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# Environmental Measurement-While-Drilling System and Horizontal Directional Drilling Technology Demonstration, Hanford Site

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# Environmental Measurement-While-Drilling System And Horizontal Directional Drilling Technology Demonstration, Hanford Site

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## ABSTRACT

The Environmental Measurement-While-Drilling (EMWD) system and Horizontal Directional Drilling (HDD) were successfully demonstrated at the Mock Tank Leak Simulation Site and the Drilling Technology Test Site, Hanford, Washington. The use of directional drilling offers an alternative to vertical drilling site characterization. Directional drilling can develop a borehole under a structure, such as a waste tank, from an angled entry and leveling off to horizontal at the desired depth. The EMWD system represents an innovative blend of new and existing technology that provides the capability of producing real-time environmental and drill bit data during drilling operations.

The technology demonstration consisted of the development of one borehole under a mock waste tank at a depth of ~ -8 m (-27 ft.), following a predetermined drill path, tracking the drill path to within a radius of ~1.5 m (5 ft.), and monitoring for zones of radiological activity using the EMWD system. The purpose of the second borehole was to demonstrate the capability of drilling to a depth of ~ -21 m (-70 ft.), the depth needed to obtain access under the Hanford waste tanks, and continue drilling horizontally. This report presents information on the HDD and EMWD technologies, demonstration design, results of the demonstrations, and lessons learned.

# ACKNOWLEDGMENTS

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  - Directional Survey Report
  - TruTracker™ Survey Report
  - Data Verification Report
  - Field Survey Data Plot

# LIST OF ACRONYMS

| | |
|---|---|
| A & L | A & L Underground, Inc. |
| AP | Activity Plan |
| BHA | Bottom Hole Assembly |
| BHI | Bechtel Hanford Incorporated |
| bps | bits per second (baud) |
| DC | direct current |
| DTTS | Drilling technology Test Site |
| EMWD | Environmental Measurement-While-Drilling |
| ERDF | Environmental Restoration Disposal Facility |
| ERT | Electrical Resistance Tomography |
| FM | Frequency Modulation |
| FDH | Fluor Daniel Hanford |
| GRS | Gamma Ray Spectrometer |
| HDD | Horizontal Directional Drilling |
| HPT | Health Physics Technician |
| IC | integrated circuit |
| KUT | Potassium, uranium, thorium |
| LMHC | Lockheed Martin Hanford Corporation |
| ma | milliamp |
| MTLSS | Mock Tank Leak Simulation Site |
| NRZ | non-return to zero |
| PC | personal computer |
| PMT | photomultiplier tube |
| PNNL | Pacific Northwest National Laboratory |
| RF | radio frequency |
| SNL | Sandia National Laboratories |
| SST | Single-shell Tank |
| TTL | transistor-transistor logic |
| TWRS | Tank Waste Remediation System |
| U. S. DOE | U.S. Department of Energy |
| V | Volt |
| WHC | Westinghouse Hanford Company |

# INTRODUCTION

Vadose zone contaminant plumes are known to exist beneath single-shell tanks (SST). At the Hanford Site, Washington (Figure 1), SSTs have released tank liquids into the subsurface creating these plumes. These plumes have been identified through gamma ray logging of both vertically oriented dry wells, and, in selected tank farms, through use of lateral wells that extend beneath the tanks. Due to safety concerns and physical degradation, these laterals are no longer available for monitoring or investigations. Early investigators (Raymond and Shdo, 1966) used the laterals in the 241-SX Tank Farm to map the extent of contamination that resulted from leaks in the 108-, 109-, and 115-SX tanks. More recent interpretations of contaminant lateral spread have been based solely on extrapolation of gamma logging results between vertical dry wells often spaced 40+ feet apart. In some instances, notably 115-SX, this method of extrapolation misses a known plume that was mapped by Raymond and Shdo (1966).

A means of assessing the presence of contaminants beneath tanks, as well as defining the actual horizontal extent of a contaminant plume is needed. These data will go far in defining the magnitude of the source term associated with a release event and possibly allow better quantification of the original leak volume. These data bear directly on the impact of releases on the environment and the ability to extrapolate these analyses to predict the impact of any releases that may take place during retrieval operations.

The Tank Waste Remediation System (TWRS), Hanford Site, has identified a need to characterize a series of "most impacted" locations that are contaminated by tank wastes. Such characterization may employ a variety of methods to develop the necessary understanding of the subsurface conditions and processes in each "most impacted" location. The TWRS Vadose Zone Program Plan identified Horizontal Directional Drilling (HDD) with Environmental Measurement-While-Drilling (EMWD) system, among other techniques, as being likely characterization technologies to be deployed. Directional drilling capability has advanced in recent years to the point where its application in the sands and gravels of the Hanford Site is a real possibility. Sandia National Laboratories has developed a means of providing real-time spectral gamma and position data as a directional drilling operation is conducted.

A demonstration of HDD with EMWD was conducted at the Hanford Site to accomplish the following:

- Define and assess the capability of HDD to follow a predetermined drill plan in a simulated tank farm environment
- Demonstrate the capability to define zones of subsurface radiological using the EMWD system.

Horizontal boreholes were drilled at two different cold test sites using the horizontal directional drilling technique. This effort demonstrated HDD and the collection of environmental information while drilling using the EMWD system. The first borehole was drilled at the Mock Tank Leak Site in the 200 East Area. This site provides a means of assessing drill bit control in a nonhazardous environment. The SNL-developed EMWD system, which contains a magnetometer and sodium iodide (NaI) gamma spectrometer, was also run in the borehole. The EMWD tool was used to verify drill bit location and to monitor for zones of naturally occurring radioactivity. The data on naturally occurring radionuclides may provide additional insight into the distribution of clastic dikes in the subsurface of the Hanford Site. The second borehole was developed at the Drilling Technology Test Site. The purpose of the second borehole was to demonstrate the capability of directionally drilling to a depth of >21 m (70 ft.), the depth needed to obtain access under the Hanford waste tanks, continue drilling horizontally, and to track position. A sample retrieval demonstration was also planned at this site.

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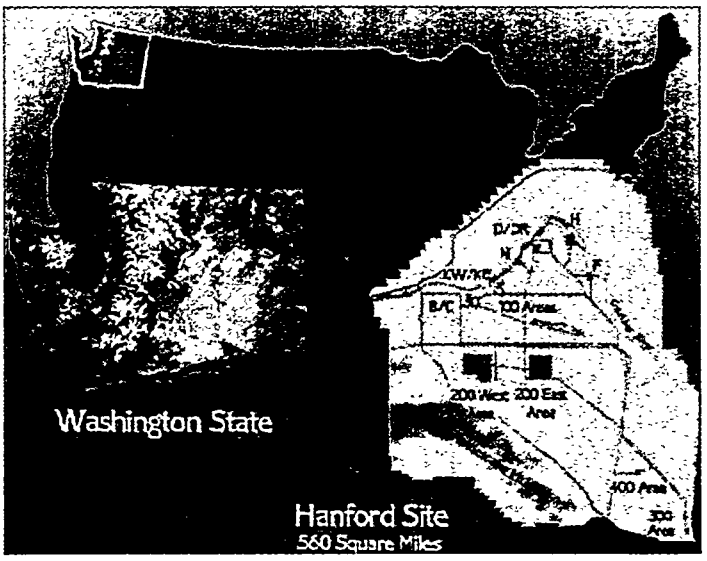


**Figure 1. Hanford Site, Washington.**

# SITE INFORMATION

## Identifying Information

| | |
|---|---|
| *Facility:* | Mock Tank Leak Simulation Site<br>Drilling Technology Test Site |
| *Location:* | DOE Hanford Site |
| *OU/SWMU:* | Cold Test Sites |
| *Type of Action:* | Technology Demonstration |
| *Technology:* | Directional Drilling and Environmental Measurement-While-Drilling |
| *Period of Operation:* | 9/14/98 to 10/2/98 |

## Site Background

### Mock Tank Leak Simulation Site

The Mock Tank Leak Simulation Site (MTLSS) is located in the north-central part of the 200 East Area (Figures 2 and 3). The mock tank consists of a 15 m (50 ft.) diameter steel "tank" (metal ring), with its base approximately 1.5 m (5 ft.) below the ground surface. While smaller than a typical 25 m (75 ft.) diameter single-shell tank (SST), the surface interferences, while not including a full suite of ancillary piping, are similar to those anticipated to be present around a full-size SST. This is a cold test site originally designed to conduct Electrical Resistance Tomography (ERT) studies.

### Drilling Technology Test Site

The second drill site for this demonstration was the Drilling Technology Test Site (DTTS) located immediately north of the 200 Area Fire Station in the Environmental Restoration Disposal Facility (ERDF) map area (Figures 2 and 4). This site has been used for a variety of drilling demonstrations.

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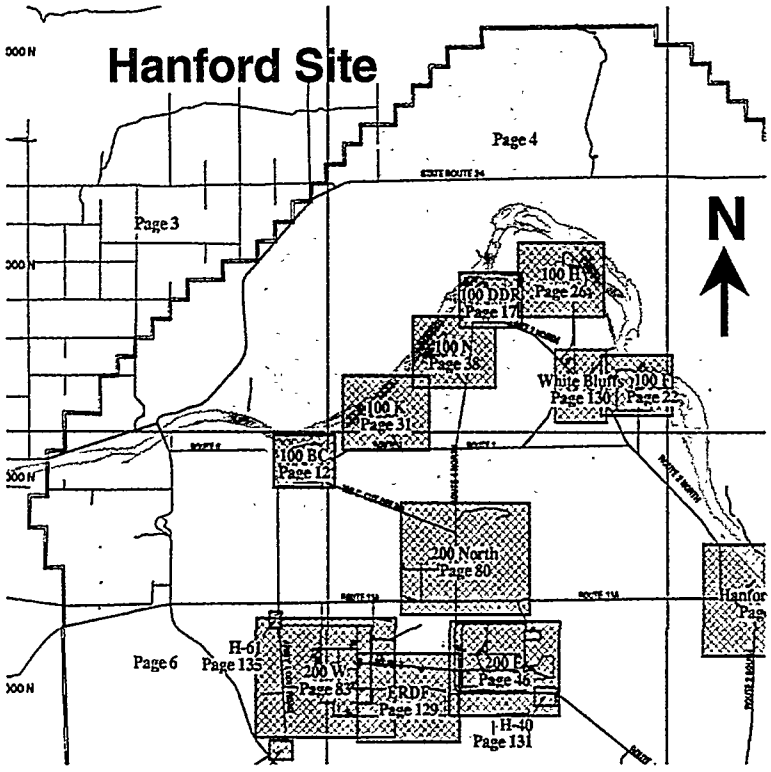


**Figure 2. Hanford Site showing location of the Environmental Restoration Disposal Facility (ERDF) and 200 East Area.**

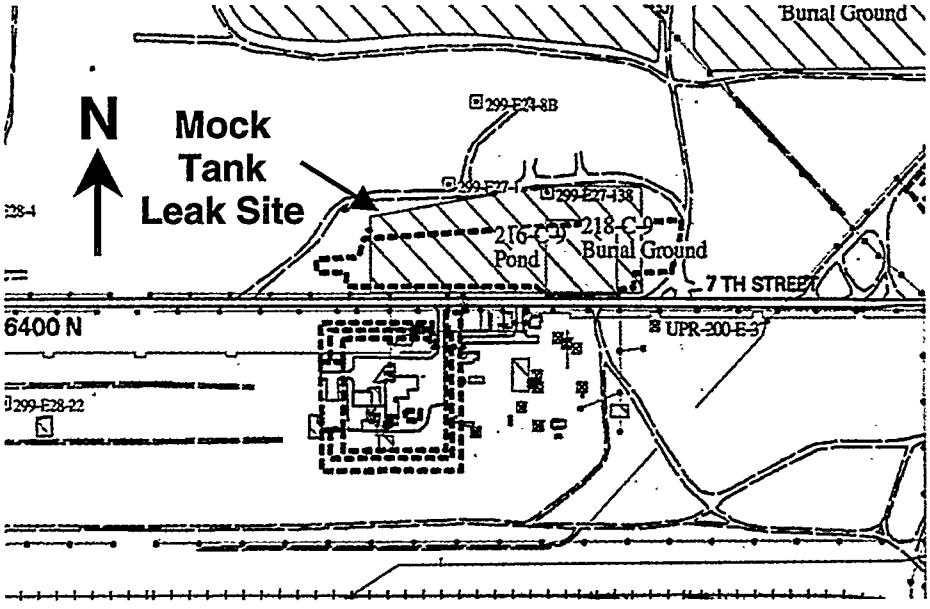


**Figure 3. Mock Tank Leak Site located in the north-central part of the 200 East Area.**

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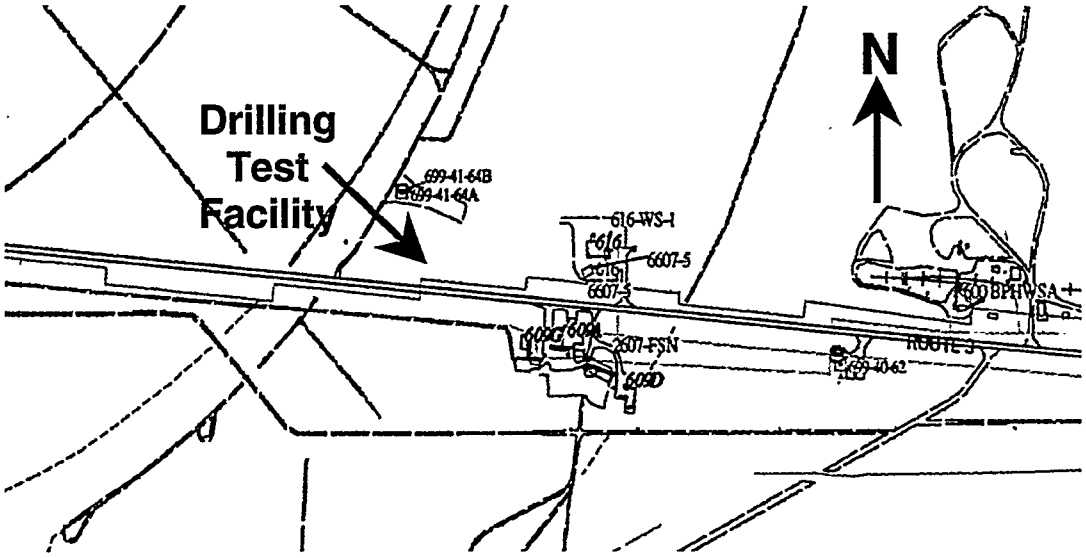


**Figure 4. Drilling Technology Test Site located north of the 200 Area Fire Station in the ERDP map area.**

## Site Geology

### Mock Tank Leak Simulation Site

The MTLSS is located in a part of the 200 East Area that is underlain by an estimated 82 m to 91 m (270 to 300 ft.) of the informal Pleistocene Hanford formation (Last et al., 1989; Lindsey et al., 1992, 1994). This formation consists of slightly consolidated, generally uncemented interstratified gravel, sand, and silt. Two of the three informal units forming the Hanford formation in the 200 East Area are present at the test site. These are the sand-dominated unit 2 and the underlying gravel-dominated unit 3. The contact between these two units lies approximately 76 m (250 ft.) below the surface at the site. The gravel-poor area surrounding the test site is defined by sand-rich lithologies interpreted from the borehole logs for wells 299-E27-1 and 299-E24-8. The dominant lithology encountered while drilling at the mock tank site was medium- to coarse-grained sand and granules, occasional pebbles, and silt-rich intervals.

The water table is believed to be at approximately 85 m (278 ft.) below the surface. All drilling activity occurred within the vadose zone. No contamination was known to be present, but sufficient differences in potassium-40 across the facies changes were anticipated to allow EMWD testing.

### Drilling Technology Test Site

The geology of the DTTS is coarser and more varied than that of the MTLSS, and thereby provided an environment to test HDD that is more representative of most SST farms. Interbedded sand, silt and gravel with a range of induration (cementation) were encountered. Some of the sand and gravel units are totally unconsolidated and presented some difficulty to controlling the drill bit during a previous test of directional drilling (WHC 1993). Gravel units near the surface (down to ~6 m) are unconsolidated and coarse to very coarse with cobbles ranging to more than 0.250 m in diameter.

The water table was anticipated to be at approximately 70 m (213 ft.) below the surface. All activity occurred within the vadose zone above. No contamination was known to be present, but sufficient differences in potassium-40 across the facies changes were anticipated to allow EMWD testing.

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# TECHNOLOGY DESCRIPTION

## Horizontal Directional Drilling

The horizontal directional drilling (HDD) process represents a significant improvement over traditional cut and cover methods for installing pipelines beneath obstructions, such as rivers or shorelines, which warrant specialized construction attention. In order to take full advantage of the benefits offered by horizontal directional drilling and produce plans which can be efficiently executed in the field, design engineers should have a working knowledge of the process. A general description of the HDD process is presented here.

The tools and techniques used in the HDD process are an outgrowth of the oil well drilling industry. The components of a horizontal drilling rig used for pipeline construction are similar to those of an oil well drilling rig with the major exception being that a horizontal drilling rig is equipped with an inclined ramp as opposed to a vertical mast. HDD pilot hole operations are not unlike those involved in drilling a directional oil well. Drill pipe and downhole tools are generally interchangeable and drilling fluid is used throughout the operation to transport drilled spoil, reduce friction, stabilize the hole, etc. Because of these similarities, the process is generally referred to as drilling as opposed to boring.

Installation of a pipeline by HDD is generally accomplished in two stages as illustrated in Figure 5. The first stage consists of directionally drilling a small diameter pilot hole along a designed directional path. The second stage involves enlarging this pilot hole to a diameter that will accommodate the pipeline and pulling the pipeline back into the enlarged hole.

