore, drilling equipment and the drilling activities must be carefully planned to avoid encountering a buried obstacle.

B. Potential Applications for Horizontal Drilling on the Hanford Site

A number of potential applications for directional drilling, including subsurface barrier installation, in situ bioremediation, large-scale hydrologic control networks, vapor extraction systems, site characterization, and site monitoring (leak detection) of TSD facilities have been identified at the Hanford Site. The following is a discussion of each of these potential applications.

(1) **Subsurface Barrier Installation** - A number of underground storage tanks have been identified as leakers or potential leakers on the Hanford Site. These high volume tanks contain high level mixed waste (i.e., mixed radioactive and chemical wastes) which are or can significantly impact the quality of the subsurface soils and eventually the groundwater. In an effort to control the potential movement of contamination from leaking tanks the DOE Underground Storage Tank Integrated Tank Demonstration Program has set up a task to identify the feasibility of totally

enclosing a tank within a low permeability barrier. Several barrier emplacement methods have been suggested including, cryogenic encapsulation, grout curtain, sheet piling, permeation grouting, and hydrofraise. All of these methods require a means for placing a horizontal or near horizontal barrier beneath the tank.

(2) **In situ Bioremediation** - In situ bioremediation has been proposed and is currently being studied as a potential solution to the reduction of chlorinated hydrocarbons (specifically carbon tetrachloride) in the groundwater beneath the Hanford Site. Carbon tetrachloride was used as a solvent in the fuel processing operations primarily in the 200 West Area in the central portion of the Hanford Site. Currently, a carbon tetrachloride groundwater plume approximately covering an area of 5 mi^2 in the 200-West Area, has been identified through numerous groundwater monitoring wells. Due to the depth of the groundwater (approximately 250 ft in the 200 West Area) it is very difficult to treat this contaminant.

Directional wells have been identified as a viable way of placing nutrients over a broad area to stimulate biodegradation of the contaminant. Horizontal wells enable the distribution of nutrients along a targeted plane which is identified as having a greater concentration of contaminants.

(3) **Large Scale Hydrologic Control Network** - A hydrologic control system composed of a series of pump and injection wells has been proposed for creating a hydraulic barrier. A hydraulic barrier would be emplaced to prevent or impede groundwater transport of contamination. Horizontal wells would significantly reduce costs of installing a network of this type due to the potentially large area of impact produced by a horizontal well.

(4) **Vapor Extraction Systems** - Another means for removing volatile organic compounds from the groundwater and vadose zone is through a proven vapor extraction system. It is well documented that a number of volatile organics (primarily carbon tetrachloride) occur in the groundwater and vadose zone on the Hanford Site. A vapor system may include the placement of a horizontal well beneath a targeted high concentration zone. An additional well is placed above the

initial well. To induce extraction, high volumes of air are circulated through the bottom well while air and contaminants are removed from the upper well.

(5) **Site Characterization** - Subsurface site characterization activities to date at the Hanford Site have been accomplished through numerous vertical boreholes primarily during the installation of groundwater monitoring wells. Horizontal wells have been proposed for collection of subsurface data, especially beneath buildings, tanks, cribs, or ponds, where conventional vertical borings are difficult or impossible to emplace. Site characterization wells may be emplaced to collect, geologic, hydrologic, or chemical information. These wells may be used for placing geophysical probes for detecting radionuclide distribution or for determining the geotechnical properties of the subsurface.

(6) **Monitoring Wells (Leak Detection)** - Monitoring wells emplaced using directional drilling methods have been proposed for leak detection monitoring beneath storage tanks. These wells would require emplacement of temporary or permanent downhole instrumentation.

1.3.2 IDAHO NATIONAL ENGINEERING LABORATORY

The Idaho National Engineering Laboratory (INEL) is a 890 mi^2 DOE facility located in southeastern Idaho. Established in 1949, the INEL was originally known as the National Reactor Testing Station. The INEL Site is one of the DOE's principal centers for conducting nuclear energy research and providing support for the U.S. Navy nuclear fleet. It has the world's largest and most varied collection of reactors, including research testing, power, and ship propulsion reactors.

Currently the primary mission of the INEL is to furnish engineering services and products, principally for peacetime atomic-energy applications, nuclear safety research, defense programs, and advanced energy concepts.

Soil and groundwater contamination occurs on the INEL Site as a result of past waste disposal practices to tanks, trenches, cribs, wells, and ponds. The INEL Site contains a wide variety of chemical and radioactive contaminants.

A. Site Specific Constraints at INEL

(1) **Regulatory** - One of the key elements to INEL's compliance with the CERCLA, SARA, and RCRA regulations is the establishment of the INEL Federal Facility Agreement and Consent Order (Tri-Party Agreement). The Tri-Party Agreement is an agreement among the U. S. Environmental Protection Agency (EPA), Idaho Department of Health and Welfare (IDHW), and the DOE. The agreement establishes schedules for the characterization, cleanup, and management of mixed and hazardous wastes at INEL over the next 30 years.

(2) **Physical** - Physical constraints refer to conditions which might effect the progress of drilling and other excavation activities. These include the following.

- **Geology** - Generally, the INEL is underlain by approximately 40 basalt flows from the land surface to a depth of 700 ft. This basalt sequence is interbedded with 15 to 20 sedimentary layers, and is overlain by a thin veneer of surficial alluvial sediments consisting of poorly sorted gravelly to gravelly sand with minor silt and clay (Anderson, 1990). Depth to water at the INEL ranges from 200 ft in the northern part of the site to more than 900 ft in the southeastern part.

- **Subsurface Piping** - Some of the locations where horizontal drilling methods may be employed, contain a dense network of underground piping. In some instances the piping is poorly mapped due to the age of the plumbing and the frequency of modifications. In addition, piping which served or serves as waste transfer lines, is likely to be highly contaminated with radionuclides and hazardous chemicals. Therefore, drilling equipment and the drilling activities must be carefully planned to avoid encountering buried obstacles.

B. Potential Applications for Horizontal Drilling on the INEL Site

A number of potential applications for directional drilling, including subsurface barrier installation, in situ bioremediation, large-scale hydrologic control networks, vapor extraction systems, site characterization, and site monitoring (leak detection) of TSD

facilities have been identified at the INEL. The following is a discussion of each of these potential applications.

(1) **Subsurface Barrier Installation** - A number of underground storage tanks have been identified as leakers or potential leakers on the INEL Site. These high volume tanks may contain mixed waste (i.e., mixed radioactive and chemical wastes) which are or can significantly impact the quality of the subsurface soils and eventually the groundwater. In an effort to control the potential movement of contamination from leaking tanks the DOE Underground Storage Tank Integrated Tank Demonstration Program has set up a task to identify the feasibility of totally enclosing a tank within a low permeability barrier. Several barrier emplacement methods have been suggested including, cryogenic encapsulation, grout curtain, sheet piling, permeation grouting, and hydrofraise. All of these methods require a means for placing a horizontal or near horizontal barrier beneath the tank.

(2) **In situ Bioremediation** - In situ bioremediation has been proposed and is currently being studied as a potential solution to the reduction of chlorinated hydrocarbons at the INEL. Due to the depth of the groundwater (approximately 200 to 900 ft depending on location on the INEL Site) it is very difficult to treat this contaminant.

Horizontal wells have been identified as a viable way of placing nutrients over a broad area to stimulate biodegradation of the contaminant. Horizontal wells enable the distribution of nutrients along a targeted plane which is identified as having a greater concentration of contaminants.

(3) **Large Scale Hydrologic Control Network** - A hydrologic control system composed of a series of pump and injection wells has been proposed for creating a hydraulic barrier. A hydraulic barrier would be emplaced to prevent or impede groundwater transport of contamination. Horizontal wells would significantly reduce costs of installing a network of this type due to the potentially large area of impact produced by a horizontal well.