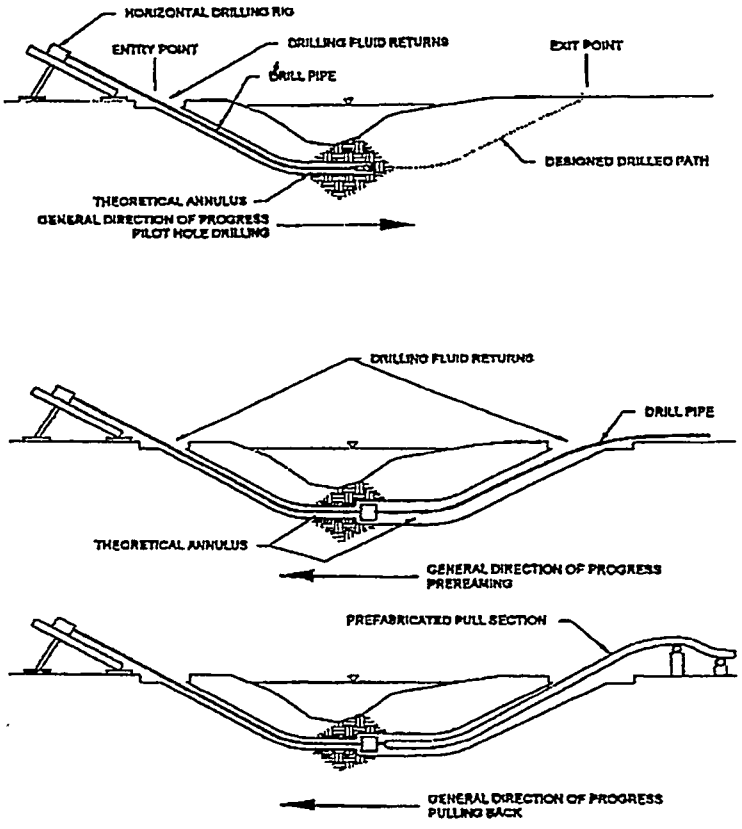


**Figure 5. The Horizontal Directional Drilling Process.**

## Pilot Hole Directional Drilling

Pilot hole directional control is achieved by applying thrust to a non-rotating drill string with an asymmetrical leading edge. The asymmetry of the leading edge creates a steering bias while the non-rotating aspect of the drill string allows the steering bias to be held in a specific position while pushing. If a change in direction is required, the drill string is rolled so that the direction of *bias* is the same as the desired change in direction. The direction of bias is referred to as the *tool face.* Straight progress may be achieved by drilling with a series of offsetting tool face positions. The drill string may also be continually rotated where directional change is not required. Leading edge asymmetry can be accomplished by several methods. Typically, the leading edge will have an angular offset created by a bent sub or bent motor housing. This is illustrated schematically in Figure 6.

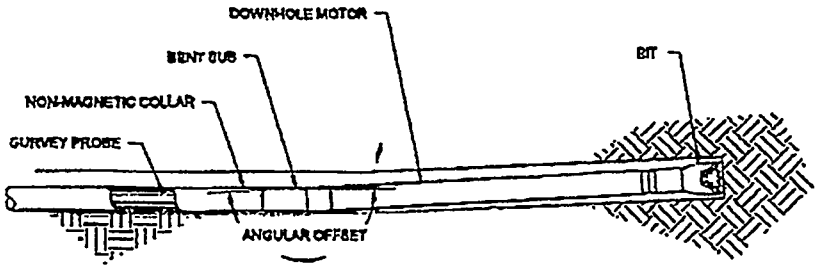


**Figure 6. Bottom Hole Assembly.**

## Jetting

In soft soils, it is common to achieve drilling progress by hydraulic cutting with a jet nozzle. In this case, the direction of flow from the nozzle can be offset from the central axis of the drill string thereby creating a steering bias. This may be accomplished by blocking selected nozzles on a standard roller cone bit or by custom fabricating a jet deflection bit. If hard spots are encountered, the drill string may be rotated to drill until the hard spot has been penetrated.

## Downhole Motors

Downhole hydraulic motors, commonly referred to as mud motors, provide mechanical cutting action required for harder soils. Mud motors convert hydraulic energy from drilling mud pumped from the surface to mechanical energy at the bit. This allows for bit rotation without drill string rotation. There are two basic types of mud motors: positive displacement and turbine. Positive displacement motors are typically used in HDD applications. Basically, a positive displacement mud motor consists of a spiral-shaped stator containing a sinusoidal shaped rotor. Mud flow through the stator imparts rotation to the rotor, which is in turn connected through a linkage to the bit.

## Casing or "Wash Pipe"

In some cases, a larger diameter wash pipe may be rotated concentrically over the non-rotating steerable drill string. This serves to prevent sticking of the steerable string and allows its tool face to be freely oriented. It also maintains the pilot hole if it becomes necessary to withdraw the steerable string.

## Downhole Surveying

The actual path of the pilot hole is monitored during drilling by taking periodic readings of the inclination and the azimuth of the leading edge. Readings are taken with an instrument commonly referred to as a probe, inserted in a drill collar as close as possible to the drill bit. The probe typically contains an orientation module with triaxial accelerometers and triaxial magnetometers for gravity and magnetic field measurements. The Tensor Steering Tool System was used for the Hanford Demonstration (See Appendix A for instrument specifications). Transmission of the downhole probe survey readings to the surface is generally accomplished through a wire running inside the drill pipe. These readings, in conjunction with the measurements of the distance drilled since the last survey, are used to calculate the horizontal and vertical coordinates along the pilot hole relative to the initial entry point on the survey.

Azimuth readings are taken from the earth's magnetic field and are subject to interference from downhole tools, drill pipe, and magnetic fields created by adjacent structures. Therefore, the probe must be inserted in a non-magnetic collar and positioned in the string so that it is adequately isolated from downhole tools and the drill pipe. The combination of bit, mud motor (if used), subs, survey probe, and non-magnetic collars is referred to as the Bottom Hole Assembly or BHA. A typical bottom hole assembly is shown as Figure 6.

## Surface Monitoring

The pilot hole path may also be tracked using a surface monitoring system. Surface monitoring systems determine the location of the probe downhole by taking measurements from a grid or point on the surface. An example of this is the TruTracker® System (See Appendix A). This system uses a surface coil of known location to induce a magnetic field. The probe senses its location relative to the induced magnetic field and communicates this information to the surface. This is shown schematically in Figure 7.

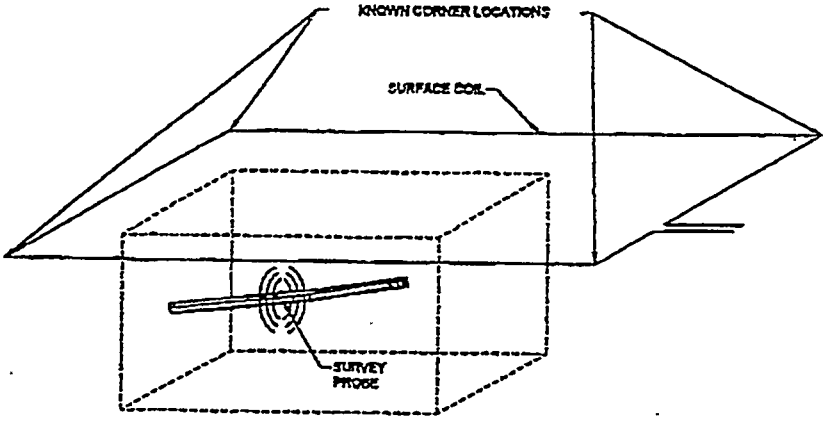


**Figure 7. TruTracker™ Surface Monitoring System.**

# Environmental Measurement-While-Drilling System

Sampling during environmental drilling is essential to fully characterize the spatial distribution and migration of near surface contaminants. However, the analysis of these samples is not only expensive, but can take weeks or months when sent to an off-site laboratory. In contrast, Environmental Measurement-While-Drilling (EMWD) screening capability saves money and valuable time by quickly distinguishing between contaminated and uncontaminated areas. The EMWD system is a complete instrumentation package capable of acquiring a variety of environmental data while collecting orientation

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information for the calculation of bit location. By linking bit location with environmental measurements, a complete log of subterranean conditions can be mapped. Real-time measurements provided by a EMWD system, with full gamma ray spectrometer (GRS) and magnetometer, enable on-the-spot decisions to be made regarding sampling strategies, enhance worker safety, and provide the added flexibility of being able to "steer" the drill bit in or out of hazardous zones.

## Technology Capabilities

The EMWD System is compatible with vertical or HDD techniques that use mud lubricant, water, or minimal drilling fluids. The down-hole sensors are located behind the drill bit and are linked by a high-speed data transmission system to a computer at the surface. Sandia-developed, Windows™-based software is used for data display and storage. As drilling is conducted, data are collected on drill bit position and on the nature and extent of contamination. Data are instantly accessible for on-the-spot decisions about drilling and sampling strategies.

## EMWD System

### *Basic System Operation*

The system is comprised of a computer, a stationary magnetic pickup coil and receiver, a battery pack and rotating magnetic coil, and a down-hole electronics package. The electronics package, complete with a gamma ray spectrometer, multichannel analyzer, magnetometer, and coaxial coil, is located inside the drill rod next to the drill bit. The coil provides both direct current (DC) power and frequency modulated (FM) signal paths between the surface and the down-hole electronics package. Figure 8 shows the instrumentation mounting locations on a typical drill rig.

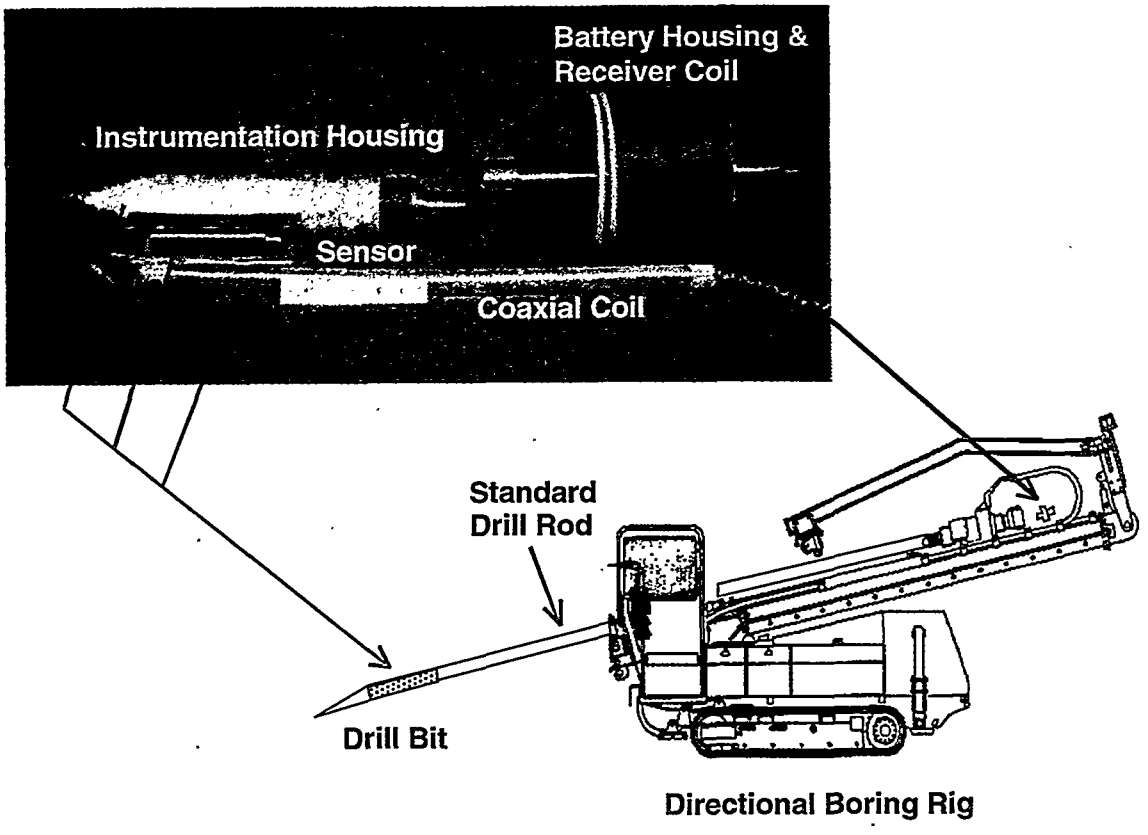


**Figure 8. EMWD-GRS system component placement on a typical directional boring rig.**

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Figure 9 shows drilling steps. As the drill string is lengthened by adding drill rod, the coaxial cable is unspooled and pulled through the new section of drill rod. The unspooled cable is attached to the battery pack and coil. The latter are mounted on the rotating drill pipe that extends behind the hydraulic head. The coil couples the FM signal between the rotating drill pipe and the stationary coil and receiver, which are mounted on the drilling platform. The receiver converts the FM signal into a serial bit stream. A computer equipped with a telemetry serial card receives the data and displays down-hole measurements, including GRS and position data, battery voltage, temperature, and role, in real time.

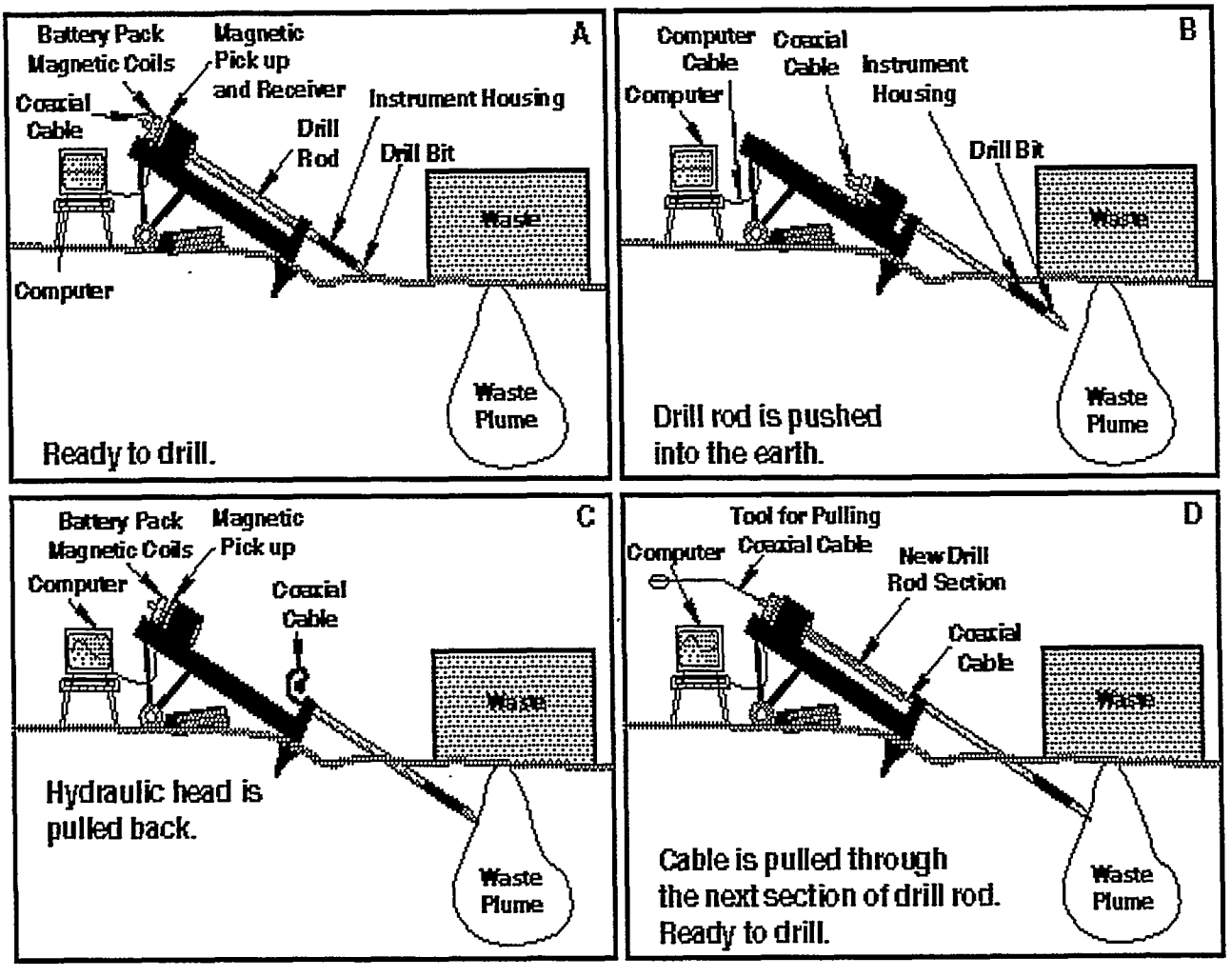


**Figure 9. The EMWD process using a coaxial cable spool.**

### *System Adaptability*

The electronics package, located near the drill bit, is easily adaptable to different sensors or data formats. Adaptability is gained by using an Actel 1020B programmable logic array. This small-surface mounted integrated circuit (IC) contains some 2000 logic gates. The Actel 1020B controls the data-stream format, logic clock, and digital interfaces. The Actel 1020B is programmed to provide the serial bit stream as bi-phase and non-return to zero (NRZ) digital. These two formats cover a wide range of communications systems including fiber optic, hardwire, and radio frequency (RF).

The system has a bit rate of 2400 bps, but the bit rate can be increased easily. A practical limit to this FM system is ~ 30,000 bps. However, if the signal coupling at the surface continues to be strong and noise-

immune, the Actel bi-phase output could drive the coaxial system directly. The bi-phase data rate could exceed 100,000 bps. Data rates that high are approaching imaged data requirements.

Another important attribute of adaptability is to provide different supply voltages for different sensors. Only battery power (30V) is supplied on the coaxial cable. Once received, this voltage is converted to four different voltages: +12V, -12V, +5V, and -5V. A DC-to-DC converter generates these different voltages. The converter increases battery life by reducing current drain from the batteries and allowing the battery voltage to range from 18V to 32V without affecting sensor electronics. A second DC-to-DC converter generates the 1300V GRS bias voltage. Current requirement for the down-hole electronics is only 32 ma at 30V.

### *Down-hole Components*

Down-hole components of the gamma ray detection sensor system being demonstrated consist of a gamma ray spectrometer (GRS), a multichannel analyzer, a 1300V power supply orientation sensors, a signal conditioning and transmitter board, and a coil containing coaxial cable for transmitting data to the surface. The down-hole components are contained within O-ring sealed stainless steel tubes to protect them from the drilling environment. The GRS detector was placed forward, toward the drill bit. The coil is in the rears to accommodate communication back to the surface.

The orientation sensor package was built by Applied Physics Systems, Mountain View CA, Model 544. This is a microprocessor controlled system utilizing a three axis fluxgate magnetometer for azimuth and three axis accelerometers for inclination. The microprocessor uses the magnetometer and accelerometers for calculation of roll, pitch, and heading. The package is approximately four inches long and 0.75 inch square and easily integrates into the existing EMWD system

The Model 544 comes with RS-232 or TTL interfaces. For our applications, the TTL interface was the natural choice. The EMWD telemetry board is setup to read orientation values from the 544 every 1.5 seconds. This data is then transmitted to the surface and stored with other measurement data verses time on a field PC. Data coming from the 544 was already in the final form, heading, pitch and roll. The 544's microprocessor also provides the calculated values for magnetic and gravitational fields. These two additional calculated values provided the system with some measure of data quality. Valid accelerometer and magnetometer readings always provide constant values for magnetic and gravitational fields. When these values were not valid, primarily do to drilling rotation, the heading, pitch and roll readings are ignored. By taking orientation readings every 1.5 seconds, a large number of readings are acquired whether the drilling was progressing or stopped for any reason, i.e. adding additional drill rods and/or change in steering trajectory. The most accurate readings are acquired when drilling has paused.

The specifications for the components included in the EMWD system as used in the Hanford demonstration are shown in Table 1.

| Table 1. Specifications of Modified EMWD System. | |
|---|---|
| Transmission Data Rate | 2400 Baud, 7 analog and 2 digital channels |
| Battery Pack | 32v, approx. 12 hrs. of continuous operation |
| Multi-Channel Analyzer | 256 Channels<br>0.150 to 1.6 MeV range<br>Complete spectrum every 20 seconds |
| Gamma Detector | 2x4 in. Sodium Iodide, NaI(TI), Crystal with matching Photo-Multiplier Tube, PMT |
| High Voltage Supply | 24v step up to 900-1600v for PMT biasing |
| Angular Orientation Sensor, Model 544 | +/- 0.5 Degrees Inclination<br>+/- 1.0 Degrees Azimuth<br>Complete set of orientation readings every 1.5 seconds |

### *Up-hole Components*

The up-hole system consists of a battery pack/coil, pickup coil, receiver, and a personal computer. During drilling, the system monitors: (1) gamma radiation by gamma ray spectrometry, (2) pitch, roll and azimuth using the orientation sensors, (3) the +12V and -12V required at the down-hole signal conditioning and transmitter board, (4) the up-hole battery voltage as measured down-hole, and (5) two temperatures associated with the detector and instrumentation.

### *Cable Deployment System*

The cable is contained in a spool located with the down-hole components of the system. The cable from the down-hole instrument package is pulled through each piece of drill pipe and through the drill head to the battery pack/coil mounted on a spindle at the rear of the drill head and is connected to the up-hole components. The coaxial cable is pulled through each section of drill pipe and the drill head using fish tape. The spindle leads to the drill fluid handling system. Drill fluid pressure is normally in the range of 300 psi (1.435 kPa) to 500 psi (2.392 kPa), but can go as high as 1500 psi (7.177 kPa). A cord grip fitting is used to seal against the 0.07" (1.8 mm) OD coaxial cable. The sealing grommet in the cord grip fitting is slit so that it can be removed from the cable, allowing the connector to pass through the body of the cord grip fitting. This arrangement has been tested to 600 psi (2.871 kPa) air, which is approximately 3000 psi (14.354 kPa) water, without leakage.

### *Data Transmission Surety*

Since human safety is a primary consideration, reliability and high data surety are priority system requirements. To meet this requirement, the system design incorporates data quality assurance techniques to ensure data reliability. The basic format used in the EMWD system is also used in the weapons complex for very high data surety where destructive testing may cost hundreds of millions of dollars and getting "one shot" reliable data is imperative.

### *Data Collection System*

The data collection system is comprised of a computer, stationary magnetic pick-up coil and receiver, battery pack and rotating magnetic coil, and the down-hole electronics package. The coils couple the FM signal between the rotating drill pipe/rotating magnetic coil and the stationary magnetic pick-up coil and receiver, which are mounted on the drilling platform. The receiver converts the FM signal into a serial bit stream. A computer equipped with a telemetry serial card receives the data and displays down-hole measurements in real time.

The EMWD system provides real-time data on as many 8 differential/single analog multiplexer and any number of digital channels. Sampling speed from analog channels can reach 100 kHz. For the EMWD system, three digital channels are used. Readings are taken at a rate of 20 per second. The telemetry system is programmable firmware that can easily support many different data formats and additional data channels. The current format (Digital FM Bi-phase, 4800 baud) provides excellent noise rejection. A SNL-designed receiver removes FM carrier noise, generates data clock, and buffers data for use by an IBM or compatible personal computer. A 36 V battery pack can supply down-hole instrumentation power for more than 24 hours of drilling. A DC to DC converter increases battery life by reducing battery current drain and allowing the battery voltage to range from 18 V to 36 V without affecting sensor electronics and data quality. The battery pack remains topside for easy maintenance.

Data transmission is digital FM in a bi-phase format. Digital FM is presently state-of-the-art for electrical data transmission, providing very high signal-to-noise ratios. Bi-phase is a technical term used in the telemetry industry that simply means each digital datum is a transition, not a level. In most digital systems, a "one" logic bit is sent as a 5 V level and a "zero" logic bit is a 0 V level. In our system, a "one" logic bit is transmitted by a transition from 5 V to 0 V and the "zero" logic bit is transmitted by a transition from 0 V to 5 V. This creates a serial bit stream that is proactive.

Self-clocking data benefits bi-phase data transmission. In simple digital data transmission, a series of zero logic bits creates a static condition where no signal is received. If the data series is very long, then the receiver can confuse a period of 12 zeros with 11 zeros or 13 zeros. In the worse case, a transmission system can fail and the receiver believes the data stream is all zero logic levels. By clocking the data in a bi-phase form, the proper operation of the timing circuits is validated. A possible failure mode for any system making a rate measurement verses time can be caused by the crystal-based timer oscillating at a harmonic. For example, a 5 MHz timing clock can run at 10 MHz. Because time is relative, a system running at twice the expected clock speed means the gamma rate calculation is halved. This fault could prevent the operator from seeing a dangerous condition. To detect clock error, the bi-phase data is tied to the clock such that any error in the timing clock is measured in the data transition rate at the surface. This validates proper operation of the instrumentation clock at all times.

For these tests, a simple bit stream comprised of all the basic elements was used. The bit stream uses a sync-word (sixteen unique bits repeated for each frame of data). The computer receives the bit stream and qualifies the incoming data for data rate, proper number of bits, and the correct sync-word. If any of these elements are incorrect, the data sync indicator changes from green to red and the data display halts. The minimum word size is sixteen bits where the upper four bits are dedicated to word count (data position in the bit stream) and parody. Naturally, the number of data channels (i.e. gamma or temperature) is unlimited for any practical purpose.

### *Drilling Platform*

The EMWD system can be adaptable for use with most drilling platforms. The drilling platform used for this demonstration was supplied by A & L Underground, Olathe, Kansas (See Appendix A for specifications). This system uses a Tensor Steering Tool System with TruTracker to measure drill bit location and depth (See Appendix A for specifications).

# PROCEDURES

All drilling was conducted following the specifications and guidance presented in the "Minimum Standards For Construction and Maintenance of Wells, *Washington Administrative Code* (WAC) 173-160, as they pertain to directional drilling (specifically, licensing of well drillers and construction and abandonment of resource protection wells). Drilling operations also conformed to EII 5.2, "Soil and Sediment Sampling." and EII 5.4, "Field Cleaning and/or Decontamination of Equipment" (WHC 1988b). All waste was handled in accordance with the requirements of WAC 173-303 and/or the site-specific Waste Control Plan. Environmental Measurement-While-Drilling procedures are given in Appendix A. Procedures for Horizontal Directional Drilling processes are give in Appendix C.

# RESULTS

## EMWD-HDD Demonstration Description

The borehole drilled at the Mock Tank Leak Simulation Site was approximately 80 m (260 ft.) in length and was developed under a "tank" ~15 m (50 ft.) in diameter and set ~ 1.5 m (5 ft.) into the ground (Figures 10 and 11). The purpose of this test was to demonstrate directional drilling and the tracking capability of the EMWD system while under a tank. The borehole was drilled using a rotary jet at an angle of 12.5° and reached a depth of ~ -8 m (-25 ft.). The bore was continued horizontal at this depth for ~ 30 m (100 ft). This put the drill bit well past the far perimeter of the mock tank. As a result of a design flaw in the sub that coupled the EMWD tool housing to the Tensor Steering Tool housing, the Tensor Steering tool wireline could not be passed through the EMWD tool housing. The tools were run separately. The EMWD tracking survey, the Tensor tool survey, and the TruTracker survey indicated average maximum depths of 7.5m (24.7 ft.), 8.1 m (26.6 ft.), and 7.3 m (23.8 ft.) respectively for this horizontal run. The absolute deviation between the EMWD tracking survey and the Tensor survey was 0.64 m (2.1 ft.) or less and between the EMWD system and the TruTracker survey was 1 m (3.3 ft.). The absolute deviation between the Tensor and TruTracker survey was 1 m (3.4 ft.). The drill bit position was known within a sphere having a radius of no greater than 1 m (3.4 ft.) and a known direction relative to the prescribed baseline at all times. The agreement between the EMWD survey and the Tensor/TruTracker surveys indicate that we were able to re-enter the borehole. The EMWD Gamma Ray Spectrometer was also operational and background gamma was recorded.

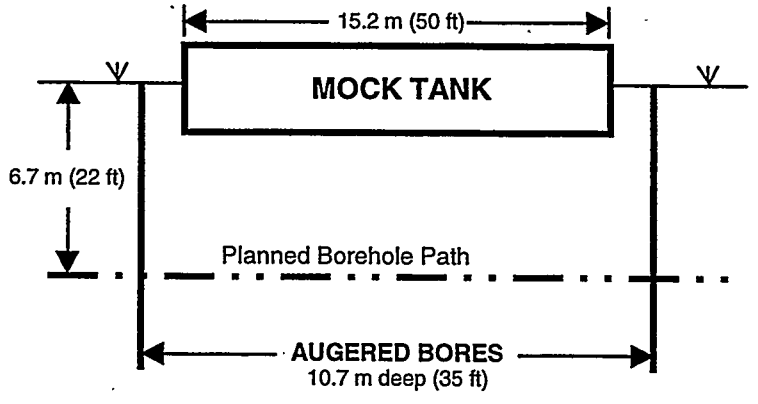


**Figure 10. Plan view of the Mock Tank Leak Site.**

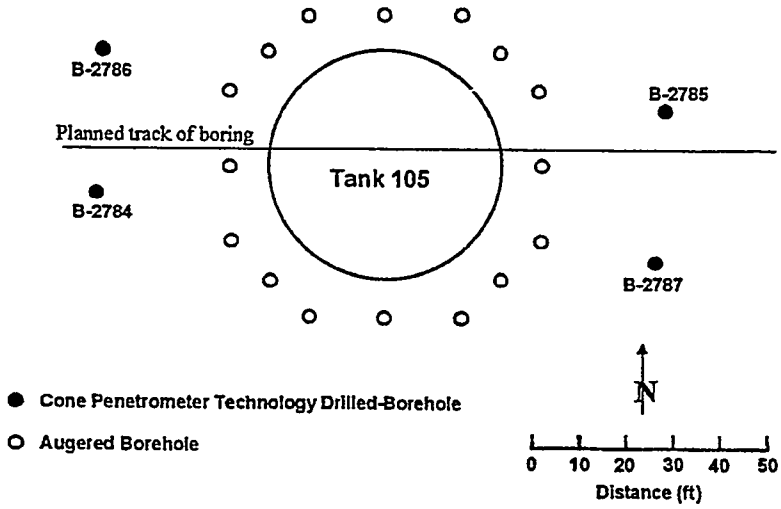


**Figure 11. Cross-sectional view of the Mock Tank Leak Site.**

The second borehole was drilled at the Drilling Technology Test Site using a mud motor to penetrate ~6 vertical meters (20 ft.) of boulders/cobbles and the remainder of the hole was drilled with a rotary jet. The purpose of this test was to demonstrate the capability of drilling to a depth of ~ -21 m (-70 ft.), the depth required to drill under a Hanford tank. The borehole was drilled at an angle of 16°, reached a depth of ~ -23 m (~-75 ft.), and went horizontal for approximately 18.3 m (60 ft.). Again, the SNL and A & L tracking systems agreed on bit location. We deviated from the drill plan and went outside the sphere having a radius of $\pm$ 1.5 m (5 ft.). A conscious decision was made not to pull back and kick out of the current hole and redirect to stay within the sphere. This decision was made due to the lack of time and funding. To demonstrate the capability pushing casing in the Hanford lithology, 18.3 m (60 ft.) of casing was emplaced at this site. We attempted to take a sample from this borehole using a small sampler, but were unsuccessful. The sampler was not designed to be used in the cobble/boulder environment at Hanford. The EMWD Gamma Ray Spectrometer was also operational and background gamma was recorded

# Determination of Bit Location

## Steering Tool Measurements

The Sandia EMWD steering tool uses a Model 544 orientation sensor from Applied Physics Systems, Mountain View, Ca. The Tensor Steering tool deployed by A & L Drilling is an orientation sensor similar to the Applied Physics magnetometer. Both of these sensors deploy three 1-G accelerometers for determination of role and pitch in three axes and a three-axis flux gate magnetometer for azimuth. Both tools also use the known total gravity (1.0Gs) and magnetic flux constants (~0.46 Webers/ft$^3$) to qualify the measurements. In addition A & L Underground deployed the TruTracker guidance system.

Under normal conditions, the total gravity as measured is constant when the drill bit is stationary. The total magnetic flux as measured is constant (in a given area) when the drill bit is stationary and there are no large ferrous materials within the local magnetic field. This means that the flux gate magnetometer must be housed in non-ferrous housing and be drilled into the ground some reasonable distance (~ 6 m, 20 ft.) away from the drill rig in order for azimuth readings to be valid.

### *Dead Reckoning*

Dead reckoning is a means of calculating position given a known starting position and a set of sequential vectors relating movement. These vectors when totaled track bit location. Orientation readings on the bit location, such as role, pitch and azimuth are not enough for dead reckoning. A displacement measurement is also needed to give bit location. The measure of displacement is the magnitude of the vector, while orientation is the angle of the vector. The Tensor Steering Tool system uses rod lengths for displacement. At the end of each rod an orientation measurement is made. Since the drill rod is 6.1 m (20 ft.) long, the displacement is always 6.1 m.

The Sandia tool differs from other steering tools in that the EMWD system uses a cable-extension position transducer attached to the drill rig carriage to measure displacement. The transducer uses a spring-loaded potentiometer to convert carriage advance (or retraction) into electrical signals, which are measured every 3 seconds while drilling. Using the transducer measurements, the EMWD system knows how much displacement has occurred between orientation readings and can calculate a new movement vector. Changes in transducer resistance are linear with drill bit displacement. Each time a drill rod is added the carriage is retracted and the transducer is reset to an initial starting position (Figure 12). The raw data file contains both time in minutes from start of transducer monitoring and time-of-day. The time-of-day value is synchronized with time-of-day spectrums captured while drilling. If the drill rig carriage returns are removed and total displacement measured, giving a plot of position verses time (Figure 13).

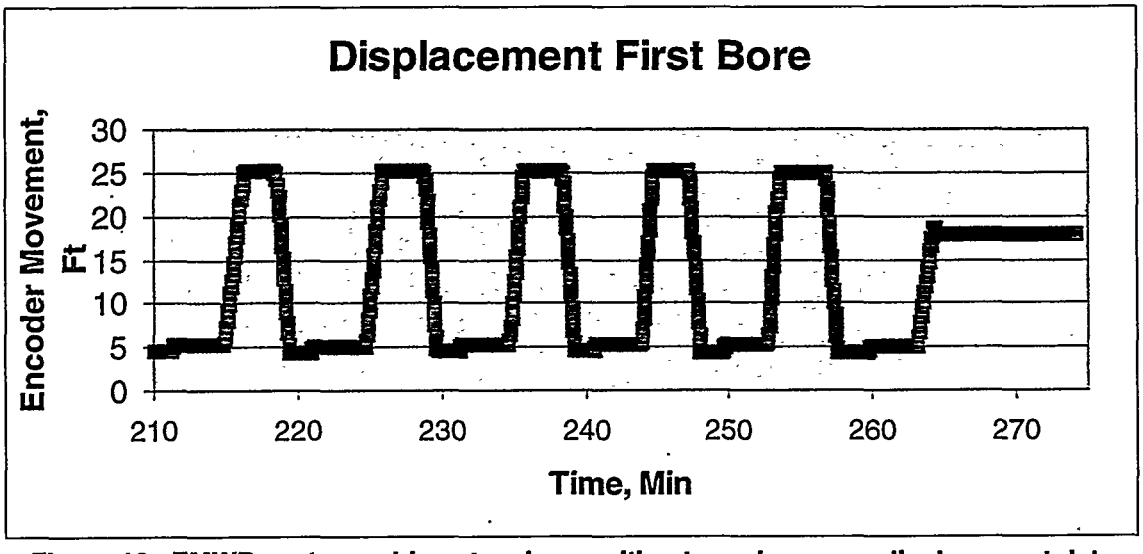


**Figure 12. EMWD system cable-extension position transducer raw displacement data.**

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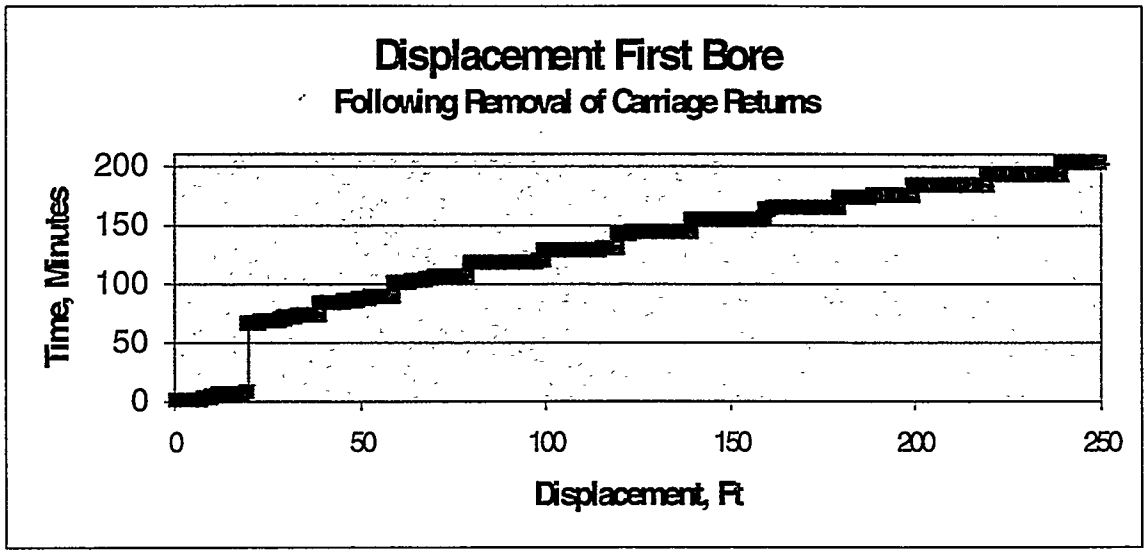


**Figure 13. EMWD cable-extension position transducer data with drill rig carriage return removed. For easy viewing, time axis is in minutes from start of Bore 1.**

As the drilling progresses, bit location is calculated by summing vectors. For easy display, the three dimensional data is normally plotted within two two-dimensional plots, depth and heading. Depth is an accumulation of pitch and displacement measurements as shown in Equation 1.