(4) **Vapor Extraction Systems** - Another means for removing volatile organic compounds from the groundwater and vadose zone is through a proven vapor extraction system. It is well documented that a number of volatile organics (primarily carbon tetrachloride) occur in the groundwater and vadose zone on the INEL Site. A vapor system may include the placement of a horizontal well beneath a targeted high concentration zone. An additional well is placed above the initial well. To induce extraction, high volumes of air are circulated through the bottom well while air and contaminants are removed from the upper well.

(5) **Site Characterization** - Subsurface site characterization activities to date at the INEL Site have been accomplished through numerous vertical boreholes primarily during the installation of groundwater monitoring wells. Horizontal wells have been proposed for collection of subsurface data, especially beneath buildings, tanks, cribs, or ponds, where conventional vertical borings are difficult or impossible to emplace. Site characterization wells may be emplaced to collect, geologic, hydrologic, or chemical information. These wells may be used for placing geophysical probes for detecting radionuclide distribution or for determining the geotechnical properties of the subsurface.

(6) **Monitoring Wells (Leak Detection)** - Monitoring wells emplaced using directional drilling methods have been proposed for leak detection monitoring beneath storage tanks. These wells would require emplacement of temporary or permanent downhole instrumentation.

1.3.3 LAWRENCE LIVERMORE NATIONAL LABORATORY

The Lawrence Livermore National Laboratory (LLNL) is located about 40 miles east of San Francisco in the Livermore Valley in southern Alameda County, approximately 3 miles east of the City of Livermore. The total area of the site is 1.27 mi^2 (DOE 1992).

Most of the following information was taken from Ziagos et al. 1992.

LLNL is a research and development facility owned by the DOE and operated by the University of California. The site was used as an air training base for the U.S. Navy during the mid- to- late 1940s. During this period solvents, gasoline, diesel, and other

compounds were released to the environment. These releases were associated primarily with airplane maintenance, and parts cleaning activities.

From 1950 to 1954, California Research and Development Company, a subsidiary of Standard Oil, occupied the southeastern portion of the site. This marked the beginning of testing with radioactive materials at the site, and probably the first releases of radioactive materials to the environment.

LLNL has occupied the site since 1952. During the history of the site, releases have occurred due to localized spills, landfills, surface impoundments, disposal pits, broken sewer lines and pipes, and leaking tanks. Releases of solvents were the most prevalent, although polychlorinated biphenyls (PCBs), metals, radionuclides (primarily tritium), gasoline, and pesticides also occurred.

In 1987, LLNL was added to the U. S. Environmental Protection Agency National Priorities (Superfund) List.

Current remediation planning at the LLNL is focusing on volatile organic compounds (VOCs), gasolines, tritium, and metals that exceed the State and Federal regulatory limits. VOCs, occur in groundwater both on and off the LLNL site. The VOCs, predominantly perchloroethylene (PCE) and trichloroethylene (TCE) occur in groundwater in concentrations as high as 10 part per million (ppm), but concentrations generally are on the order of a few parts per billion (ppb) to a few hundred ppb. VOCs in groundwater underlie about 85% of the LLNL site. Several small plumes with independent sources and contaminant signatures coalesce into a larger plume. This plume encompasses a total area of about 1.4 square miles. The calculated volume of VOCs in the subsurface is less than 200 gallons. The vertical thickness of the VOC groundwater plumes varies from about 30 to 100 ft, and VOCs are seldom found beneath a depth of about 200 ft.

Fuel hydrocarbons (including free product in some locations) in concentrations up to several hundred ppm, and the only lead detected in groundwater (38 ppb) above regulatory standards occurs in confined areas immediate to the vicinity of onsite gasoline fuel tank leaks. The fuel components extend about 500 ft radially of the spill, and do not extend below a depth of about 150 ft.

Chromium exceeds its drinking water standard in groundwater in about 15 wells in various locations around the site, with a maximum concentration of 160 ppb. The source of this chromium in groundwater is believed to be natural, although the discharge from the cooling tower to surface drainage prior to 1980 when chromates were used as corrosion inhibitors may also have contributed. Cadmium has been detected at or above regulatory limits (up to 200 ppb) from bailed groundwater samples from boreholes and one monitoring well in several isolated areas around the site.

A. Site Specific Constraints at LLNL

(1) **Regulatory** - As is the case with other DOE sites, the LLNL's environmental characterization and cleanup activities are primarily regulated by CERCLA, SARA, and RCRA.

(2) **Physical** - Physical constraints refer to conditions which might effect the progress of drilling and other excavation activities. These include the following.

- **Geology** - The geologic materials to be drilled include unconsolidated gravel, sand, silt, clay and consolidated conglomerates, sandstone, siltstone, and claystone. Boreholes will range up to 350 ft in depth. Unstable hole conditions may cause slow difficult drilling due to consolidated rock units and groundwater pressure have been encountered in previous drilling efforts.

B. Potential Applications for Horizontal Drilling on the LLNL Site

The primary applications for horizontal drilling at the LLNL, include the evaluation of underground storage tanks and remediating areas where buildings have been located over old disposal pits. Horizontal drilling may also be appropriate at Site 300 (LLNL's Testing facility), where shallow confined aquifers may need remediated.

1.3.4 NEVADA TEST SITE

The Nevada Test Site (NTS) is located in Nye County, Nevada, about 85 miles northwest of Las Vegas. The NTS is about 100 miles by road from Las Vegas.

Potential soil and groundwater contamination occurs on the NTS as a result of weapons testing which was conducted at various depths. Although RCRA sites have been identified at the NTS, few of these sites have been characterized to determine extent, type, and quantity of contamination. Lead appears to be a common contaminant associated with the subsurface blast locations. Other locations on the NTS have surface contamination (primarily plutonium) from surface testing of nuclear weapons.

A. Site Specific Constraints at the Nevada Test Site

(1) **Regulatory** - Relative to other DOE locations, the NTS is in the preliminary stages of defining the regulatory structure which will govern waste characterization and cleanup activities. As this regulatory structure becomes better defined, the information can be added to subsequent revisions to this document.

(2) **Physical** - Physical constraints refer to conditions which might effect the progress of the excavation activities. These include the following.

- **Geology** - Detecting and delineating the extent of contamination to the groundwater beneath the NTS may be very difficult considering the vadose zone ranges in thickness between 800 and 2000 ft. The uppermost aquifer underling the NTS (assuming no perched water zones) lies within carbonate or volcanic deposit which are overlain by tuff and ash beds. The uppermost sediments are classified as valley fill alluvium.

B. Potential Applications for Horizontal Drilling on the NTS

Since the NTS is in its early stages of developing programs for characterizing and remediating its waste sites, no specific needs related to horizontal drilling were identified. It is likely, however, that horizontal drilling systems will be useful in defining the depth and extent of blast zones.

1.3.5 SAVANNAH RIVER SITE

The majority of information contained in this section is derived from the Savannah River Site Environmental Impact Statement (DOE, 1987). The Savannah River Site (SRS) is a 301 mi^2 controlled access area near Aiken, South Carolina. The SRS is a major installation which began operations in the early 1950's. Major site facilities include five nuclear reactors, a fuel and target fabrication plant, a naval fuel materials facility, two chemical separations plants, the Defense Waste Processing Facility (DWFP), and the Savannah River Laboratory (SRL). The SRS is the nation's primary source of reactor-produced defense materials.