Equation 1: Present Depth = Sum[Displacement*Cos(Pitch)] + starting depth

Heading is an accumulation of azimuth and displacement as shown in Equation 2. To better guide the drilling process, heading is normalized to the initial or desired heading. The resulting plot is a measure of drill bit location left or right of the desired line.

Equation 2: Present Heading = Sum[Displacement*Sin(Azimuth-Initial Heading)] + starting heading

### *TruTracker™ Measurements*

The TruTracker Guidance System uses externally generated magnetic field and the magnetometers inside the orientation instrument to track bit location. External fields are generated using a wire loop located on the surface and a high current supply. The loop is centered along the desired drill path or centerline. The TruTracker loop was 15.2 m (50 ft.) wide centered above the planned drill path for Mock Tank Test Site drilled to a depth of ~ -7.6 m (-25 ft.) (See Appendix F). The test at Drilling Technology Test Site was to a depth of ~ -23 m (-75 ft.), therefore the loop was 45.7 m (50 ft.) wide centered above the planned drill path (See Appendix F). The Tensor tool and TruTracker measurements are made at the end of each rod while the drilling has stopped. The TruTracker system takes magnetometer readings while energizing the wire coil with high current (~100 Amps). Two readings are made, one with the current flow in a positive direction and one with the current reversed. Reversing the current reverses the magnetic field. Using the three axis magnetometer measurements for the two polarities, TruTracker determines a left-right measurement from the centerline of the drill bit location.

In general, the TruTracker method provides a more accurate left-right measurement of the bit location than the Tensor Tool method of summing of vectors using earth's magnetic field. The TruTracker method also generates an inclination, however it may not be as accurate as the inclination from the accelerometers.

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## Comparison of Bit Location Data for the MTLSS

The EMWD tool was to be used in a stainless steel housing to allow natural magnetic fields to penetrate unaltered. The end caps that join the EMWD housing to the Tensor tool housing and the drill rod were damaged; therefore, a backup housing made from common iron steel was used. The EMWD orientation sensor magnetometer is non-functional in the iron steel housing. The EMWD tool detected and recorded this error. As a result, no valid azimuth readings were obtained from the Sandia tool while drilling using the common steel housing

Drilling the first borehole in the Hanford lithology using the Tensor/TruTracker systems was initially difficult. However, upon re-entry with the EMWD system drilling was significantly easier. This is an indication that the drill bit followed the same path upon reentry of the borehole. The bit location measurements from the Tensor, TruTracker and Sandia tools are directly comparable for depth. The Mock Tank Test Site borehole depth plot showing calculated depth profiles from the EMWD, Tensor, and TruTracker tools are shown in Figure 14. All depth readings are easily within the required ± 1.5 m (5 ft.) window of each other (See Appendix F). The EMWD tool initially took readings every 3 m (10 ft.). This was done to increase accuracy while drilling the initial bend radius. Once the drilling progresses horizontally this error normally is less of a concern. The EMWD tool can quickly make orientation measurements anytime the tool is stopped for a few seconds.

The planned drilling profile was for a straight line heading along 226.7 degrees (where 360 is North and 270 degrees is heading West). The TruTracker left-right measurement was used during drilling to keep the drill bit on the planned heading. Upon completion of the drill, the Tensor tool left-right measurement was calculated. Here again, these measurements are within ± 1.5 m (5 ft.) (Figure 15, and Appendix F). For left-right measurements, the TruTracker measurement is the more accurate than the Tensor orientation left-right measurement.

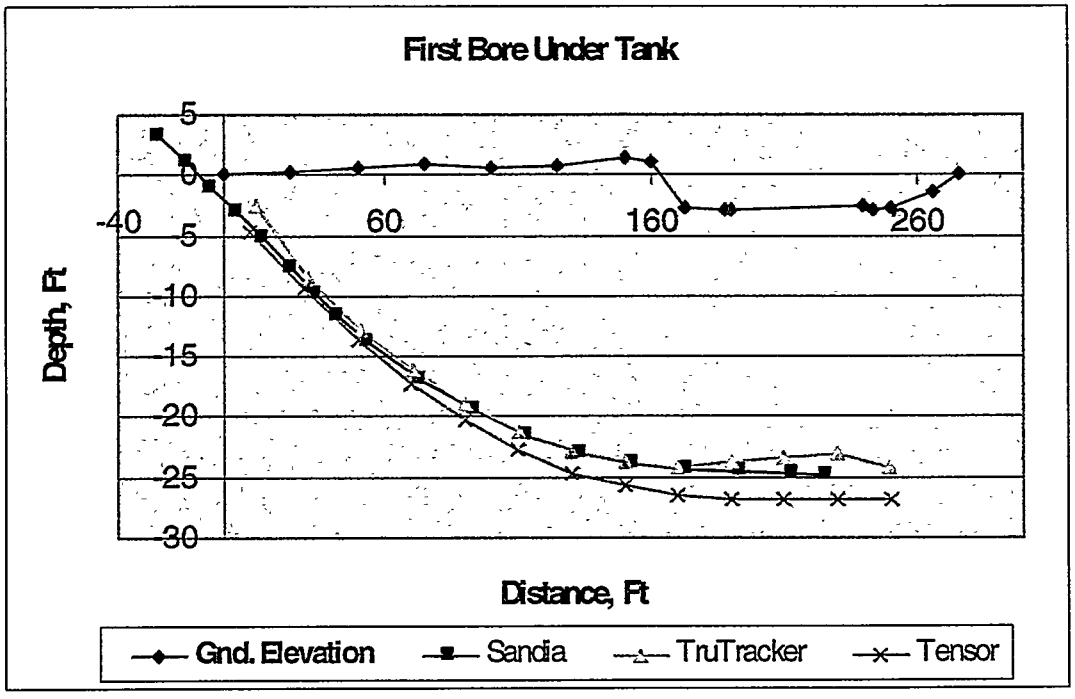


**Figure 14. Mock Tank Leak Simulation Site borehole depth plot showing calculated depth profiles from the EMWD, Tensor, and TruTracker tool. The mock tank was inside the surface ground depression.**

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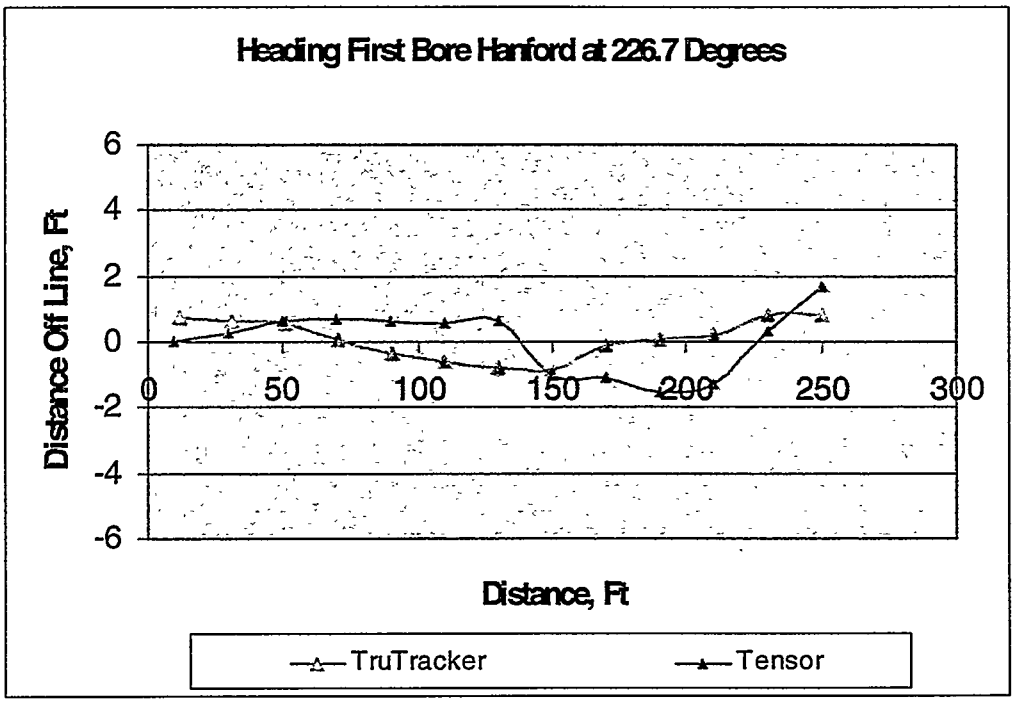


**Figure 15. Plot of the drill bit heading for the Mock Tank Test Site drill.**

## Comparison of Bit Location Data for the Drilling Technology Test Site

The second drill was conducted at the Drilling Technology Test Site. The target depth was ~ -23 m (-75 ft.), resulting in a bore of ~122 m (~400 ft.). The borehole was re-entered to run the EMWD tool in the stainless steel housing out to a length of 61 m (200 ft.).

The results of the position data from this bore are shown in Figure 16. As in the first drill, three independent depth readings are in very close agreement and well within the required ± 1.5 M (5 ft.) window. When the Sandia tool was located inside an iron casing the first 18.3 m (60 ft.), it was not able to provide azimuth reading. The use of heavy equipment above the desired drilling path used to anchor the drill rig in place also interfered with the azimuth measurement. These large steel structures (a commercial 18-wheeler and large backhoe) interfere with the natural earth magnetic fields. While the EMWD, Tensor, and TruTracker tools give accurate depth data under these conditions, neither the Tensor tool nor the EMWD tool could make valid azimuth measures while under large steel structures. However, the TruTracker is not affected by surface equipment giving valid azimuth measurements; therefore, it was used for the left-right measurement on this drill. The TruTracker heading data is shown in Figure 17. While we deviated from the desired heading more than the 1.5 m (5 ft.) window, we knew the position of the drill bit at all times. In drilling under the Hanford tanks, both a magnetometer system and the TruTracker system will be necessary to reliably guide and track the drill bit position.

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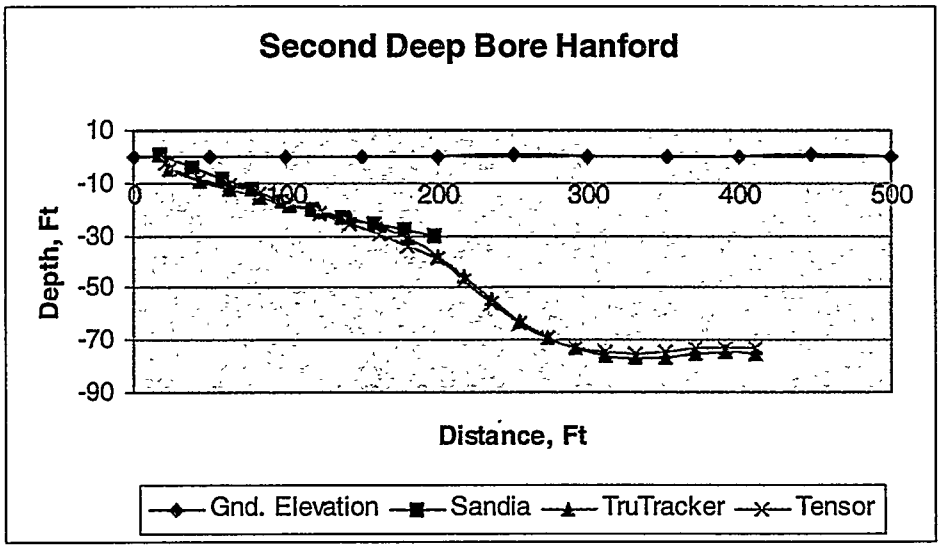


**Figure 16. Three depth readings from the Drilling Technology Test Site Bore.**

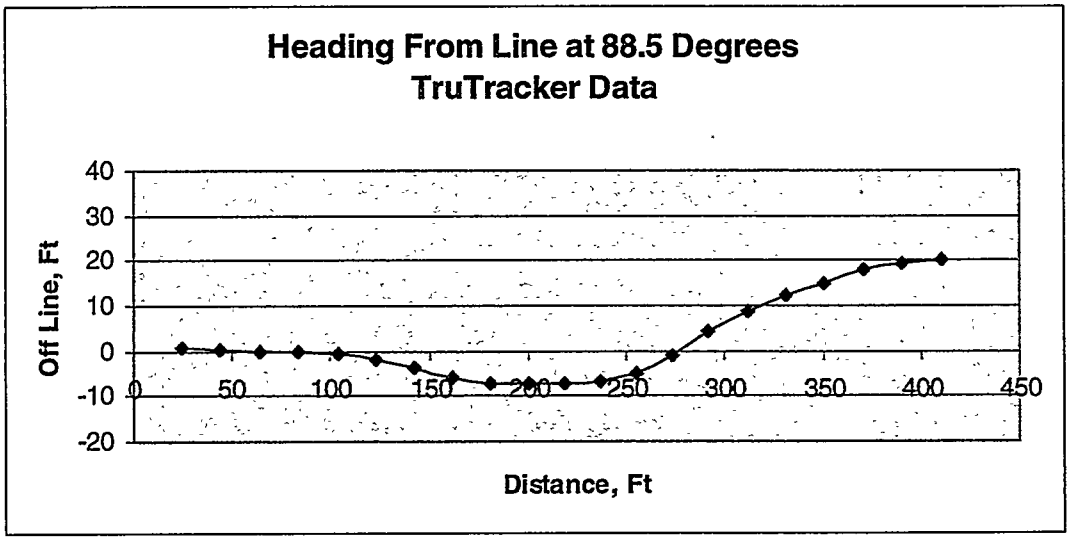


**Figure 17. Heading from the Drilling Technology Test Site drill.**

## Gamma Spectrometer Data

The Gamma Spectrometer portion of the EMWD system has been successfully demonstrated at a "hot test" site. The sites used for the EMWD/HDD Hanford demonstration were cold sites, that is they contained no contamination. The only possible gamma emitter that could be detected are naturally occurring $^{40}K$, uranium, and thorium (KUT). Differences in KUT concentrations are thought to indicate clastic dikes that exist at the Hanford site.

EMWD Gamma Spectrometer was operational before, during, and after the completion of borehole #1 at the Mock Tank Test Site (Figures 18-20). Figures 18 and 19 show calibration spectra for Thorium and Potassium in the common Fe housing, respectively. The Fe housing and the magnetometer magnetically coupled to render these calibrations invalid. Figure 20 shows a typical spectrum taken while drilling.

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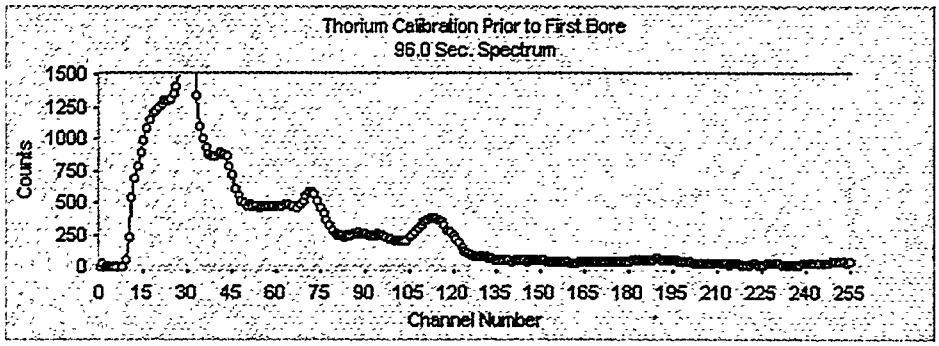


**Figure 18. Thorium calibration in Fe Housing prior to drilling first borehole. Due to magnetic coupling of the Fe housing and the photomultiplier, the normal field calibrations are no longer valid.**

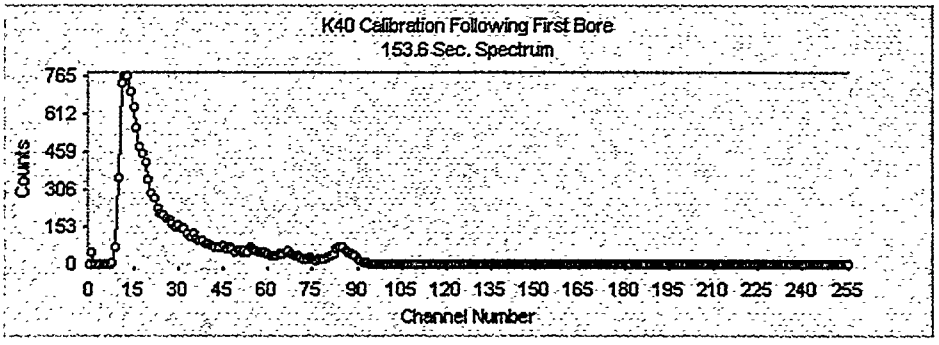


**Figure 19. $^{40}$K peak (channel 87) in Fe Housing after drilling first borehole.**

Gamma spectra from borehole # 2 at the Drilling Technology Test site were taken using the stainless steel housing, but with one magnetic Fe joining sub. The magnetic Fe sub may have adversely affected the calibration of the instrument. However, Figure 21 shows a set of sequential spectra that suggest $^{40}$K is detectable. Under ideal conditions, we would expect a $^{40}$K peak between channels 175-195. The second spectrum in the sequence shows elevated counts in this area over the previous or subsequent spectra. This could possibly be $^{40}$K. In Figure 22, elevated counts are also detected in the typical $^{40}$K region.

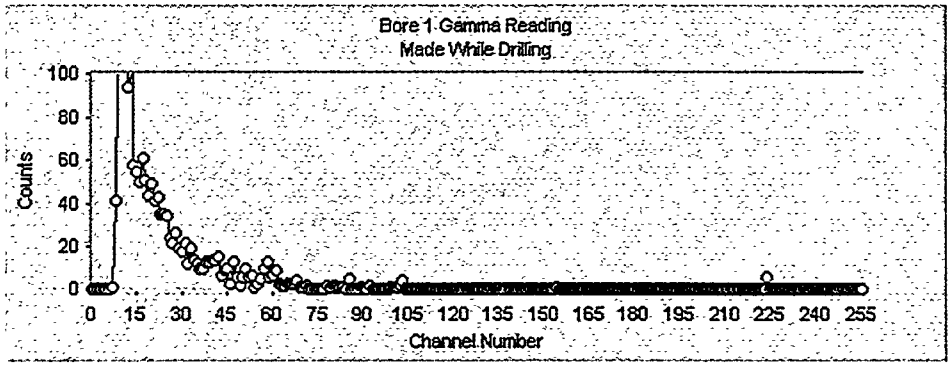


**Figure 20. Gamma Spectrometer reading taken during drilling of borehole #1 at the Mock Tank Test Site.**

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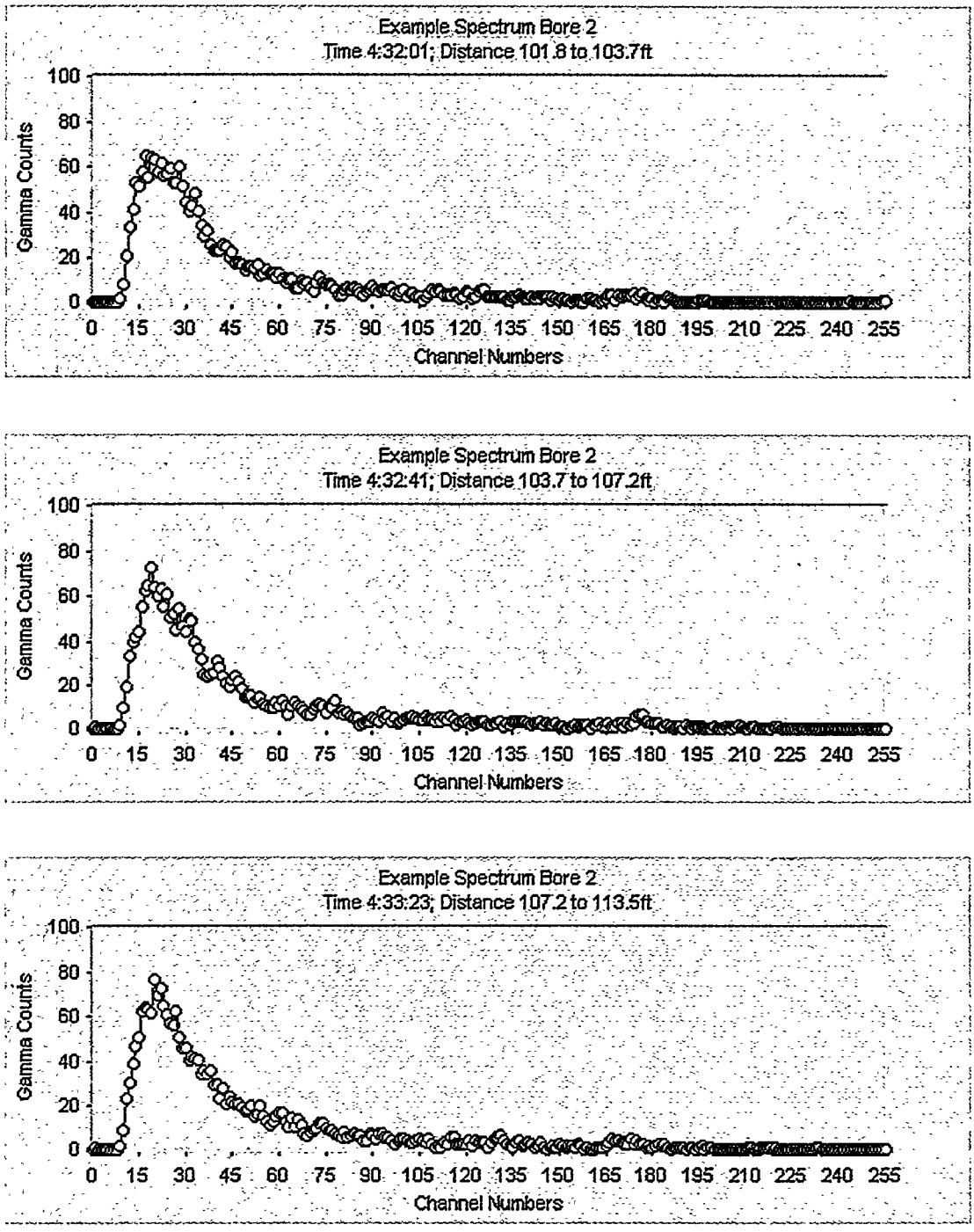


**Figure 21. Sequential spectra taken while drilling borehole # 2 at the Drilling Technology Test site. The second spectrum in the sequence shows elevated counts over the previous or subsequent spectra in channels 175-195, the typical region for $^{40}K$.**

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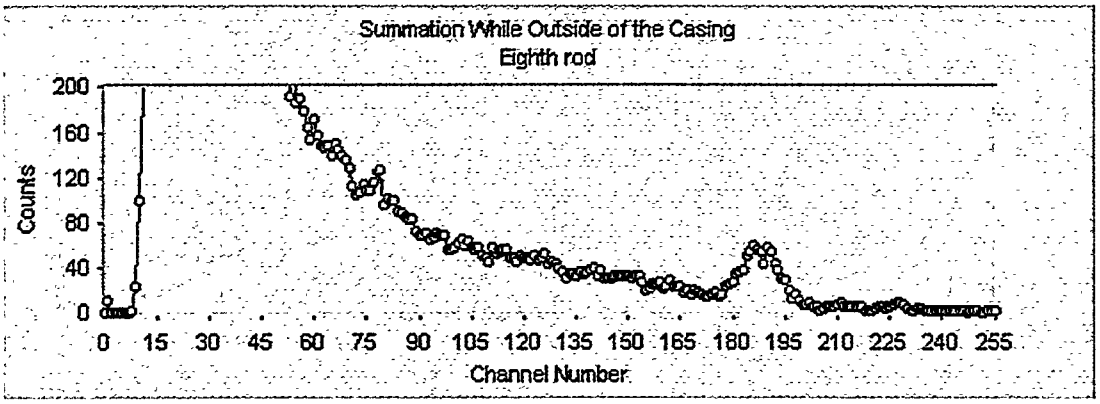


**Figure 22. Summation (3.84 min) of spectra while outside the casing (rod 7), borehole #2, Drilling Technology Test Site. Note elevated counts in channel 175-195. This could possibly be $^{40}K$.**

Other downhole data is collected during drilling. The plots in Figure 23 are from 20 seconds of high-speed (18.75 Readings Each Second) data taken while drilling borehole #2 at the Drilling Technology Test Site. The first plot shows the operator rolling the bit back and forth to advance the drill bit though the rocky ground. The second and third plots show the downhole battery voltage and temperature being continually monitored while drilling.

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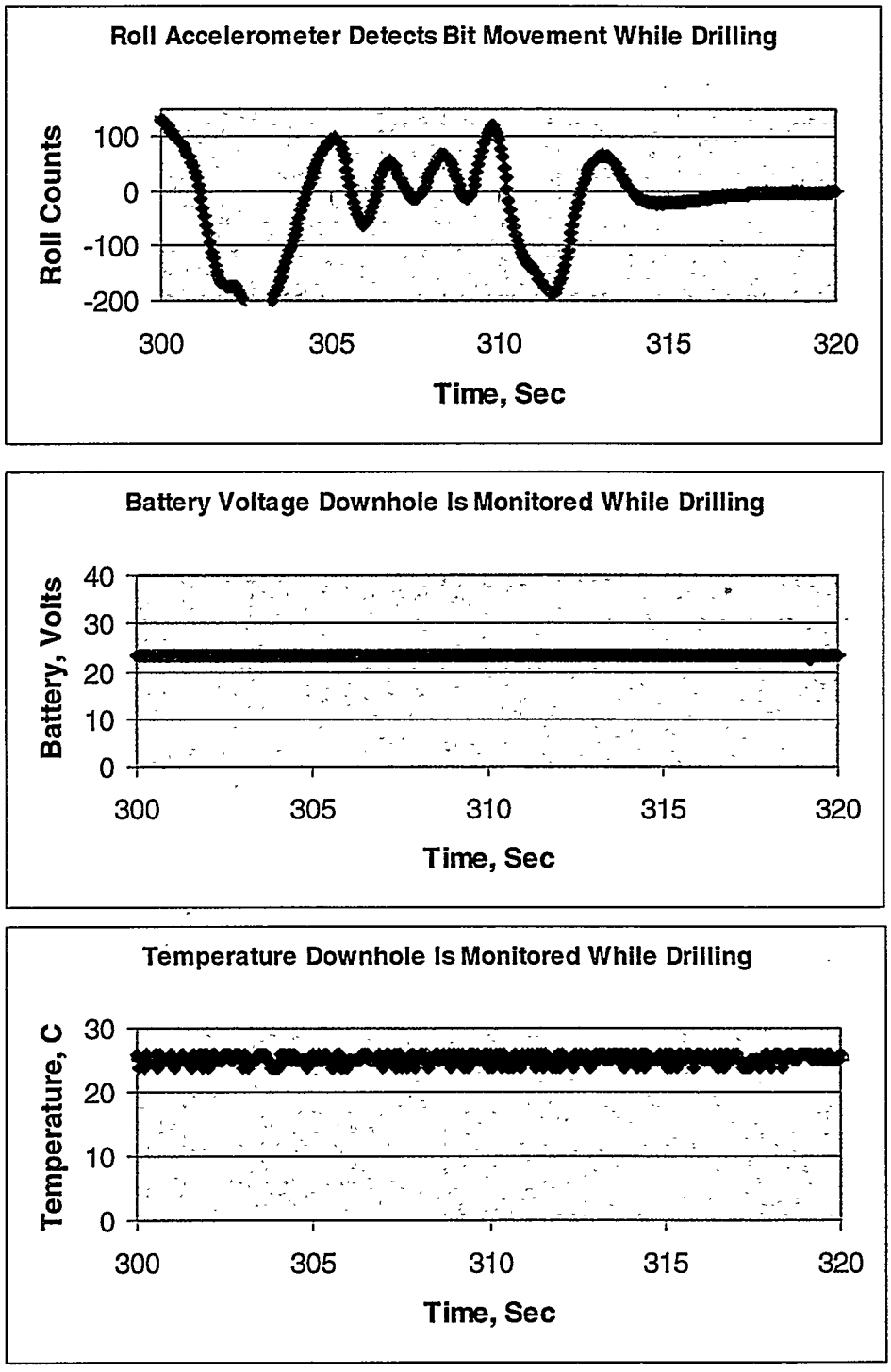


**Figure 23. Plots of other data monitored while drilling. The first plot shows the operator rolling the bit back and forth to advance the drill bit though the rocky ground. The second and third plots show the downhole battery voltage and temperature being continually monitored while drilling.**

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# DISCUSSION

## Position Location Capability

The boreholes in these demonstrations were drilled using the Tensor/TruTracker™ system for position location and drill bit guidance. As a result of a design flaw in the sub that coupled the EMWD tool housing to the Tensor Steering Tool housing, the Tensor Steering tool wireline could not be passed through the EMWD tool housing. The boreholes were re-entered to run the EMWD tool.

For the first borehole at the Mock Tank Test Site, the drill bit position was known within a sphere having a radius of no greater than 1.1 m (3.5 ft.) and a known direction relative to the prescribed baseline at all times. That is, the drill bit successfully followed the planned trajectory. The EMWD tracking survey, the Tensor tool survey, and the TruTracker survey were in good agreement. The agreement between the EMWD survey and the Tensor/TruTracker surveys indicate that we were able to re-enter the borehole. The borehole at the Drilling Technology Test Site deviated from the drill plan. For the first part of the drill, the drill bit was high, but on trajectory. As the drill progressed, the drill bit was brought into alignment with the desired depth, but was off trajectory. However, the EMWD and Tensor/TruTracker tracking systems agreed on bit location. Drilling practice is to grout and pull out of the borehole to a point where you were on trajectory and re-drill. A conscious decision was made not to pull back and redirect to stay on the planned trajectory, but to continue to drill to depth. This decision was made due to time and funding considerations. The driller was able to bring the drill bit back to the planned depth profile.

Placing the EMWD tool and Tensor/TruTracker system in the same housing will eliminate the problems of the simultaneous deployment of two systems. Such a housing has been designed and is in fabrication. The Sandia EMWD tool has been modified to provide TruTracker like readings. With these modifications, bit location will be determined by using calibrated inclination measurements from two accelerometer tools. The calibration of the accelerometer systems will be conducted with the tools inside the drill housing. The EMWD accelerometer tool is presently calibrated inside the drill housing. This is not presently the case with the Tensor tool. Calibration inside the drill housing should provide inclination to within 0.4 degree.

Azimuth readings from the orientation tools (Tensor and EMWD) will only be used when valid as indicated by the total magnetic field constant. Azimuth readings will only be valid when the drilling has progressed beyond the drill rig interference and away from any other metal surface structures. These interim azimuth readings can help validate the TruTracker™ readings. The TruTracker™ method using external fields can be used reliably to track azimuth while under structures that cause magnetic interference, such as waste tanks. Additional testing may be needed to validate the performance of the TruTracker™ methods when in the presence of large iron structures.

## Gamma Spectrometer Capability

The EMWD Gamma Spectrometer was operational during both of the drills. However, since both drill sites were "cold" test sites, the only possible gamma radiation to be detected was naturally occurring background radiation from potassium-40, uranium, and thorium (KUT). An iron housing was used to drill the EMWD tool into the borehole. The iron housing and the magnetometer in the EMWD tool magnetically coupled. This coupling caused a shift in the channel location of detected species. This rendered our calibration unusable to definitively identify species detected. While elevated gamma counts were observed that most likely were $^{40}K$, this can not be verified. While a stainless steel housing was

used on the second drill, one iron crossover sub was used. While the gamma spectra show elevated count in the typical $^{40}K$ region, however, the presence of the iron crossover sub makes this data questionable. Placing the EMWD tool in the same Monel housing with the Tensor tool will eliminate the problems of magnetic coupling.

## Activity Plan Metrics

The Activity Plan set performance metrics for the EMWD/HDD demonstration. The sites chosen for the demonstration addressed two requirements necessary for drilling beneath the Tank Farms: 1) the ability to follow a drill plan while drilling beneath a steel tank, and 2) the ability to follow a drill plan while drilling in soils typical of the Tank Farms. The Mock Tank Test Site was used to drill beneath a steel tank maintaining directional control. The Drilling Technology Test Site was used to demonstrate the ability to maintain directional control while penetrating soils similar in nature to those beneath the tank farms. The following performance features were evaluated:

- The ability to advance the borehole
- The ability to direct the drill bit and know its location
- The ability to collect soil samples.

The evaluation of the Horizontal Directional Drilling and Environmental Measurement-While-Drilling is based on criteria outlined in the Activity Plan. Success/Failure are described as follows:

- Success: Meets all requirements
- Partial Success: Meets some requirements, allowing use on more limited basis
- Failure: Unable to meet requirements.

Multiple criteria for evaluating success or failure are specified for each metric. These criteria have been evaluated independent of each other and summarized in the following section.

### Metric 5.1

*Success Criteria*

Will directional drilling work in the Hanford environment, and can the bit be located with sufficient accuracy to avoid compromising facility integrity?

Drilling success was judged on versatility, bit location, hole re-entry, fluid return, drill string decontamination, additives, and drill rig size. Each of these criteria discussed separately.

***Criterion 1. Versatility*** - The drill will be judged on whether it can advance and be recovered through the following material:

- Hanford Formation gravels (must) - **Accomplished**
- Hanford Formation sands (must) - **Accomplished**
- Plio-Pleistocene silt-rich sands (desirable) - **Not Attempted**
- Caliche-rich zone (desirable) - **Not Attempted**
- Cemented Ringold Formation (bonus) - **Not Attempted**

The sites chosen for the demonstration only afforded the opportunity to penetrate the Hanford formation gravels and sands. The drills successfully demonstrated the ability to both penetrate and be recovered from these materials at both test sites. The drill at the Drilling Technology Test Site did experience some

difficulty in penetrating the large gravels and cobbles found at this site, but with the use of a mud motor was able to succeed. The drill rig was not sufficiently anchored to adequately handle the drilling conditions at this site and had difficulty in achieving an adequate angle of penetration to maintain the planned drill path while using the mud motor. Due to the nature of the overlying geologic conditions, integrity of the hole was difficult to maintained. However, the EMWD tracking survey indicated that integrity was sufficient for re-entry of the borehole. On pullback there was some collapse of the hole that required some rotation to remove the drill rods. Even with the difficult drilling conditions encountered at the drilling test site, the drill was able to advance to the required depth. This demonstration criterion was met.

***Criterion 2. Bit Location*** - The drilling methods must meet the following criteria:

- The bit must be able to follow a planned trajectory through the subsurface. While drilling, the bit location must be known and verifiable at all times to within ± 1.5 m (5 ft.). - **Accomplished**
- The system must be capable of permitting independent verification of bit location without unduly inhibiting drilling progress. - **Accomplished**

In the drill at the Mock Tank Test Site, the bit successfully followed the planned trajectory. For the drill at the Drilling Technology Test Site, the attempt to follow the planned trajectory path was less successful. Considerable difficulty was experienced in controlling the drill path. For the first part of the drill, the drill bit was high, but on trajectory. As the drill progressed, the drill bit was brought into alignment with the desired depth, but was off trajectory.

The large cobbles in the upper 6-9 vertical meters (20-30 vertical feet) made the use of a downhole mud motor necessary to advance the bit as the jetting tool was meeting with refusal. The large cobbles and gravel, typical of Hanford geology, also presented problems for the mud motor causing it to start drilling upward. The drill rig had to be repositioned to provide a steeper angle of entry to compensate for the drilling conditions. Once through the cobbles directional control was maintained both with the mud motor and the jetting assembly. Following a sampling attempt, the drill bit kicked off when re-entering the borehole to continue the drilling. The tools were pulled back and several attempts were made to bring the bit and drill path back on line, but was met with limited success.

A mutual decision was made by the EMWD/HDD Demonstration team to continue advancing the borehole to the planned depth of 21 m (70 ft.) and to attempt to use the steering capabilities (bent sub) to bring the bit back to center and reestablish the correct borehole path. The reasoning behind this decision was that the EMWD/HDD Demonstration team knew the usual practice of pullback and grouting the current hole to the point where the difficulty was encountered was possible. This was not done due to time and funding considerations.

At the termination of drilling, the deviation both to the left and downward had been reversed and the bit was being turned back to the planned path. The bit location was ~0.8 m (2.7 ft.) below the planned trajectory, which is within the required 1.5 m (5 ft.) of being on depth trajectory, but was approximately 5.8 m (19 ft.) to the left. This part of the Bit Location criterion was fully met on the first drill, but was minimally met on the second drill with explanation.

It should be noted that the demonstration at the Drilling Technology Test Site was a last minute change that was made to the Activity Plan. Additionally, the decision to drill to a depth of 21 m (70 ft) was made one day prior to the start of drilling.

The ability to provide independent verification of bit location without unduly inhibiting drilling progress was fully demonstrated. The Tensor Steering Tool and the TruTracker™ Tool, provided by Horizontal

Technologies, Inc., were used together while drilling. The use of these two tools permitted independent verification of bit location without unduly inhibiting drilling progress. Borehole locations were verified during the subsequent runs using the EMWD. This gave three independent drill bit location surveys. This part of the Bit Location criterion was fully met.