Operations at the SRS generate a variety of hazardous, low-level and mixed wastes. These include hazardous wastes such as spent degreasing solvents; low-level radioactive wastes such as contaminated gloves, wipes, and liquid discharge from disassemble basins in the reactor areas; and mixed wastes such as condensate from the evaporation of high-level waste (mercury with radionuclides); process water and laboratory wastes (solvents with uranium); tritiated waste oil; and, solutions used in measuring radiation (liquid scintillation solvents).

Groundwater contamination (and presumably soil contamination) has occurred on the SRS as a result of past waste disposal practices. The contaminants detected include volatile organic compounds (degreasing solvents), heavy metals (lead, chromium, mercury, and cadmium), radionuclides (tritium, uranium, fission products, and plutonium), and other miscellaneous chemicals (e.g., nitrates). Concentrations of these substance have exceeded maximum contaminant levels and other regulatory standards or guideline concentrations.

A. Site Specific Constraints at Savannah River

(1) **Regulatory** - Remedial and corrective actions performed at the SRS, must conform to RCRA, HSWA, CERCLA, SARA, the South Carolina Hazardous Waste Management Act (SCHWMA), and various DOE administrative orders. To date, these actions have included the removal and storage of previously buried wastes and contaminated soils; the design, construction, and operation of liquid effluent treatment facilities; the use of an air stripping system; the design of a two-stage,

rotary-kiln incinerator to detoxify hazardous wastes; and, other waste disposal demonstrations.

(2) **Physical** - Physical constraints refer to conditions which might effect the progress of drilling and excavation activities. These include the following.

- **Hydrogeology** - The SRS is located on the Upper Coastal Plain. The site is underlain by a thick wedge (approximately 1000 feet thick) of unconsolidated sands, clayey sands, and sandy clays. The water table beneath most of the site ranges from 30 to 100 ft.

- **Forest and Wetlands** - Nearly the entire SRS is either forested or is considered wetlands. In fact, approximately 90 percent of the SRS is covered by forest. This condition makes access to portions of the site difficult.

B. Potential Applications for Horizontal Drilling on the SRS

A number of potential applications for directional drilling, including subsurface barrier installation, in situ bioremediation, large-scale hydrologic control networks, vapor extraction systems, site characterization, and site monitoring (leak detection) of TSD facilities have been identified at the SRS. The following is a discussion of each of these potential applications.

(1) **Vapor Extraction Systems** - An in situ air stripping well system was successfully installed at the SRS. This system, which utilizes two parallel horizontal wells has been successful in removing 16,000 pounds of trichlorethylene (TCE) and tetrachloroethylene (PCE) from soils and groundwater beneath the site. Plans at the SRS involve installation of additional wells, and demonstrating other remediation technologies (Kaback, et al. 1991)

(2) **In situ Bioremediation** - The existing horizontal wells used in the air stripping system will be used to demonstrate an in situ bioremediation that will consist of injection of methane/air mixture to stimulate methanotrophic microorganisms

known to have the capability to degrade TCE to carbon dioxide, water, and hydrogen chloride in an aerobic system (Kaback, et al. 1991).

1.3.6 LOS ALAMOS NATIONAL LABORATORY

The Los Alamos National Laboratory (LANL) is a 42 mi^2 site located on the Pajarito Plateau on the east flank of the Jemez Mountains about 25 miles northwest of Santa Fe, New Mexico. The plateau consists of a series of mesas and canyons that terminate at the Rio Grande River. The LANL was established in 1943 as Project Y of the War Departments's World War II Manhattan Engineering District. The mission of Project Y was the design and development of the first nuclear fission bomb. Today, LANL is a microcosm of the nuclear weapons complex.

Hazardous substances are present beneath the LANL area as a result of wastes disposal to pits, trenches, and shafts in the mesas and canyons (Krueger 1990).

A. Site Specific Constraints at Los Alamos

(1) **Regulatory** - Since LANL has not been listed on the CERCLA National Priorities List but has been issued a RCRA permit requiring clean up, RCRA provides the most appropriate regulatory framework for the site. The RCRA permit specifies a three step corrective action process that is spelled out in great detail.

(2) **Physical** - Physical constraints refer to conditions which might effect the progress of the excavation activities. These include the following.

- **Geology** - Most of the finger like mesas in the LANL area are formed in Bandelier Tuff. Ashfall, ashfall pumice, and rhyolite tuff form the surface of Pajarito Plateau. The tuff, ranging from non-welded to welded is over 1,000 ft thick in the west and thins to about 260 ft to the east. It was deposited by a series of volcanic eruptions in the Jemez Mountains beginning about 1.3 million years ago. The tuff is underlain by the Puye Conglomerate with Chino Mesa basalt interfingerings to the east. Underneath these is the Tesuque sediment formation, which extends across the Rio Grande Valley and is in excess of 1,000 ft thick (ESG 1989).

- **Hydrogeology** - Groundwater occurs in three systems: 1) shallow alluvium in canyons; 2) perched groundwater; and 3) the deep aquifer. The shallow alluvial aquifer exists due to intermittent runoff into the canyons which infiltrates the alluvium. Perched water occurs 120 to 150 ft deep in the conglomerate and basalts. The deep aquifer is isolated from the other systems by 350 to 620 ft of unsaturated tuff and volcanic sediments. The water table is 1,200 ft deep along the western margin of the plateau, and 600 ft deep on the eastern margin (ESG 1989).

B. Potential Applications for Horizontal Drilling on the Los Alamos Site

Horizontal drilling needs for the LANL have not been identified at this time.

1.3.7 FERNALD ENVIRONMENTAL MANAGEMENT PROJECT

The Fernald Environmental Management Project (FEMP) formally called the Feed Materials Production Center (FMPC) is a uranium metal production facility located in southwestern Ohio, approximately 18 miles northwest of Cincinnati and 8 miles southwest of Hamilton. The FEMP is situated on a 1.6 mi^2.

During the summer of 1989, production of uranium metal was suspended in order to focus the plant resources on cleanup. The FEMP currently remains in inactive status except for continuing environmental studies and related activities (DOE 1990).

In addition to uranium production facilities, the site also contains waste storage facilities consisting of waste pits, storage silos, a burn pit, a clearwell, two fly ash piles, a sanitary landfill, and lime sludge ponds. These facilities are the targets of the environmental activities at the FEMP.

Elevated levels of uranium and other radionuclides and hazardous chemicals have been detected in groundwater, surface water, and sediments at the FEMP. Principal public health concerns are associated with an off site plume of uranium in groundwater in areas serviced by private wells (DOE 1991a).

A. Site Specific Constraints at the FEMP

(1) **Regulatory** - Both active and inactive operations at the FEMP must achieve compliance with the special environmental requirements of the Federal Facility Compliance Agreement (FFCA) entered into with the U.S Environmental Protection Agency, Director's findings and orders of the State of Ohio, and specific requests from Congressional entities (Yeasted et. al 1988).

(2) **Physical** - Physical constraints refer to conditions which might effect the progress of the excavation activities. These include the following.

- **Geology** - At the FEMP, nearly 49 ft of clay-rich glacial till, generally described as silty clay loam, overlie sand and gravel. The till is a comprised of a mixture of unstratified clay, sand, and gravel. More than 200 ft below the surface of the FEMP lies bedrock consisting of alternating layers of limestone and shale (WMCO 1990).

- **Hydrogeology** - A large aquifer system is contained in sand and gravel deposits underlying the FEMP and most of southwestern Ohio. This aquifer is a major source of fresh water for industries and residence. The groundwater flow is in the easterly direction under the waste pit and production area, while on the southern edge of the facility groundwater moves to the south.

B. Potential Applications for Horizontal Drilling on the FEMP Site

No Horizontal drilling needs for the FEMP have been identified at this time.