***Criterion 3. Hole Reentry*** - The directionally drilled hole must be able to be reentered if the drill string is retracted for any reason. - **Accomplished**

Hole reentry was successfully demonstrated on both drills. For the first bore, at total depth, the drill string was removed and the EMWD tool attached. The drill string was then run back to bottom with the bit remaining in the original hole. The EMWD tracking survey agrees with both the Tensor and TruTracker™ surveys. The drill string with the EMWD tool was again retracted, the borehole was grouted on pullout, and abandoned.

Some difficulties in whole reentry were experienced in the second drill. The large gravels and cobbles in the upper 6-9 vertical meters (20-30 vertical feet) could not be stabilized sufficiently to permit hole reentry without some re-drilling. However, re-entry with the sampler and again with the EMWD tool was accomplished using the jet drill and by using casing. Installation of surface casing provided a means to assure reentry of the hole. Again, the EWWD tracking survey agreed with both the Tensor and TruTracker™ surveys verifying borehole reentry. The borehole reentry criterion was fully met.

***Criterion 4. Fluid Return*** - Ideally, the bore should be able to be advanced without returning drilling fluids to the point of entry. - **Not Accomplished**

During drilling at the Mock Tank Test Site, drilling fluids were circulated to the surface at a rate of 150-200 gallon per minute. Total volume of fluids lost to the formation and/or surface is approximately 1700 gallons. No system was in place to accurately measure and record fluid loss. The volume was estimated based on remaining volumes in the water storage tank and the mud circulation tanks. During the drilling of the second boring, drilling fluids were also pumped at 150-200 gallons per minute. Considerable loss of drilling fluids occurred through the upper 6-9 vertical meters (20-30 vertical feet) of gravels and cobbles, but most of the circulation returned once more consolidated formations were encountered. An estimated 10-15,000 gallons of drilling fluid were lost to the formations or to surface through breakouts.

Contrary to expectations, considerable volumes of drilling fluids were required to advance the borings. It was demonstrated that the tighter sands and more consolidated formations did not take much fluid, causing it to be returned to surface. For the purpose of this demonstration, the ideal situation could not be attained; careful handling of drilling fluid returns will be required if this system is to be used in highly contaminated areas.

Air could possibly be used in place of drilling fluids. Areas to investigate would be to determine the capacity of air needed to operate a mud motor and the volume of detergent that would be required to carry the solids from the well bore. The use or air would reduce the drilling cost and the issue of containment and exposure to contaminants would be minimized. Some casing would need to be installed near the surface and grouted prior to drilling. A reverse circulating head would be attached to the casing and a line from the annulus side of the head to a containment tank would be used to transport the drilling spoils from the well bore to the containment facility. The air would be scrubbed through bags or filters on site. The end result would be a tank of dry rock shards. No drilling mud, water, dust or airborne particulate would be present throughout drilling operations.

***Criterion 5. Drill String Decontamination*** - The drill string is to be decontaminated as it is withdrawn from the bore. - **Not Tested**

Demonstration of decontamination of the drill string as it was withdrawn from the borings was not demonstrated as both drills were conducted at "cold" sites. A wiper rubber was placed on the drill rod, through which it was withdrawn. This rubber wipes the drilling mud from the drill pipe as it is pulled through. No other method was used to clean the string.

This should not be considered a failure, but as a partial success. Methods can be implemented to successfully decontaminate the exterior surfaces of the drill string as it is extracted. The ends of the drill rods can be capped to seal off the interior surfaces to mitigate contamination spread. If drilling fluid is not re-circulated, the interior of the drill string may remain clean from contamination.

***Criterion 6. Additives*** - Ideally, the bore should be able to be advanced without the use of drilling mud or additives. - **Not Accomplished, with explanation**

In both drills, the principal method of advancing was a jetting action at the bit. For this test, drilling fluid was pumped through the bit in a jetting action to wash material from the face of the bore. To create a jet sufficient to advance the bore, fluid was pumped at a rate of 150-200 gallons per minute. The drilling contractor stated that with his pump, they could not pump at a slower rate. When advancement became difficult, the pumping rate was increased.

Contrary to expectations, the used of drilling mud is preferred over the use of only water. The mud forms a cake along the borehole wall keeping the borehole open and limiting the migration of fluids to the formation. As stated above, air can be use in place of drilling fluids. For the purpose of this demonstration, it became clear prior to the demonstration that the ideal conditions were not attainable. Provisions for the use of drilling muds and additives had been made prior to starting the demonstration.

***Criterion 7. Drilling Rig Size*** - The rig is to be sized to meet the requirements associated with penetrating the formations, EMWD and sampling. - **Accomplished**

The drill rig was sized to meet these requirements. During the drilling of the second drill, the drill rig could not be anchored sufficiently to prevent skidding when drilling with the mud motor because of the difficulty of emplacing the anchor pins through the cobble layer. Although the rig used overcame these difficulties, a means of placing the anchor pins would have made the advance through the zone of large cobbles easier and aided in maintaining directional control.

The EMWD tool was not deployed while drilling, but was run on the drill string following completion of the borings. The drilling rig easily met the requirements of the EMWD. The engineering difficulty was associated with the crossover subs that mate the EMWD tool with the Tensor Steering Tool housing. Placing the EMWD tool and Tensor/TruTracker™ system in the same housing has eliminated the problems of the simultaneous deployment of two systems. Another option is to only use the EMWD tool with the TruTracker™ system. This option is also under design.

The sample collection effort was not successful because a small 1-foot long by 2-inch diameter sampler was used. This was an undersized sampler for the Hanford soils and broke off and was left in the boring. The use of a coring tool, which are commercially available, would be more appropriate for these soils and is likely to be successful.

This criterion can be considered a partial success, as the drill was able to penetrate the formations encountered and met the needs of the EMWD tool. The sampling efforts failed, but the failure can be overcome.

In addition to the drilling success criteria, drilling failure criteria were evaluated. These criteria include

ability to advance the bore, incompatibility with the EMWD tool, borehole closure, location verification, and contaminant containment. These are discussed below:

*Failure Criteria*

***Criterion 1. Ability to Advance the bore*** - If the drill string is unable to advance the bore the necessary distances through the required formations, the test has failed. - **Passed**

Both borings were advanced the distances planned. This criterion was met.

***Criterion 2. Incompatibility with EMWD Tool*** - If the system is incompatible with the EMWD tool, the test has failed. - **Passed**

The EMWD tool was unable to be run with the drill string while drilling. The crossover subs were incompatible with the drill string tools for running with the directional tool. Also, the design of the crossover subs made it extremely difficult to run the necessary wires through to the EMWD tool.

The drilling system is compatible with the EMWD tool; however, the mating with the Tensor Steering tool was not. Placing the EMWD tool and Tensor/TruTracker™ system in the same housing has eliminated the problems of the simultaneous deployment of two systems. This criterion was partially met.

***Criterion 3. Borehole Closure*** - If borehole cannot be kept open when the drill string is removed and the directional drilling rig cannot carry casing along with the drill bit, the test has failed. - **Passed**

The first boring remained open throughout the drilling operation. The drill string was extracted and the boring re-entered twice with no difficulty and no indication of hole instability. The second boring not as successful in the upper portion where large cobbles and gravels at the surface had a tendency to collapse the borehole. This caused difficulty for reentry and eventually resulted in the bit being diverted from total reentry and a new hole being drilled. The use of casing alleviated this problem. The casing was reamed into the borehole over the drill string to a depth of 60 feet. Although not carried while advancing the bit, this capability should be able to be successfully applied.

This criterion was partially met. It was demonstrated, however, that the large cobbles and gravels of the Hanford formation will need to be stabilized with the installation of casing, as drilling mud alone was incapable of providing adequate stabilization in this zone.

***Criterion 4. Location Verification*** - If the location of the drill bit cannot to be verified, the test has failed. - **Passed**

Two systems, the Tensor Steering tool and the TruTracker™ system Technologies were used to independently verify bit location while drilling. The EMWD tool was run after the drilling was completed and was able to verify the bit path. This criterion was met.

***Criterion 5. Contamination Containment*** - If contaminated drilling fluid cannot be adequately contained and controlled, the test has failed. - **Not Tested**

In this demonstration, no contaminated drilling fluid was generated as both drills were conducted at "cold" test sites. This criterion was not tested. No special precautions beyond standard drilling practices for drilling mud control were taken.

## Metric 5.2

*Success Criteria*

Can directional drilling be used in combination with onboard sensors to map vadose zone contaminant plumes?

Success for "cold" and "hot' sites are listed below:

### *Cold Test Site*

Criterion 1. KUT Concentrations - KUT concentrations must be recognizable using the sodium iodide detector. - **Partially Accomplished**

Criterion 2. Geologic System Differentiation - The system must sufficiently sensitive to detect and locate changes in KUT signatures as small as 0.3 m (1 ft.) wide. - **Not Accomplished**

Criterion 3. Background KUT Detection - The system must be able to detect background KUT. Background potassium, uranium and thorium in the sediments are 10 to 20 pCi/g $^{40}$K, 0.5 to 1 pCi/g $^{238}$U, and 0.4 to 1.5 pCi/g $^{232}$Th. - **Partially Accomplished**

The EMWD Gamma Spectrometer was operational during both of the drills. However, since both drill sites were "cold" test sites, the only possible gamma radiation to be detected was naturally occurring background radiation from potassium-40, uranium, and thorium (KUT). An iron housing was used to drill the EMWD tool into the first borehole. The iron housing and the magnetometer in the EMWD tool magnetically coupled. This coupling caused a shift in the channel location of detected species. This rendered our calibration unusable to definitively identify species detected. While elevated gamma counts were observed that most likely were $^{40}$K, this can not be verified. While a stainless steel housing was used on the second drill, one iron crossover sub was used. While the gamma spectra show elevated count in the typical $^{40}$K region, however, the presence of the iron crossover sub makes this data questionable. Placing the EMWD tool in the same monel housing with the Tensor tool will eliminate the problems of magnetic coupling. These criteria were only marginally met, as we not have a reliable calibration to definitively identify the detected peaks.

### *Hot Test*

Criterion 1. $^{137}$Cs Measurement - The EMWD must be able to measure $^{137}$Cs concentrations from 10 pCi/g up to $10^4$ pCi/g. - **Not Tested**

This metric was not evaluated. The no drilling was conducted at a "hot" site. However, the EMWD system has successfully measured $^{137}$Cs contamination at the Savannah River Site (Lockwood, et al.).

Criterion 2. Plume Location - The equipment must be able to resolve a plume location to within ± 2 ft. specifications as the directional drilling bit locator. - **Not Tested**

This metric was not evaluated.

*Failure Criteria*

Criterion 1. EMWD Tool Operation - One failure criterion was identified: Failure will be defined as the tool's inability to withstand the drilling environment. The tool is defined as both hardware and software elements. - **Accomplished**

The EMWD tool was functional for both drills. Minor cable problem did cause a noisy signal gamma signals, but this was corrected.

### Metric 5.3

Can directional drilling support collection of samples useable for chemical, radiological, physical and hydrological analyses? - **Failed with explanation**

Criterion 1. Useable Samples – Usable samples are recovered from a known location in the borehole.

Sample collection was not attempted in the first drill (Mock Tank Leak Simulation Site). Attempts to collect samples from the second drill failed. No useable samples were recovered. The sample collection effort was not successful because a small 1-foot long by 2-inch diameter sampler was used. This was an undersized sampler for the Hanford soils and broke off and was left in the boring. The use of a coring tool, which are commercially available, would be more appropriate for these soils and is likely to be successful.

### Metric 5.4

How "Good" Are Samples And How Well Known Is The Location From Which The Sample Was Taken? This metric was not applicable as sample collection failed.

### Metric 5.5

How well can the drilling machine be decontaminated after advancing through a radiologically contaminated zone? - **Not Tested**

This metric was not applicable as both drills were performed at "cold' test sites. Success criteria include minimal equipment exposure, fluid containment, low worker exposure, engineered barriers restricting possible contamination, rig/site release. Attempts were not made to demonstrate the capability of contamination control. Engineering controls can be applied successfully to minimize exposure to personnel and equipment if the drilling is conducted in a radiological site.

## Summary of Results in Meeting Activity Plan Metrics

Although some of the Activity Plan Metrics were not met, a partial success was realized in the demonstration of the ability of the directional drilling method to penetrate Hanford formations. The directional control can be maintained in some of the soils and full verification of the bit location was achieved. The following is a summary of the successes and failures realized:

### Successes

- Versatility: The drill was able to penetrate the Hanford formation sand, gravels and cobbles.
- Bit Location: Verification of bit location was made with two independent systems while drilling and post drilling by a third system.
- Hole Reentry: Borehole integrity was well maintained of the boring at the Mock Tank Test Site allowing withdrawal and reentry of the tool string and partially maintained at the Drilling Technology Test Site.
- Borehole Integrity: Hole integrity was maintained in fine sands and gravels.
- Drill Rig Size: The drill rig was adequately sized for the demonstration.
- Ability to Advance the bore: The drill was able to advance the bore the necessary distances through the required formations.
- Compatibility with the EMWD Tool: The EMWD system was run with the drill string, but not with the Tensor Steering Tool

- Borehole Closure: Temporary casing was able to be installed and removed.

### Failures

- Fluid Return: Contrary to expectations, considerable drilling fluids were required to advance the drills.
- Borehole Integrity: Hole integrity was not able to be maintained in the larger gravels and cobbles indicative of the Hanford formation without temporary casing.
- Additives: Drilling mud was used for both drills.
- Usable Samples: Samples were not obtained or evaluated.
- Background KUT concentrations: The detection of background KUT was not verified.

### Metrics not tested

- Drill String Decontamination
- Contamination Containment
- Map Vadose Contaminant Plumes

# CONCLUSIONS

The EMWD/HDD demonstration at Hanford was successful in drilling horizontal boreholes. The demonstration met approximately 60% of the metrics tested. Three metrics were not tested because the demonstrations were not conducted at a "hot" site. Demonstrating that horizontal directional drilling will work in the Hanford environment and that the bit can be located with sufficient accuracy to avoid compromising facility integrity was a success. Verification of bit location was fully demonstrated with the use of three tracking surveys. The EMWD tool was adaptable to the drill string; however, it was not adaptable to the Tensor Steering housing. The data from EMWD tracking system agreed with the Tensor/TruTracker™ tracking survey. The gamma spectrometry capability was not adequately tested in this demonstration to assess its capabilities; however, these capabilities have been verified at other "hot" site tests. The drill was able to advance the required distances, hole integrity maintained, and the boreholes were re-entered.

The uses of additives, the ability to sample, and fluid return metrics were not met. The ability to decontaminate the drill string and contamination containment were not demonstrated. This indicates there are areas for improvement. In particular, housing the EMWD tool and the Tensor steering tool in the same monel, sampling with a coring tool, and in particular taking time for a readiness review prior to the demonstration will resolve many of the problems experienced in this demonstration. Areas for improvement are discussed in the Lessons Learned section.

## Lessons Learned

### Safe Working Practices

Safety in all operations at the any DOE site is of the utmost in importance. Safe working practices need to be strictly enforced and a safety consciousness established with the drilling subcontractor and its' crews. The drilling contractor conducting this demonstration is cognizant of the fact that the drilling crew was not totally prepared for following basic safety protocol or more restrictive safety protocol of a radiological site. Stringent criteria need to be in place as a contractor pre-qualification requirement.

The drilling contractor for this demonstration has instituted a safety education program for selected drilling personnel that includes classroom and practical experience. All personnel involved in the operations must follow the demonstration safety plan. Lack of safe working practices in any environment, in particular at the tank farms, is unacceptable.

## Site Setup

The demonstration sites need to be ready for the arrival of the demonstration team. All necessary surveys, equipment, power, water, sanitary facilities, etc. should be identified prior to the initiation of the demonstration. Pre-operational radiological survey of equipment should be conducted prior to mobilization to the site.

## Equipment

The drilling subcontractors' equipment should be thoroughly inspected prior to arrival on site. This inspection should include equipment guards, walkway railings, stairways, overhead machinery and other areas that could result in injuries. All hoses should be inspected and where required replaced prior to mobilization to the site. The equipment must be thoroughly cleaned of all soils and contaminants (such oils, fuel, and grease), and all leaks shall be repaired. Only tools and equipment required to accomplish the job should be allowed onto the site. If possible, an ongoing drilling operation being run by the drilling subcontractor should be visited routinely by a Hanford Safety Engineer to observe safety practices and identify areas of concern.

It is extremely important that equipment entering a contaminated environment, or expected to encounter contamination, such as from drilling under the tank farms, be in good working condition. Equipment failures may occur; however, all equipment should be inspected and operated prior to entry to the site to ensure it is working. If there is any doubt about the reliability of a piece of equipment, it should be replaced. For equipment that historically has a moderate to high failure rate (e.g. pumps, hoses, etc.), backup replacements should be readily available or on hand.

All down hole tools to be used should be checked to ensure threads are compatible and/or crossover subs are available.

## Drilling Fluid/Contamination Containment

Prevention of and containment of spills is essential in all environments. The purpose of this ground cover is to contain leaks and spills from the equipment. When spills occur, they need to be cleaned up immediately to reduce potential for spreading and to minimize waste generation. The containment system (3 mm plastic sheeting, lumber berms, and plywood pads for equipment) is not adequate for use at a "Hot Site" demonstration. The sheeting was too thin, easily torn, and worn through with the drill crew traffic. Hydraulic fluid leaks and spills can easily leak the soils beneath the plastic and can also spread out over the surface of the plastic sheeting, eventually spreading the contaminants to traffic areas and onto the drill rig. Where such failures or leaks could occur, containment needs to be established which not only contains the spills, but also adequately isolates them, preventing them from spreading to clean areas. Traffic areas need to be identified and kept clean.

In addition, containment needs to be established for the entire drill location where equipment is staged that come in contact with soils and/or fluids circulated from the borehole. Control zones need to be identified and established to reduce personnel exposure. Equipment needs to be shielded or protected from potential contamination. The ground shielding needs to be of adequate strength to resist tearing and puncturing from drilling activities. The containment needs to be routinely inspected for breaches, and if found, repaired immediately. If a breech of the containment has resulted in a release, it should be cleaned

up immediately. Equipment should be configured to increase safety and reduce the spread of contamination, and unnecessary tools/ equipment removed from the exclusion site.

For radiological site where ongoing horizontal drilling activities will occur, more permanent containment and decontamination structures should be considered. The drilling contractor has met with an environmental engineering and design firm to develop preliminary drilling containment designs.

### Demonstration Design

The design of this demonstration was satisfactory; however, delays in funds transfer and changes in scope caused some difficulties. The final Activity Plan was completed in August, but a change in scope occurred after its issuance. This delayed the placement of the drilling contract and limited demonstration preparation time. Due to a lack of time, a readiness review was not performed.

In future demonstrations a minimum of four months is needed after the completion of the Activity Plan. A Readiness Review at the site with the site personnel, the drilling contractor and the EMWD team approximately 6 weeks prior to the demonstration is a must. Many of the difficulties encountered in this demonstration could have been recognized and corrected.

## Recommendations

Areas have been identified as needing improvement to meet the needs of the ER customer. Both the Drilling contractor and the EMWD team are working to correct the deficiencies identified by this demonstration. The following recommendations are suggested for review:

- Explore alternative drilling spoils removal options, such as a air/foam drilling after the emplacement of casing to collect airborne spoils or use of a reduce mud system.
- Conduct a "cold" demonstration to address those criteria not met or not tested. Conduct the demonstration as if were a "hot" site demonstration. Areas to be addressed include:
    1. Drill other formations (Plio-Plistocene silt-rich sands, caliche-rich zone, and the Ringold)
    2. Show full functionality of the EMWD tool with the Tensor/TruTracker™ systems or use only the EMWD tool with the TruTracker™ system
    3. Run the demonstration as a full "Hot" site demonstration with appropriate safety, containment, and decontamination procedures
    4. Collect samples with a core tool and develop procedures for handling.
    5. Use the TruTracker system to directionally drill under a Hanford-type tank to verify its capability.
- Conduct a "Hot" site deployment addressing the following issues:
    1. Permanent containment and decontamination structures
    2. Method for anchoring the drill rig
    3. Map vadose contaminant plumes.

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# APPENDIX A

## EMWD Procedures, Calibration Methods, and Quality Assurance

## EMWD Data Collection Procedures

The data collection procedures used with the EMWD system are the following:

1. Check for full operation of tool and computer interface prior to attachment of downhole tool to drill string or mounting uphole components on drill rig.
2. Mount system and verify system functionality.
   a. Check downhole battery voltage >22V.
   b. Take temperature measurement.
   c. Collect normal background spectra at drill site.
   d. Verify system lock reading.
3. Run decom software using default setup.
4. With system mounted behind the drill bit, test rotate the drilling rig while monitoring wired connections and computer.
5. After visual verification that the system is working, start the normal drilling process.
6. Start data storage by providing a file name and continuously record data while drilling as follows:
   a) Gamma Spectrometer readings
      1) Each spectrum is a fixed accumulation of data for 19.2 sec
      2) After each drill rod segments, stop recording, close data file and name.
      3) Restart recording under a new data file name; start drilling the next rod segment.
      4) Repeat steps (2) and (3) until drilling is completed.
   b) Magnetometer readings are taken
   c) Potentiometer readings are taken
7. Close the PC file and store file to secondary backup system.
8. Commence pullback of drill rod.

## EMWD Calibration Procedures, Quality Control Checks, and Corrective Action

This section describes the calibration procedures that apply to the EMWD system. It also contains a discussion of the corrective action to be taken if the QC parameters fall outside of the evaluation criteria.

### *Gamma Spectrometer Calibration Procedures*

Calibration was consistent with procedures in Westinghouse Hanford WHC-SD-EN-TI-293, Rev. 0 and with Grand Junction calibration techniques for the Grants, New Mexico, calibration pits. The Westinghouse Hanford document covers the procedures for calibrating gamma-ray well logging tools using Hanford formation models. Calibration procedures for the EMWD system is covered in "Environmental Measurement-While-Drilling Gamma Ray Spectrometer (EMWD-GRS) System Technology Demonstration Plan for Use at the Savannah River Site F-Area Retention Basin (SAND 96-2019)

In general, a complete calibration is required every six months with an initial check before and after each drilling operation. Complete calibration every six months can be performed at calibration pits at any DOE calibration facility. The calibration to be performed has two stages. First, the linear energy peak

used to channel number calibration normally uses several radioactive elements of differing gamma energy emissions. Second, the gamma flux correlation to waste concentrations requires test pits of known flux and contamination levels. These pits can be found at a number of DOE facilities, but those best-known and used most frequently are the A and B models located at Grand Junction, Colorado.

Complete calibration generates a set of coefficients correlating spectral count rates at differing energy locations to amounts of soil contamination. Should these coefficients exceed limits or fail to produce acceptable results, the system must be recalibrated or repaired at Sandia National Laboratories, Albuquerque, New Mexico.

Initial check before and after drilling uses a simple potassium-40 (K-40) (or other common isotope) of known energy emission. This then becomes part of the data file for validation of system operation while the drilling measurements are being taken. A simple visual inspection of the initial check data is sufficient to approve the start of drilling. A failed spectrum would require replacement of failed system components. This work could be done in the field. The gamma spectra data to be used for evaluating the EMWD system were collected during the site assessment at the Hanford Site. Sample collection and analysis methodologies, including quality control procedures, have been fully described by Hanford.

### *Calibration Verification of the Orientation Measurement for the EMWD*

The EMWD uses a small orientation instrument (Model 544) manufactured by Applied Physics Systems, Mountain View Ca. The manufacture's specification for the Model 544 is ±0.5 degrees for roll and inclination and ±1.0 degrees for azimuth. The Sandia calibration will verify sensor performance while installed within the drill housing. Verification is a two-part process involving only the two measurements used to calculate drill bit location; inclination and azimuth. First and most critical is the inclination measurement. Inclination is a difficult measurement for any orientation instrument. Inclination errors lead to elevation errors while drilling, which increase the chances of drilling into man-made structures above or underground.

Inclination

To validate inclination, the EMWD system is mounted in the drill housing used during drilling. The housing with the EMWD system is then placed onto a level optical table. The optical table is verified level to 0.0005 in/ft. using a 15 in. master precision level. The orientation readings for inclination will be compared to manufactures specification for each quadrant of roll: 0, 90, 180, and 270 degrees. Error readings will be recorded and calibration coefficients for tool at 90 degrees vertical will be generated for error correcting while drilling.

Azimuth

To validate azimuth, the EMWD system is mounted in the drill housing. The housing with the EMWD system is then taken to an open field away from any buildings and power lines. The goal of this experiment is not to calibrate the azimuth measurements but to verify that the housing is not effecting the orientation readings.

Using a normal compass the system is directed North. The Model 544 will provide a North reading plus a reading of magnetic field intensity. The North reading will be verified and the magnetic field intensity must have a reading of 0.5 gauss to indicate that the housing is not effecting the azimuth readings.

## Quality Assurance

The quality assurance section (QA) for this demonstration specifies procedures that were used to ensure data quality and integrity. Careful adherence to these procedures will ensure that data generated by the demonstration will meet the desired performance objectives and will provide sound analytical results.

Gamma Ray Spectrometer and magnetometer readings will be taken and analyzed on site using the EMWD system technology. These magnetometer readings were compared to position data collected by the driller using the Tensor tracking tool and TruTracker™. The SNL project leader, field team leader and technology operator was responsible for data readings and analysis quality assurance/quality control (QA/QC) throughout the demonstration. QA/QC activities for the EMWD system included activities to assure that the demonstration would provide data of the necessary quality.

### *Data Quality Parameters*

The data obtained during the demonstration must be of sound quality for conclusions to be drawn on the performance of the EMWD system. For all measurement and monitoring activities conducted for the EPA, the Agency requires that data quality parameters be established based on the proposed end uses of the data. Data quality parameters include six indicators of data quality: representativeness, completeness, comparability, accuracy, precision, and lower-limiting the detection threshold for elimination of false-positive readings.

Representativeness

Representativeness refers to the degree to which the data accurately and precisely represent the conditions or characteristics of the given parameter. In this demonstration, representativeness was ensured by executing consistent data collection procedures, including reading locations, reading procedures, and data storage. Using each method at its optimum capability to provide results that represent the most accurate and precise measurement that each method is capable of achieving also ensured representativeness.

Completeness

Completeness refers to the amount of data collected from a measurement process compared to the amount that was expected to be obtained. For this demonstration, completeness refers to the proportion of valid, acceptable data generated using each method.

The completeness objective for data collection during this demonstration was to take spectral and magnetometer readings continuously during the drilling process. The drilling process continued at the Mock Tank Test Site for approximately 250 ft. (~77 m). Never before has such a complete data set been taken. The EMWD magnetometer readings were compared to the position readings obtained by the driller.

There is a physical limitation to the sensitivity and resulting range of spectral gamma measurement. These limitations relate to crystal size and maximum data collection rates. Expected range for the in NaI spectrometer is

Comparability

Comparability refers to the confidence with which one data set can be compared to another. The primary objective of this demonstration was to evaluate how well the EMWD system performed in determining position compared to data obtained by the Tensor/ TruTracker ™ used by the driller.
A secondary objective was to determine how well the EMWD system performed in determining presence K40 compared to analytical data derived from previous site assessment. The expectation is to be consistent with off-site analysis methods.

Accuracy

Accuracy for gamma spectrometer readings refers to the difference between the contamination readings and a reference standard. The resulting accuracy contains error variances from both the repeated contamination readings and the reference standard. The analytical reading from sampled soil will be the standard. The analytical reading is a single valued number with error bars. The EMWD system gamma spectrometer readings are a function of contamination reading versus location and sample period. Ideally, the EMWD system would be exposed to soils with uniformly distributed contamination consistent with the small sample used in laboratory analytical measurement. These ideal conditions did not exist during the demonstration.

Using the statistical nature of the gamma process and calibration information taken from calibration standards, New Mexico (Leino et. al, 1994), the comparable accuracy was established. Calibration procedures are listed in Appendix C.

Historically, it has been understood that the standard deviation of the gamma count rate is equal to the square root of the measured count. The measured count increases has the sample period increases. For example, a deviation of 10% must have a measured count equal to 100. To increase accuracy, controls must be placed on the rate of drilling. The limiting drilling rate has not been established. The industry drilling standard for natural gamma backgrounds is 2 to 10 ft. per minute.

Precision

Precision refers to the degree of mutual agreement among individual measurements and provides an estimate of random error. Precision was established using SNL external calibration sources and checks of the EMW tool for response in native soil. The EMWD system collects data at a sufficiently high rate so that the drilling rate does not affect data quality in moderately to highly contaminated soils. If a radiological "hot spot" is encountered, the drilling rate can be reduced to provide sufficient radiation count statistics. Random error is directly related to sample period, drilling rate (changing environments), and contamination levels (count rate). For greater precision at low contamination levels, the sample period must be increased and drilling rate was reduced, if not stopped altogether.

Probability of False-Positive

The probability of a false positive is the probability of a contaminated soil condition that does not exist.

The statistical nature of gamma measurements and electronic noise in any gamma measurement system does not provide a true zero reading. Given any sample period, there is a probability of measuring gamma relating to the energy levels of radiological material such as K-40 even without any laboratory-measurable quantities present. This problem requires setting the measurable threshold of radiological material (such as K-40) below the minimum the system can measure accurately. This lower limit is an important parameter in preventing unwanted expense. The lower limit is a function of the sample period and drilling rate. The lower limit was determined through background measurements at the radiologically "cold" site. Approximately 100 measurements were taken to statistically parameterize the background radiation count rates. The lower limit was consistent with other off-site analysis methods.

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# APPENDIX B

## Commercial Drilling Equipment Descriptions/Specifications and Procedures for the HDD-EMWD Hanford Demonstration

## A&L Underground, Inc.

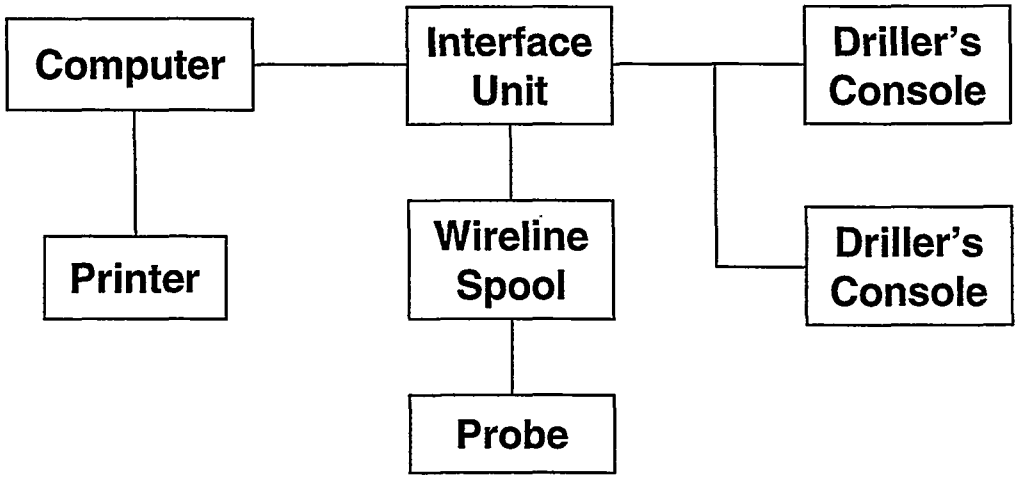
## Specifications for Directional Drilling Rig IV
## Drill Rig Used for Hanford Demonstration

| | | |
|---|---|---|
| **Dimensions:** | | |
| Length | 20' Skid | 20' |
| Width | 7' | 8' |
| Height | 6'6" | 9' |
| Operating Weight | 15,000 lbs. | 28,000 lbs |
| **Drill Carriage Specifications:** | | |
| Maximum Spindle Speed | 120 RPM | |
| Maximum Spindle Torque | 16,000 ft. lbs. | |
| Maximum Thrust | 120,000 lbs. | |
| Maximum Pullback | 120,000 lbs. | |
| Carriage Length | 25' | |
| **Drilling Fluid Pump Unit (TEE Gardner Denver Triplex Pump):** | | |
| Power Source: CAT 3406 | 300 HP | |
| Mixing Tank Capacity | 1,600 gal. | |
| Maximum Drilling Fluid Pressure | 1,500 PSI | |
| Normal Operating Pressure | 300 PSI - 1,200 PSI | |
| Maximum Flow Rate | 200 GPM | |
| Normal Drilling Flow Rate | 120 GPM | |
| Normal Backreaming Flow Rate | 120 GPM - 200 GPM | |
| **Power Source:** | | |
| Cummings 300 HP | | |
| Hydraulic Pump Capacity: | | |
| 1 @ 80 GPM | | |
| 1 @ 120 GPM | | |
| 1 @ 20 GPM | | |
| Maximum Pressure | 5,000 PSI | |
| Total Hydraulic Flow - Maximum | 220 GPM | |

## Tensor Steering Tool System

### *Steering Tool System Components*

The Tensor Steering Tool System (see attached specification sheets) consists of a Probe, Interface Unit, IBM compatible Computer, Printer, Driller's Console(s), and Software.

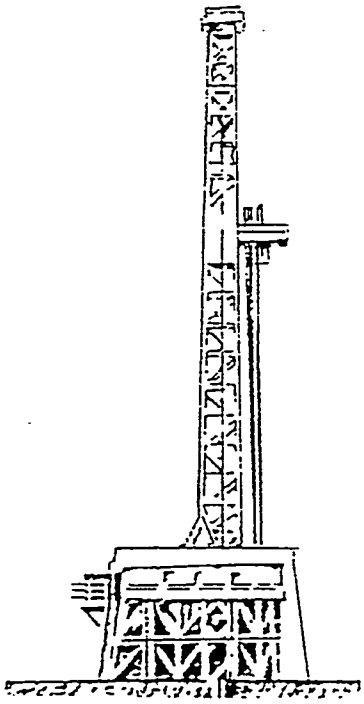


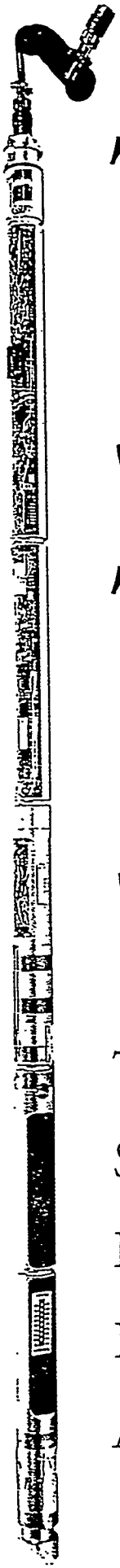

### *Probe*

The Probe consists of an orientation module (magnetic and gravitational sensors), digitizing circuitry, modulating circuitry, and control circuitry. Upon power up the orientation module's thermal model data is transmitted uphole. This is followed by a continuous transmission of raw sensor data, which is used to calculate directional information.

### *Interface Unit*

The Interface Unit contains power control circuitry, demodulating circuitry, and interface circuitry. Power is supplied to the Probe and data is received from the Probe; demodulated and sent to the Computer. The Computer calculates directional information and sends it to the Driller's Console via the Interface Unit.





# TENSOR STEERING TOOL SYSTEM

THE INDUSTRY STANDARD FOR RELIABLE, ACCURATE, PERFORMANCE UNDER ALL CONDITIONS

# TENSOR STEERI

## WITH SHOCK MONITORING AND SURVEY ACCURACY, OPTIONAL GAMMA

The Tensor Steering Tool System has highest accuracy and is all-angle—now in new, second generation form to meet the most demanding steering needs. It produces Tensor survey quality data in any orientation, from straight down to straight up. The overall system with software includes complete self-testing capabilities. Data quality measurements are displayed to the operator at all times for confirming proper downhole probe operation.

Shock level of the downhole tool is qualitatively monitored, telling the driller when drilling is rough so weight-on-bit and/or pump rate can be adjusted. If the high shock cannot be reduced to an acceptable level — motor, bit, or stabilizer problems are indicated. The Shock Isolated Probe (Superprobe)provides four times greater shock and vibration survival, is enveloped in a beryllium copper pressure barrel and can sustain maximum operating pressure of 12,000 psi. The barrel is 1.75 inches in diameter, 6 feet long and with probe installed weighs 25 pounds.