1.3.8 OAK RIDGE RESERVATION

The Oak Ridge Reservation (ORR) is a 91 mi^2 site located within the corporate limits of the city of Oak Ridge, in eastern Tennessee. The ORR site is predominantly to the west and south of the population center of the city. It lies in a valley between the Cumberland and southern Appalachian mountain ranges and is bordered on one side by the Clinch River. The Cumberlands are about 10 mi northwest; 70 mi to the southeast are the Great

Smoky Mountains. Except for the city of Oak Ridge, the land within 5 mi of the ORR is predominantly rural, used largely for residences, small farms, and pasture land.

The ORR was established in the early 1940's as the "Manhattan Project" location for the graphite reactor that was to serve as a prototype for the plutonium production reactors. An adjacent "Hot Pilot Plant" was constructed to allow reprocessing of the graphite reactor fuel for plutonium recovery and process development. These two facilities, along with associated support units, made up the core of operation at the ORR for several years. From initial start up, large quantities of fission products and uranium waste solutions as well as solid radioactive wastes were generated. Today, the ORR consists of three major operating facilities: the Y-12 Plant, the Oak Ridge National Laboratory (ORNL), and the Oak Ridge Gaseous Diffusion Plant (ORGDP).

A. Site Specific Constraints at the Oak Ridge Reservation

(1) **Regulatory** - A Federal Facility Agreement (FFA) for the Oak Ridge Reservation was approved in November 1991 by the United States Environmental Protection Agency Region IV, the DOE, and the Tennessee Department of Environment and Conservation. The effective date of the agreement is January 1, 1992. The objective of the agreement is to ensure that environmental impacts resulting from operations at the Oak Ridge Reservation, both past and present, are thoroughly investigated and remediated to protect the public health, welfare, and environment.

(2) **Physical** - Physical constraints refer to conditions which might effect the progress of the excavation activities. These include the following.

- **Geology** - Oak Ridge is located in the Valley and Ridge physiographic province, a belt of faulted and folded rock that lies between the Blue Ridge subdivision of the Appalachians to the southeast and the Appalachian Plateau to the northwest. In the Oak Ridge area, the province is about 50 mi wide and is marked by a series of great overthrust faults. These faults moved layers of rock roughly 2 mi thick as much as several tens of miles to the northwest. Due to erosion, thick sequences of this thrusted rock are exposed at the surface in the Oak Ridge area (Weeren et al. 1974).

The rock formations dip from 20° to 45° to the southeast. The rock types are sedimentary consisting of shale, sandstone, limestone, and quartzite. There has been some problems with keeping vertical boreholes straight using air rotary due to deflection of the bit off the dipping bedrock.

The groundwater table at the ORR is relatively shallow compared to other DOE sites (10 ft below ground surface in some places).

B. Potential Applications for Horizontal Drilling on the ORR Site

No Horizontal drilling needs for the ORR have been identified at this time.

1.3.9 SANDIA NATIONAL LABORATORY

The majority of ER-related activities (e.g., technology development and testing) at Sandia National Laboratory (SNL) occur on two locations as part of the Mixed-Waste Landfill Integrated Demonstration (MWLID) program. These areas are known as the Chemical Waste Landfill (CWL) and the Mixed-Waste Landfill (MWL).

The CWL was operated from 1962 to 1985. It occupies .003 mi^2 and is composed of small (10 by 30 ft), specific waste-type disposal cells. The cells were excavated to a shallow depth of 8 to 10 ft. The cells are unlined and during their operating history received acids, organics, metals, and reactants. The CWL began receiving wastes in 1962 and , pursuant to RCRA, was granted interim status for landfill operations in 1982. In 1984, the interim status for landfill operations were transferred to a surface storage operation. All land disposal operations ceased by 1985.

In 1984, a thorough review of available disposal records revealed that a small amount of radioactive waste had been disposed of in the CWL. The disposal locations cannot be verified; therefore, a portion of the site is treated as a Radioactive Materials Management Area (RMMA). Because of restrictions against generating mixed wastes, drilling is prohibited into or under the RMMA.

The MWL was established for disposal of classified and unclassified wastes, including hazardous, radioactive, and mixed wastes. It was operated from 1959 to 1989. It occupies .003 mi^2 and is composed of large (50 by 150 ft), composite disposal cells. The cells were excavated to 10 to 50 ft. The cells are unlined and during their operating history, received tritium, fission products, activation products, and solidified liquids.

A. Site Specific Constraints at the SNL

(1) **Regulatory** - No site specific regulatory requirements were identifies for the SNL at the time of this document.

(2) **Physical** - Physical constraints refer to conditions which might effect the progress of the excavation activities. These include the following.

- **Geology** - Both the CWL and MWL are located in an alluvial deposit and have an arid environmental setting. The water table occurs at approximately 480 ft below land surface at both sides. Drilling difficulties are usually due to multiple layers of course gravel and a hard caliche lens which occurs at a depth of 300 ft.

B. Potential Applications for Horizontal Drilling on the SNL Site

A number of goals related to the MWLID have been established as a strategic plan to meet the regulatory requirements established at the SNL. Horizontal drilling technologies will be included in meeting the following goals:

- Characterize quantities and distributions of contaminants and site properties and conditions associated with the CWL and MWL while minimizing disturbance of the landfills.

- Demonstrate remediation technologies at the CWL and MWL, emphasizing in situ technologies (transformation, containment, and stabilization).

1.3.10 ROCKY FLATS PLANT

The following site description was obtained from DOE 1991b.

The Rocky Flats Plant is a government-owned, contractor-operated facility, that is part of the nationwide nuclear weapons production complex. The Plant was operated for the U.S. Atomic Energy Commission (AEC) from its inception in 1951 until the AEC was dissolved in January 1975. At that time, responsibility for the Plant was assigned to the Energy Research and Development Administration (ERDA), which was succeeded by the DOE in 1977. Dow Chemical U.S.A., an operating unit of the Dow Chemical Company, was the prime operating contractor of the facility form 1951 until June 30, 1975. Rockwell International was the prime contractor responsible for operation of the Rocky Flats Plant from July 1, 1975 until December 31, 1989. EG&G, Rocky Flats, Inc. became the prime contractor at the Rocky Flats Plant on January 1, 1990, and currently operates the Plant.

The primary mission of the Rocky Flats Plant is to fabricate nuclear weapon components from plutonium, uranium, and other non-radioactive metals (principally beryllium and stainless steel). Parts made at the Plant are shipped elsewhere for assembly. In addition, the Plant reprocesses components after they are removed from obsolete weapons for recovery of plutonium.

Both radioactive and nonradioactive wastes are generated in the production process. Current waste handling practices involve on-site and off-site recycling of hazardous materials, on-site storage of hazardous and radioactive mixed wastes, and off-site disposal of solid radioactive materials at another DOE facility. However, both storage and disposal of hazardous, radioactive and radioactive mixed wastes occurred on-site in the past. Preliminary assessments under the ER Program identified some of the past on-site storage and disposal locations as potential sources of environmental contamination.

A. Site Specific Constraints at the Rocky Flats Plant

(1) **Regulatory** - One of the key elements to Rocky Flat's compliance with the CERCLA, SARA, and RCRA is the establishment of the Interagency Agreement (IAG). The IAG was signed as a compliance document January 20, 1991. The

IAG is an agreement among the U. S. Environmental Protection Agency (EPA), DOE, and the Colorado Department of Health. The agreement establishes schedules for the characterization, cleanup, and management of mixed and hazardous wastes at the Rocky Flat's Plant over the next 30 years.

(2) **Physical** - Physical constraints refer to conditions which might effect the progress of the excavation activities. These include the following.

- **Geology** - The uppermost sediments underlying the Rocky Flats Plant consist of varying amounts of silt, clay, sand, and gravel. These alluvial sediments vary in thickness. Directly beneath these alluvial sediments, except in the western portion of the Plant, is the Arapahoe Formation which consists predominantly of claystones and siltstones with minor silty sandstones evident in the central and eastern portions of the Plant. The Arapahoe Formation varies in thickness up to 270 ft.

  Depth to water at the Rocky Flats Plants varies between 10 and 50 ft with perched water zones (sometimes multiple zones) evident over the majority of the site.

B. Potential Applications for Horizontal Drilling on the Rocky Flats Plant

Horizontal drilling is planned for use in the second phase of the interim measures/interim remedial actions for operable unit No. 2 on the Rocky Flats Plant. This phase will use horizontal drilling methods for accessing subsurface contamination with the focus on removing VOC's.

1.4 HORIZONTAL DRILLING APPLICATION MATRICES

The final phase of the technical forum was to produce a matrix for each of the DOE sites which specifies the subsystem equipment recommended for each application. The purpose of this exercise was to combine all the information of the workshop and forum into a usable format for designing the optimum horizontal drilling system for a particular application at a particular DOE site. Generally, two subsystems were recommended; the

first being the preferred system, the second being the first alternative. The most expensive state-of-the-art subsystem was not chosen as the preferred system unless the application required (i.e., drilling next to high level underground storage tanks which will require the most precise state-of-the-art directional control equipment). It was apparent through doing this exercise that defining the optimum subsystem for a particular application is highly dependant on project specific variables (e.g., extent of contamination, hydrogeology, data quality objectives, project budget, etc.). However, these matrices will provide general guidance to the planning of horizontal drilling projects as they apply to remediation, monitoring, barrier emplacement, characterization, and hydrologic control.

Finally, the footnote identified with each subsystem denotes the stage of development and availability of the subsystem equipment. The developmental stage of the equipment often is an indication of the potential time and cost associated with fully developing the components for use.

The following are the matrices for the Hanford Site, Idaho National Engineering Laboratory, Lawrence Livermore National Laboratory, Nevada Test Site, Rocky Flats Plant, Sandia National Lab, and Savannah River Site (Tables 3-9, respectively). Information for constructing matrices for Fernald Environmental Management Project, Los Alamos National Laboratory, and Oak Ridge Reservation were not available at the time of this document.

Table 3. Horizontal Drilling Applications Matrix for the Hanford Site

	DIRECTIONAL CONTROL	CIRCULATION MEDIA	DRILLING TOOLS	CUTTINGS CONTAINMENT	COMPLETION DESIGN
VAPOR EXTRACTION	STEERING SYSTEM$_1$ MWD$_1$	BIODEGRADABLE FLUID (ENV. ACCEPT)$_2$ AIR MIST$_1$	DOWNHOLE MOTOR - AIR$_2$ (DHM - AIR) DHM - FLUID$_1$	SEALED$_2$ (DEPENDS ON LOCATION)	4" S.S./NO PACK$_1$ HDPE$_1$
INSITU BIOREMEDIATION	STEERING SYSTEM$_1$ MWD$_1$	AIR/MIST$_1$ FLUID$_1$	DHM - AIR$_2$ DHM - FLUID$_1$	SEALED$_2$	S.S./NO PACK RETRACTABLE TO PREVENT BIOFOULING$_2$
MONITORING (LEAK DETECTION)	GYRO w/ SURVEY$_1$ SINGLE/MULTIPLE SHOT$_1$	AIR$_1$ FLUID$_1$	DHM - AIR$_2$ DHM - FLUID$_1$	SEALED$_2$	S.S./NO PACK $_1$ LINER$_1$
BARRIERS	GYRO$_1$ STEERING TOOL$_1$	FLUID$_1$	DHM - FLUID$_1$ MICROTUNNEL$_1$	SEALED$_2$	INJECTION PIPE$_1$ LINER$_1$
CHARACTERIZATION	STEERING$_1$ GYRO$_1$	AIR$_1$ AIR/MIST$_1$	DHM - AIR WITH CORING$_2$	SEALED$_2$	TEMPORARY CASING$_1$ ABANDON$_1$
HYDROLOGICAL CONTROL (PUMP AND INJECT)	GYRO$_1$ SINGLE SHOT$_1$	AIR$_1$ FLUID$_1$	DHM - AIR$_2$ DHM - FLUID$_1$	SEALED$_2$	S.S. PRE-PACK$_1$ S.S. GRAVEL PACK$_2$

Subscript Explanation: 1) available in industry, 2) available in industry but needs modifications, 3) conceptual.

Table 4. Horizontal Drilling Applications Matrix for the Idaho National Engineering Laboratory

	DIRECTIONAL CONTROL	CIRCULATION MEDIA	DRILLING TOOLS	CUTTINGS CONTAINMENT	COMPLETION DESIGN
VAPOR EXTRACTION	STEERING SYSTEM$_1$ GYRO w/ SURVEY$_1$	BIODEGRADABLE FLUID (ENV. ACCEPT)$_2$ AIR MIST$_1$	DOWNHOLE MOTOR - AIR$_2$ (DHM - AIR) DHM - FLUID$_1$	SEALED$_2$ (DEPENDS ON LOCATION)	4"-6" S.S. SLOTTED$_1$ HDPE$_1$
INSITU BIOREMEDIATION	STEERING SYSTEM$_1$ GYRO w/ SURVEY$_1$	AIR/MIST$_1$ FLUID$_1$	DHM - AIR$_2$ DHM - FLUID$_1$	SEALED$_2$	S.S./NO PACK RETRACTABLE TO PREVENT BIOFOULING$_2$
MONITORING (LEAK DETECTION)	STEERING SYSTEM$_1$ GYRO w/ SURVEY$_1$	AIR$_1$ FLUID$_1$	DHM - AIR$_2$ DHM - FLUID$_1$	SEALED$_2$	S.S./NO PACK $_1$ LINER$_1$
BARRIERS	STEERING SYSTEM$_1$ GYRO w/ SURVEY$_1$	FLUID$_1$	DHM - FLUID$_1$ MICROTUNNEL$_1$	SEALED$_2$	INJECTION PIPE$_1$ LINER$_1$
CHARACTERIZATION	STEERING SYSTEM$_1$ GYRO w/ SURVEY$_1$	AIR$_1$ AIR/MIST$_1$	DHM - AIR WITH CORING$_2$	SEALED$_2$	TEMPORARY CASING$_1$ PLASTIC$_1$
HYDROLOGICAL CONTROL (PUMP AND INJECT)	STEERING SYSTEM$_1$ GYRO w/ SURVEY$_1$	AIR$_1$ FLUID$_1$	DHM - AIR$_2$ DHM - FLUID$_1$	SEALED$_2$	S.S. PRE-PACK$_1$ S.S. GRAVEL PACK$_2$

Subscript Explanation: 1) available in industry, 2) available in industry but needs modifications, 3) conceptual.

Table 5. Horizontal Drilling Applications Matrix for the Lawrence Livermore National Laboratory

	DIRECTIONAL CONTROL	CIRCULATION MEDIA	DRILLING TOOLS	CUTTINGS CONTAINMENT	COMPLETION DESIGN
VAPOR EXTRACTION	STEERING SYSTEM$_1$ GYRO/SURVEY$_1$	AIR/MIST$_1$	DHM - AIR$_2$ DHM - FLUID$_1$	AIR/LIQUID$_1$	4" S.S. SLOTTED/NO PACK$_1$ 4" PLASTIC/SLOTTED$_1$
INSITU BIOREMEDIATION	STEERING SYSTEM$_1$ GYRO/SURVEY$_1$	AIR/MIST$_1$	DHM - AIR$_2$ DHM-FLUID$_1$	AIR/LIQUID$_1$	4" S.S./SLOTTED/ GRAVEL PACK$_2$ 4" PLASTIC/SLOTTED/ GRAVEL PACK$_2$
MONITORING (LEAK DETECTION)	STEERING SYSTEM$_1$ GYRO/SURVEY$_1$	MUD$_1$ AIR$_1$	JACKING/HAMMERS$_2$ DHM - AIR$_2$	AIR/LIQUID$_1$	2"-4" S.S./NO PACK$_1$ LINED$_1$
BARRIERS	NOT APPLICABLE	NOT APPLICABLE	NOT APPLICABLE	NOT APPLICABLE	NOT APPLICABLE
CHARACTERIZATION	STEERING SYSTEM$_1$ GYRO/SURVEY$_1$	FLUID$_1$ AIR$_1$	JACKING/HAMMERS$_2$ PUNCH - CORING$_2$	AIR/LIQUID$_1$	TEMPORARY CASING$_1$ ABANDON$_1$
HYDROLOGIC CONTROL (PUMP AND INJECT)	STEERING SYSTEM$_1$ GYRO/SURVEY$_1$	AIR$_1$ FLUID$_1$	DHM - AIR$_2$ DHM - FLUID$_1$	AIR/LIQUID$_1$	4" S.S./PREPACK$_1$/ GRAVEL PACK$_2$

Subscript Explanation: 1) available in industry, 2) available in industry but needs modifications, 3) conceptual.

Table 6. Horizontal Drilling Applications Matrix for the Nevada Test Site

	DIRECTIONAL CONTROL	CIRCULATION MEDIA	DRILLING TOOLS	CUTTINGS CONTAINMENT	COMPLETION DESIGN
VAPOR EXTRACTION	STEERING SYSTEM$_1$ GYRO w/ SURVEY$_1$	AIR/FOAM$_1$	AUGER$_1$ DHM - AIR$_2$	SEALED$_2$ (DEPENDS ON LOCATION)	S.S. SCREEN w/ GRAVEL PACK$_2$
INSITU BIOREMEDIATION	STEERING SYSTEM$_1$ GYRO w/ SURVEY$_1$	AIR/FOAM$_1$	AUGER$_1$ DHM - AIR$_2$	SEALED$_2$	S.S. SCREEN w/ GRAVEL PACK$_2$
MONITORING (LEAK DETECTION)	STEERING SYSTEM$_1$ GYRO w/ SURVEY$_1$	AIR/FOAM$_1$	AUGER$_1$ DHM - AIR$_2$	SEALED$_2$	S.S. SCREEN w/ GRAVEL PACK$_2$
BARRIERS	STEERING SYSTEM$_1$ GYRO w/ SURVEY$_1$	AIR/FOAM$_1$	AUGER$_1$ DHM-AIR$_2$	SEALED$_2$	S.S. SCREEN w/ GRAVEL PACK$_2$
CHARACTERIZATION	STEERING SYSTEM$_1$ GYRO w/ SURVEY$_1$	AIR/FOAM$_1$	AUGER$_1$ DHM-AIR$_2$	SEALED$_2$	S.S. SCREEN w/ GRAVEL PACK$_2$
HYDROLOGICAL CONTROL (PUMP AND INJECT)	STEERING SYSTEM$_1$ GYRO w/ SURVEY$_1$	AIR/FOAM$_1$	AUGER$_1$ DHM - AIR$_2$	SEALED$_2$	S.S. SCREEN w/ GRAVEL PACK$_2$

Subscript Explanation: 1) available in industry, 2) available in industry but needs modifications, 3) conceptual.

Table 7. Horizontal Drilling Applications Matrix for the Rocky Flats Plant

	DIRECTIONAL CONTROL	CIRCULATION MEDIA	DRILLING TOOLS	CUTTINGS CONTAINMENT	COMPLETION DESIGN
VAPOR EXTRACTION	$GYRO_1$ MWD_1	AIR_1 $AIR/MIST_1$	DOWNHOLE MOTOR - $(DHM)_1$	$SEALED_2$	4" $S.S./GRAVEL\ PACK_2$ $HDPE_1$
INSITU BIOREMEDIATION	$GYRO_1$ MWD_1	AIR_1 $FLUID_1$	DHM_1	$SEALED_2$	4" $S.S./GRAVEL\ PACK_2$ $HDPE_1$
MONITORING (LEAK DETECTION)	$GYRO_1$ MWD_1	AIR_1 $AIR/MIST_1$	DHM_1 $CORING/HAMMER_1$	$SEALED_2$	LARGE DIA. $HDPE_1$
BARRIERS	$GYRO_1$ MWD_1 PILOT HOLE	ANY_1	DHM_1 $JACKING/HAMMER_1$	$SEALED_2$	4" $S.S./GRAVEL\ PACK_1$ $HDPE_1$
CHARACTERIZATION	$GYRO_1$ MWD_1	AIR_1 $AIR/MIST_1$	DHM_1 $CORING/SONIC_2$	AIR_2	4" $S.S./GRAVEL\ PACK_1$ $HDPE_1$
HYDROLOGICAL CONTROL (PUMP AND INJECT)	$GYRO_1$ MWD_1	$FLUID_1$ AIR_1	DHM_1 $CORING/SONIC_2$	$SEALED_2$	4" $S.S./GRAVEL\ PACK_1$ $HDPE_1$

Subscript Explanation: 1) available in industry, 2) available in industry but needs modifications, 3) conceptual.

Table 8. Horizontal Drilling Applications Matrix for the Sandia National Lab Site

	DIRECTIONAL CONTROL	CIRCULATION MEDIA	DRILLING TOOLS	CUTTINGS CONTAINMENT	COMPLETION DESIGN
VAPOR EXTRACTION	STEERING SYSTEM$_1$ GYRO/SURVEY$_1$	AIR/MIST$_1$	DHM - AIR$_2$	AIR$_1$	4" S.S. SLOTTED/NO PACK$_1$ 4" PLASTIC/SLOTTED$_1$
INSITU BIOREMEDIATION	STEERING SYSTEM$_1$ GYRO/SURVEY$_1$	AIR/MIST$_1$	DHM - AIR$_2$	AIR$_1$	4" S.S./SLOTTED/ GRAVEL PACK$_2$ 4" PLASTIC/SLOTTED/ GRAVEL PACK$_2$
MONITORING (LEAK DETECTION)	STEERING SYSTEM$_1$ GYRO/SURVEY$_1$	NONE$_2$ AIR$_1$	JACKING/HAMMERS$_2$ DHM - AIR$_2$	AIR$_1$	2"-4" S.S./NO PACK$_1$ LINED$_1$
BARRIERS	STEERING SYSTEM$_1$ GYRO/SURVEY$_1$	AIR$_1$ FLUID$_1$	ANY	AIR$_1$	INJECTION PIPE$_1$ LINER$_1$
CHARACTERIZATION	STEERING SYSTEM$_1$ GYRO/SURVEY$_1$	NONE$_2$ AIR$_1$	JACKING/HAMMERS$_2$ PUNCH - CORING$_2$	AIR$_1$	TEMPORARY CASING$_1$ ABANDON$_1$
HYDROLOGIC CONTROL (PUMP AND INJECT)	STEERING SYSTEM$_1$ GYRO/SURVEY$_1$	AIR$_1$ FLUID$_1$	DHM - AIR$_2$ DHM - FLUID$_1$	AIR$_1$	4" S.S./PREPACK$_1$/ GRAVEL PACK$_2$

Subscript Explanation: 1) available in industry, 2) available in industry but needs modifications, 3) conceptual.

Table 9. Horizontal Drilling Applications Matrix for the Savannah River Site

	DIRECTIONAL CONTROL	CIRCULATION MEDIA	DRILLING TOOLS	CUTTINGS CONTAINMENT	COMPLETION DESIGN
VAPOR EXTRACTION	ANY (GYRO NOT NECESSARY)	FLUID$_1$ NONE$_2$	ANY	LIQUID RETENTION$_1$	4" S.S./SLOTTED/ NO PACK$_1$ 4" PLASTIC/SLOTTED$_1$
INSITU BIOREMEDIATION	ANY (GYRO NOT NECESSARY)	FLUID$_1$ NONE$_2$	ANY	LIQUID RETENTION$_1$	4" S.S./SLOTTED/ GRAVEL PACK$_2$ PLASTIC/SLOTTED/ GRAVEL PACK$_2$
MONITORING (LEAK DETECTION)	GYRO WITH STEERING$_1$	FLUID$_1$ NONE$_2$	ANY	LIQUID RETENTION$_1$	2"-4" S.S./NO PACK$_1$ LINER$_1$
BARRIERS	GYRO WITH STEERING$_1$	FLUID$_1$ NONE$_2$	ANY	LIQUID RETENTION$_1$	INJECTION PIPE$_1$ LINER$_1$
CHARACTERIZATION	GYRO WITH STEERING$_1$	AIR/MIST$_2$	DHM - CORE$_1$ RESONANCE$_3$	LIQUID RETENTION$_1$	TEMPORARY CASING$_1$ ABANDON$_1$
HYDROLOGIC CONTROL (PUMP AND INJECT)	ANY (GYRO NOT NECESSARY)	FLUID$_1$ NONE$_2$	ANY	LIQUID RETENTION$_1$	PACK OR GRAVEL PACK$_2$

Subscript Explanation: 1) available in industry, 2) available in industry but needs modifications, 3) conceptual.

Table 10. Horizontal Drilling Applications Matrix for the Fernald Environmental Management Project

At the time of this document no horizontal drilling needs were identified for the Fernald Environmental Management Project. Should these needs be identified in the future, a drilling application matrix will be constructed and added to subsequent revisions to this document.

Table 11. Horizontal Drilling Applications Matrix for the Los Alamos National Laboratory

At the time of this document no horizontal drilling needs were identified for the Los Alamos National Laboratory. Should these needs be identified in the future, a drilling application matrix will be constructed and added to subsequent revisions to this document.

Table 12. Horizontal Drilling Applications Matrix for the Oak Ridge Reservation

At the time of this document no horizontal drilling needs were identified for the Oak Ridge Reservation. Should these needs be identified in the future, a drilling application matrix will be constructed and added to subsequent revisions to this document.

2.0 CONCLUSIONS AND RECOMMENDATIONS

The horizontal drilling system needed at DOE arid sites, will most likely be a combination of technologies or subsystems. At present there is not a system available that can meet the demands of drilling in unconsolidated gravel deposits with a high degree of accuracy and meet the safety concerns associated with drilling near mixed waste facilities. More development is needed to combine the subsystems that have the highest potential to meet those demands.

Technological advancements in horizontal drilling are occurring rapidly. For example, much of the information and technologies presented at this workshop were in the development stages. Even those technologies that have been used for environmental applications in the past are continuously being refined to meet demanding conditions.

There are a number of things that can be done to assist in the further development of this new innovative technology which include building upon the information gained during this workshop. This can be accomplished through additional workshops as well as equipment demonstrations. The following workshop subjects and demonstrations should be considered in the future:

- air and liquid containment systems for drilling in radioactive and mixed waste locations
- high precision directional control equipment for drilling near structurally fatigued or highly contaminated facilities
- demonstration of horizontal drilling tools at the location of their intended use
- demonstration of containment systems using passive tracer material for evaluating efficiency

3.0 REFERENCES

Anderson, S. R, 1990. *A Preliminary Geohydrologic Evaluation of Basalt and Sediment Underlying the Snake River Plain at the Idaho National Engineering Laboratory.* Geological Society of America, Abstracts with Programs, 86th Annual Meeting. Cordilleran Section, v. 22, no. 3.

ESG 1989. *Environmental Surveillance Group, Environmental Surveillance at Los Alamos During 1988.* LA-11628-ENV, Los Alamos National Laboratory, Los Alamos, New Mexico.

Kaback, D. S., B. D. Looney, C. A. Eddy, T. C. Hazen, 1991. *Innovative Ground Water and Soil Remediation: In Situ Air Stripping Using Horizontal Wells*, Proceedings of the Fifth Outdoor Action Conference on Aquifer Restoration, Ground Water Monitoring, and Geophysical Methods, pp. 47-51, May 13-16, 1991, Presented by the Association of Ground Water Scientists and Engineers, Division of NWWA.

Krueger, J. W., 1990. *The Los Alamos National Laboratory Environmental Restoration Program.* LA-UR-90-3397, Los Alamos National Laboratory, Los Alamos, New Mexico.

McLaughlin, T. J., S. P. Airhart, K. L. Beattie, J. K. Rouse, S. J. Phillips, 1992. *Subsurface Barrier Technologies as Potential Interim Actions for Department of Energy Underground Storage Tanks.* WHC-SA-1549-FP, Prepared for the U.S. Department of Energy by Westinghouse Hanford Company. To be presented at Spectrum '92, Boise, Idaho, August 23-27, 1992.

DOE, 1992. *Final Environmental Impact Statement, Lawrence Livermore National Laboratory and Sandia National Laboratories - Livermore Sites, Livermore, California.* DOE/EIS-0028, United States Department of Energy, Washington, D.C.

DOE, 1991a. *Treatability Study Work Plan for the Vitrification of Resudues from Silos 1, 2, and 3.* U. S. Department of Energy, Fernald Office, Fernald, Ohio.

DOE, 1991b. *Phase II RFI/RI Workplan (Alluvial) for the 903 Pad, Mound, and East Trenches Areas, Operable Unit Number 2.* 21100-WP-OU02.1, Rocky Flats Plant Office.

DOE, 1990. *Remedial Investigation Report for Operable Unit 4.* U. S. Department of Energy, Oak Ridge Office, Oak Ridge, Tennessee.

DOE, 1987. *Waste Management Activities for Groundwater Protection Savannah River Plant, Aiken, South Carolina.* Final Environmental Impact Statement. Volume 1. DOE-EIS-0120, U.S. Department of Energy, Washington D.C.

Weeren, H. O., G. D. Brunton, W. deLaguna, and J. G. Moore, 1974. *Hydrofracture Site Proof Study at Oak Ridge National Laboratory*, ORNL/TM-4713, Union Carbide Corporation, Oak Ridge, Tennessee.

Westinghouse Materials Company of Ohio, 1990. *Feed Materials production Center Annual Environmental Report for Calendar Year 1989.* FMPC-2200, Westinghouse Materials Company of Ohio, Cincinnati, Ohio.

Woodruff R. K., R. W. Hanf, M. G. Hefty, R. E. Lundgren, 1991. *Hanford Site Environmental Report for Calendar Year 1990.* PNL-7930/UC-602, Prepared by Pacific Northwest Laboratory for the U.S. Department of Energy, Richland, Washington.

Yeasted, J. G., D. J. Carr, C. R. Conner, and R. T. Wilde, 1988. *Complex Environmental Requirements Compel Logical Approach: The CERCLA Framework at Fernald.* U. S. Department of Energy, Oak Ridge Office, Oak Ridge, Tennessee.

Ziagos, J. P., R. W. Bainer, M. D. Dresen, J. D. Hoffman, 1992. *Environmental Restoration at the Lawrence Livermore National Laboratory Livermore Site.* UCRL-JC-109493 ext abs., Lawrence Livermore National Laboratory, Livermore, California.

DISTRIBUTION

Number of copies

OFFSITE

Number of copies	
1	Willard P. Acheson **K & M Engineering** 583 Allegheny Avenue Oakmont, PA 15139
1	Steve Airhart **Bovay Northwest Inc.** 660 Swift, Suite D Richland, WA 99352
1	David Louis Biancosino **Department of Energy - HAZWRAP Program** P.O. Box 2003 - MS/7606 Oak Ridge, TN 37831-7606
1	Dee Jay Burrie **Shannon & Wilson, Inc.** 1354 Grandridge Blvd Kennewick, WA 99336
1	Mr. Chuck Cline **State of Washington** **Department of Ecology** MS PV-11 Olympia, WA 98504-8711
1	Dr. George Cooper **University of California, Berkeley** Engineering Geoscience 414 Hearst Mining Building Berkeley, CA 94720
1	Mr. Richard Davidson **Woodward-Clyde Consultants** Stanford Place 3, Suite 1000 4582 South Ulster Street Denver, CO 80237
1	Mr. James C. Dunn **Sandia National Laboratories** Geothermal Research Division 6242 Albuquerque, NM 87185
1	Chris Edison, C.E.I. **Bovay Northwest Inc.** East 808 Sprague Avenue Spokane, WA 99202

1 Gregory Scott Goral
Michels Pipeline Construction, Inc.
P.O. Box 128
817 West Main Street
Brownsville, WI 53006

1 Colin B. Goranson
Lawrence Berkeley Laboratory
1498 Aqua Vista Road
Richmond, CA 94805

1 Joel M. Hubbell
EG&G, Idaho National Engineering Laboratory
P.O. Box 1625, MS 2107
Idaho Falls, ID 83415

1 Pamela S. Innis
U.S. Environmental Protection Agency
712 Swift, Suite 5
Richland, WA 99352

1 Eric J. Jensen
Bovay Northwest Inc.
660 Swift, Suite D
Richland, WA 99352

1 Philip Webb Johnson
Neyrfor Weir Turbo Drilling
P.O. Box 870207
Tuscaloosa, AL 35487-0207

1 Dr. Dawn S. Kaback
Westinghouse, Savannah River Company
P.O. Box 616
Aiken, SC 29802

1 Haraldur Karlsson
Eastman Christensen Environmental Systems
P.O. Box 670968
Houston, TX 77267-0968

1 Carlos P. Kenda
Eastman Christensen Environmental Systems
P.O. Box 670968
Houston, TX 77267-0968

1 Mr. Robert Lampert
Applied Navigation Systems
3025 Buena Vista Dr.
Paso Robles, CA 93446

1	William C. Lyons **Neyrfor Weir Turbo Drilling** 1008 Rocky Road Socorro, NM 87801
1	David W. May **Cherrington Environmental** 222 Big Hollow Houston, TX 77042
1	Gene Mckay, President **Bovay Northwest Inc.** East 808 Sprague Avenue Spokane, WA 99202
1	Thomas J. McLaughlin, Tri-Cities Office Manager **Bovay Northwest Inc.** 660 Swift, Suite D Richland, WA 99352
1	Mr. Jerry Mercer **Sandia National Laboratories** P.O. Box 5800 Div. 6252 Albuquerque, NM 87110
1	Mark Dennis Nickelson **Martin Marietta Energy System, Inc.** P.O. Box 2003 MS-7606 Oak Ridge, TN 37831
1	Mr. William Overby, Jr. **BDM Engineering Services Company** 1199 Van Voorhis Road Suite 4 Morgentown, WV 26506
1	Dr. Paul Pettit **Haliburton NUS** P.O. Box 721110 Houston, TX 77272
1	Frank W. Pita **Shannon & Wilson, Inc.** P.O. Box 300303 Seattle, WA 98103
1	Mr. Roy Powell **Neyerfor Wier Turbo Drilling** 19506 Highway 59 North Suite 201 Humble, TX 77338

1 David Franklin Putman
Raytheon Services Nevada
101 Convention Center Drive, Suite P-280
Las Vegas, NV 89109

1 Mr. David Russell
K&M Engineering
4642 Warrior Trail
Lilburn, GA 30247

1 Michael L. Ryall
Weir Group PLC
149 Newlands Road, Cathcart
Glasgow, Scotland G44 4EX

1 Rafael Simon
University of California, Berkeley
Engineering Geosciences
Hearst Mining Building
Berkeley, CA 94720

1 Robert E. Smith, Vice President
Bovay Northwest Inc.
East 808 Sprague Avenue
Spokane, WA 99202

1 Mr. Ron Tagliapietra
Michels Pipeline Construction Inc.
817 West Main Street
P.O. Box 128
Brownsville, WI 53006

1 Matthew Donald Van Steenwyk
Applied Navigational Devices
3025 Buena Vista Drive
Paso Robles, CA 93446

1 William R. Weltin
Michels Pipeline Construction, Inc.
817 West Main Street
Brownsville, WI 53006

1 Kendrick Wayne Wentzel
K&M Engineering
2001 L. Street, N.W.
Washington, D.C. 20036

1 Dana L. White
Stone & Webster Engineering
P.O. Box 550
Richland, WA 99352

1	David D. Wilson **CDM Federal Programs Corp.** 1626 Cole Boulevard Suite 100 Golden, CO 80401	
1	Ellery H. Wilson **EG&G Environmental Management** 14142 Denver West Parkway Golden, CO 80401	

ONSITE

1	**U.S. Department of Energy - Richland Operations Office**	
	K. M. Thompson	A5-15
5	**Pacific Northwest Laboratory**	
	T. M. Brouns	P7-41
	G. V. Last	K6-96
	S. P. Luttrell	K6-96
	S. L. Stein	BSRC
	Hanford Technical Library	P8-55
48	**Westinghouse Hanford Company**	
	M. R. Adams	H4-55
	J. E. Auten	L4-78
	J. D. Berger	L0-18
	J. A. Bultena	N3-06
	J. W. Cammann	H4-14
	B. R. Cassem	N3-05
	J. L. England	L7-09
	D. B. Erb	H4-55
	K. R. Fecht	H4-56
	M. G. Gardner	N3-06
	M. C. Hagood	H4-55
	D. O. Hess	L6-57
	R. L. Jones	N3-05
	G. L. Kasza	H5-29
	V. L. King	H4-56
	A. J. Knepp	H4-56
	K. J. Koegler	H4-55
	K. A. Lindsey	H5-29
	H. E. McGuire	B3-63
	G. W. McLellan	N3-05
	P. D. Mix	L4-92
	D. J. Moak	N3-05
	D. R. Myers	H4-14
	N. M. Naiknimbalkar	H4-55
	R. W. Powell	H4-14
	W. H. Price	N3-05
	V. J. Rohay	H4-56

K. D. Reynolds	H5-29
W. V. Setzer	N3-06
W. E. Stewart	H4-14
J. A. Stottlemyre	K6-75
D. S. Takasumi	L4-78
K. M. Thompson DOE-RL	A5-15
D. E. Trader DOE-RL	A5-90
B. W. Volk	N3-05
R. I. Watkins	E6-41
D. C. Weekes	H5-29
B. A. Williams	H4-56
T. M. Wintczak	L4-92
R. D. Wojtasek	L4-92
Central Files	L8-04
EDMC (2)	H4-22
ERE Records Center	H4-55
IRA (3)	H4-17
Resource Center	N3-05