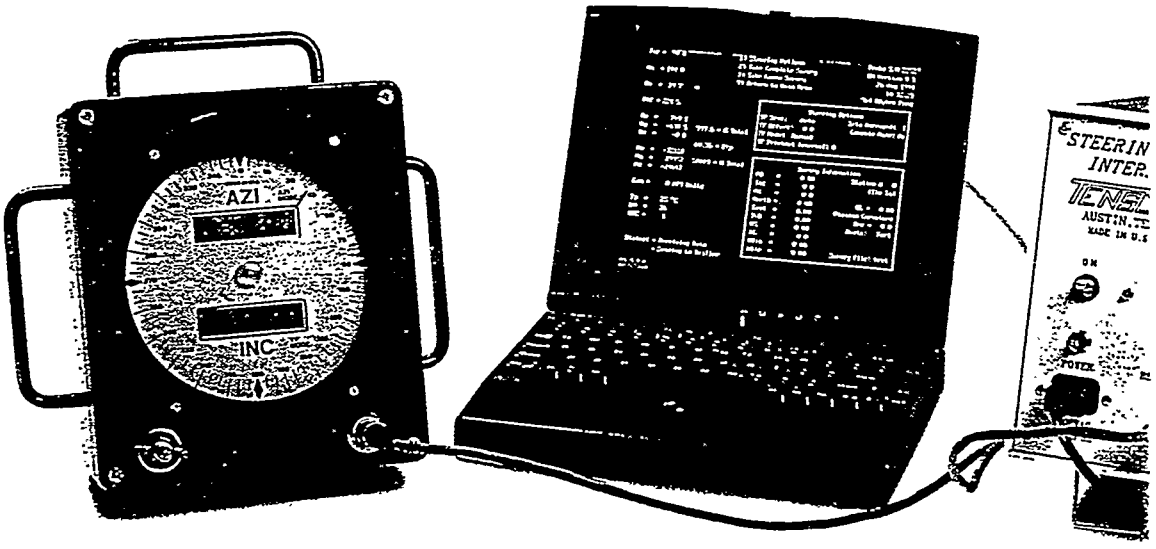
The Tensor Steering Tool System consists of the Downhole Probe, Interface Unit, Driller's Console, Computer with Printer, and Steering Tool Software.

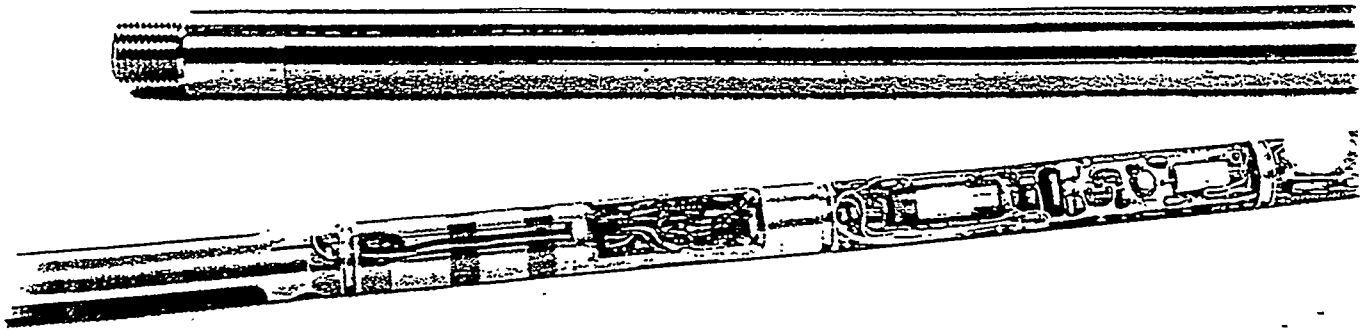
DOWNHOLE PROBE contains an orientation module with triaxial accelerometers and triaxial magnetometers for gravity and magnetic field measurements, a temperature sensor, signal digitizing circuitry, a frequency-shift-keying modulator for communication via the wireline, and power regulation and control circuitry. An optional gamma sub, containing a gamma sensor system comprised of a detector assembly and a high voltage module, mounts below the regular housing.

INTERFACE UNIT contains power control, signal demodulating, and interface circuitry.

COMPUTER customer furnished choice of IBM compatible 386 or 486 with 640K RAM, math coprocessor, two disk drives (one floppy and one hard drive preferred), one serial port and one parallel port.

DRILLER'S CONSOLE displays toolface angle with servo-driven pointer, plus two back-lighted liquid crystal displays — one for azimuth and azimuth mode, the other for inclination and toolface mode. Now sealed in a watertight enclosure.



# G TOOL SYSTEM

PRINTER customer furnished choice for producing surveys and hard copy records of directional information during steering tool run.

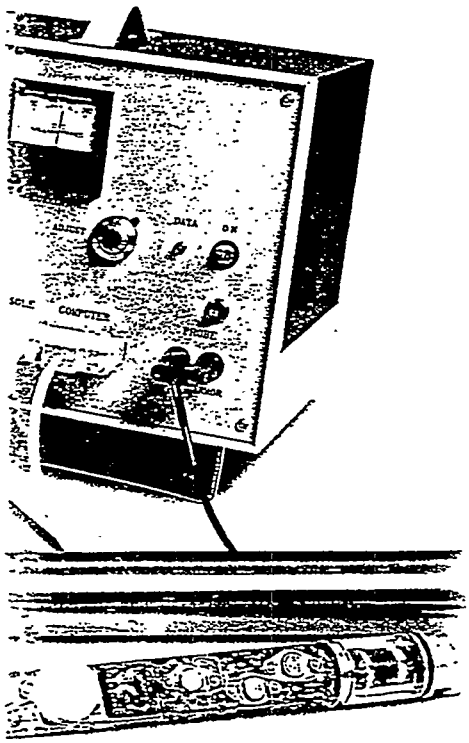
SOFTWARE provides steering tool operating programs, as well as routines for system configuration and start up, data recording, survey calculation and printout, Driller's Console and Interface Unit tests. probe diagnostics and Tensor Roll Test calibration check.

## DEMANDING APPLICATIONS

- Re-entry
- Drain hole
- Microtunneling
- Trenchless construction
- Borehole Surveying
- River crossings
- Kickoff and landing section

## RUGGED • RELIABLE • ACCURATE

- Field proven thousands of times
- Tool shock monitoring
- Easy to set up and operate
- Continuous error checking
- ›matic and manual
  ...ection of toolface modes and offset
- Survey quality accuracy
- Steers in any orientation
- Reliable data transmission
- Large, high visibility, continous display



## SPECIFICATIONS

DIRECTIONAL PERFORMANCE
Maximum lateral displacement error:
2.6 feet per 1,000 feet, or conical uncertainty of ± 0.15 degrees maximum.
Survey resolution: 0.1 degree.

DOWNHOLE PROBE (Shock Isolated)
Maximum operating temperature:
+ 150°C (+ 302°F) within specifications;
+ 175° C (+347°F) survival.
1.750 in. diameter, 76 in. long, 25 lbs.
In beryllium copper pressure barrel.

INTERFACE UNIT
8 in. h x 11 in. w x 11 in. d; 12 lb.

DRILLER'S CONSOLE
9 in. h x 8 in. w x 4-1/2 in. d; 10 lb. with 50 ft. and 100 ft. cables.

SYSTEM INPUT POWER
60 watts maximum, 120 VAC, 50 to 60 Hz
(excluding computer and printer).

## WARRANTY

One year limited warranty against defects in material and workmanship.

## TYPICAL SYSTEM

For one job capability:
2 or 3 Downhole Probes, 2 Driller's Consoles, and 2 Interface Units.

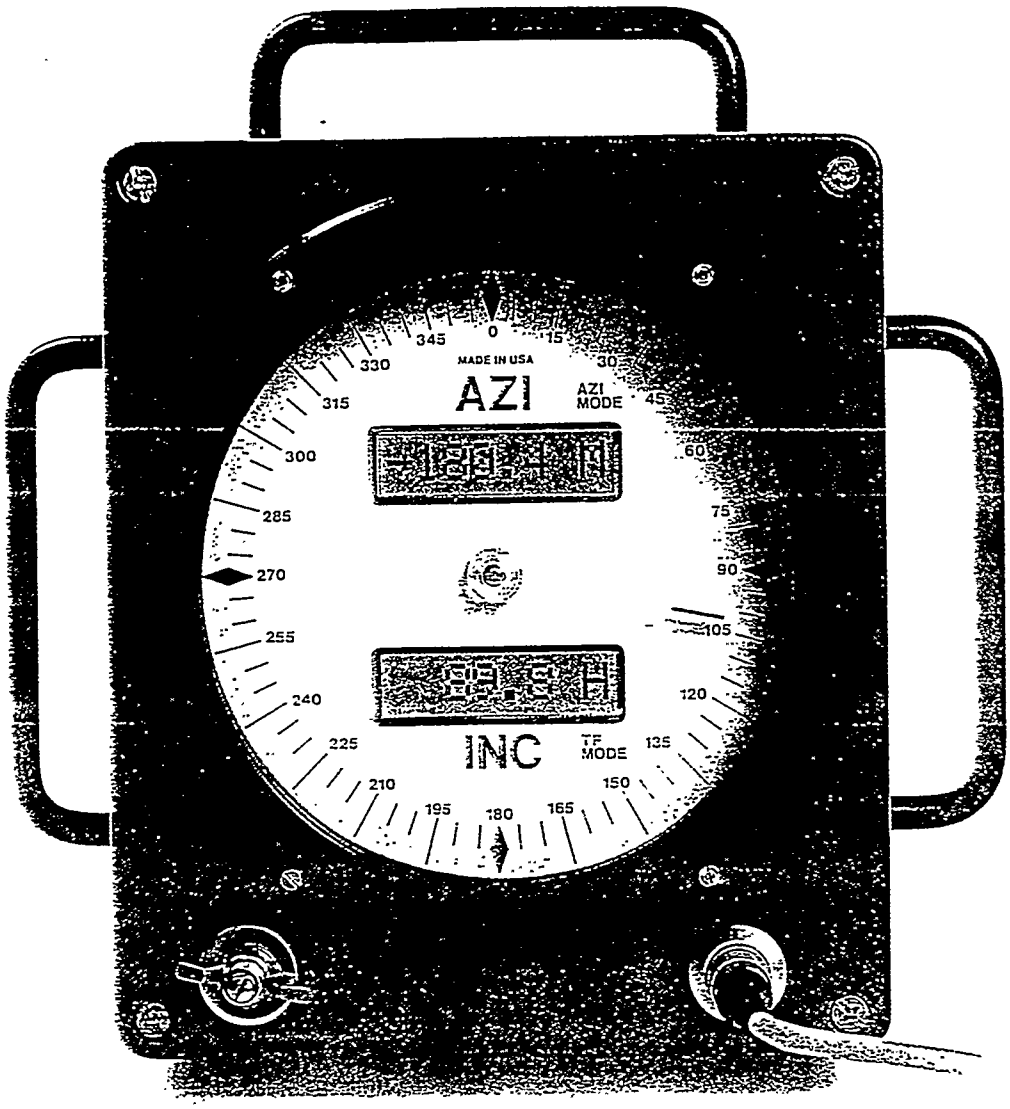
## OPTIONAL FEATURES

TRU TRACKER® GUIDANCE SYSTEM
(requires a license to operate; contact Tensor)
for shallow drilling such as pipeline river crossings and tunnels. accurate both laterally and vertically to 0.2 foot per 10 feet of borehole depth (2%).

GAMMA SENSOR
High efficiency natural radiation sub.
Adds 5 ft. in length and 20 lbs. weight

EXPLOSION PROOF HOUSING
for Driller's Console.

CUSTOMER LOGO AND COLORS
for Driller's Console and Interface Unit.




for additional details:

TENSOR

Mailing address: P.O. Box 14843
Austin, Texas 78761
Street address: 1340 Royston Lane
Round Rock, Texas 78664

Tel: 512. 251-4131
Fax: 512. 251-5708

*The material contained herein is subject to change as improvements are made.*

## TruTracker™ — a Superior Tracking System for HDD

### *History*

In 1987, Tensor introduced Magnetic Guidance to river crossing drilling. The steering system, which was intended to function equally well for the oilfield drilling industry, turned out to be an industry standard for both industry because of its outstanding performance in terms of accuracy and reliability. However, in river crossing applications, due to the frequently "polluted" magnetic environment due to the presence of railroad tracks, power line towers and other pipelines, to name a few items, the azimuth was often corrupted in varying degrees.

In response to the problem of magnetic interference, a method was developed by Tensor to effectively restore the desired accuracy in placing the wellbore in the prescribed location without expensive and time-consuming redrills. U.S. Patent No. 4,709,486 was issued to Philip H. Walters and assigned to Tensor, Inc. The name TruTracker™ was given to this method, and it was welcomed by the HDD industry as a practical means of drilling a wellbore in spite of magnetic interference.

### *How it Works*

TruTracker™ is an ancillary method to the Tensor Steering Tool system. That is, it is an added procedure for eliminating, or greatly reducing, magnetic interference. The procedure is as follows:

a) A coil (or coils) is laid out centered over (or as nearly so as possible) the proposed borehole alignment. The corners, or inflection points, are located (the position is measured with respect to the centerline, elevation of the entry stake and an "away" reference, often the entry stake) and are entered into the computer.

b) The ends of the coil are connected to a direct current source such as a welding machine, and the current in the coil is measured to an accuracy of at least 1%.

c) At an appropriate point, such as where each joint of drill pipe is added, a TruTracker measurement is taken. At this time, drilling and pumping has stopped and the probe is stationary. The welding machine is then connected and current flows in the coil. The data is taken from each sensor and stored along with the coil current. Current is reversed, and the data is taken again.

d) The program then generates a model of the magnetic field distribution in the space about the coil, methodically compares the direction and intensity of the field at many positions below the coil to the direction and intensity measured by the probe until a match is found (within a very small tolerance), and finally reports the left-right position and the depth (elevation) below the reference elevation. Note that, in effect, the first set of data is subtracted from the second, removing the earth's magnetic field as well as the interference field. What remains is twice the value of the field generated by the coil, which is used for the resulting magnetic field model.

e) If proper accuracy is used 1) in measuring the locations of the coil corners and the current in the coil in each direction, and 2) in entering the information into the computer; and, if measurements are not attempted too close to the ends of the coil; then, the resulting position of the probe determined by the program will be within +/- 2 percent of the coil width (normally laid out the same width dimension as hole depth).

# APPENDIX C

## Drilling Procedures for the HDD-EMWD Hanford Demonstration

## A&L UNDERGROUND, INC.

## Horizontal Directional Drilling Procedures

The following procedures are general in nature and do not describe every possible use nor system available today. There are two (2) locating systems mentioned in this procedure and the "wire line" system will be designated as subprocedure a).

1. Establish entry and exit points and angles.
2. Determine drill path.
3. Do clearing of right of way and jobsite area.
4. Set up drilling machine on entry point and at proper entry angle.
   a) Set up Tensor wire steering system on both sides.
5. Mix appropriate drilling fluids as needed.
6. Make sure pullback pipe is ready for installation and on rollers if needed.
7. Drill pilot hole while using above ground locator for guidance.
   a) Drill pilot hole while using Tensor steering system, following proposed drill path.
8. After pilot hole is complete, backream in stages, to the appropriate pullback diameter (usually 1.5 times the diameter of the pipe to be installed).
9. Upon completion of reaming, attach pullback reamer and swivel to the pullback head on the product pipeline.
10. Pull back product pipeline utilizing the drilling equipment and appropriate pipe-lifting equipment on the pipe side.
11. Upon completion of pullback, tear down equipment, secure both ends of installed pipe and demobilize.
12. Ensure jobsite is clean according to specifications.

These procedures can be used on all sizes of rigs and pipelines.

## Procedures for Health and Safety

All personnel in the vicinity of the drilling operation shall wear protective clothing and external dosimeters (TLDs). Those operators who will handle the equipment (drill strings, tremie pipe, sampler, etc.) will wear gloves. If a significant potential exists for drilling mud splashing onto operators, they shall wear gloves.

Air samples will be collected in the vicinity of the drilling operation. The samples will be collected each work shift and analyzed using onsite instrumentation. If elevated activity is detected, the health and safety plan will be revised to require respiratory protection. If the samples indicate the potential for a measurable intake of radioactivity, bioassay samples will be collected for each operator, which will be analyzed for the radionuclides of concern.

See each procedure for additional health and safety items.

## Procedures for Grouting Holes

After each boring is completed, the drill string will be withdrawn. A tremie pipe, consisting of threaded and joined 1% inch galvanized pipe will be pushed back into the boring, utilizing the boring rig.

High solids bentonite grout will be mixed with a paddle mixer in an oval shaped stock tank. The grout will be pumped down the tremie pipe, using a Chem-grout CG-050 grout pump. The tremie pipe will be withdrawn as the bore fills with grout, eliminating air pockets within the grout. This will be continued until the boring is grouted to ground surface.

Health and Safety during Grouting Operations. A dose rate instrument will be used to continuously monitor pipe (drill string, tremie pipe, drill bits, etc.) Removed from the boring. If the readings from the instrument exceed levels of concern for the project, the pipe will be isolated (e.g., wrapped in plastic sheeting) and removed from service. It will not be returned to service until it has been cleaned and resurveyed.

Pipes that meet the dose rate criteria upon removal from a boring will be placed in a containment area. This pipe may be reused within the same boring without the need for decontamination. Before the pipe is to be used in a new boring however, a contamination survey will be conducted on external surfaces. Any pipe that exceeds project criteria for contamination will be cleaned and resurveyed prior to its use in any new boring.

Upon completion of boring and sampling activities, all equipment used will be surveyed for contamination. Any equipment that does not meet project release criteria will be decontaminated and resurveyed. Any equipment that cannot be decontaminated will be packaged for disposal as low-level radioactive waste.

All plastic sheeting, protective clothing, and other consumables will be collected in containers. The containers will be surveyed to determine if the waste can be released as non-contaminated trash. Any waste that cannot meet release criteria will be packaged for disposal as low-level radioactive waste. Any water, cleaning solutions, and other liquids used in the decontamination of equipment will be contained. Upon project completion, these liquids will be sampled for their radioactivity content. Wastes that meet project release criteria will be discharged through a pre-approved drain to a permitted discharge point. Wastes that exceed clean-up criteria will be transferred to the site operator for treatment prior to discharge.

## Procedures for Soil Sampling

Using a "Ditch Witch" Horizontal Soil Sampler.

Start a normal horizontal bore, stopping two to three feet away from sample area. Remove the drill string, remove drill bit and steering mechanism, and connect soil sampler to end of drill string.

Push sampler through bore, then continue to push it into undisturbed soil until sample area is reached.

Retract drill string approximately 18 inches and the sampler tube automatically locks in open position. Push the sampler forward, filling the tube with soil.

Retract the drill string, remove sampler, and remove sample tube from sampler. Seal sample tube, complete chain of custody and send to designated lab.

Follow the health and safety precautions for drill pipe and boring equipment when handling soil sampling equipment.

### *Sample Handling*

Once the sample tube is sealed, its external surfaces will be cleaned. The sample tube will be capped on each end, and the caps wrapped with Teflon tape, covered with plastic tape. The sample tube will be sprayed with a soap and water solution, and scrubbed with a brush if necessary, to remove surface contamination. The sample tube will then be surveyed to ensure that it meets U.S. Department of Transportation (DOT) requirements for removable surface contamination. A dose rate measurement will then be made of the sample tube to estimate the amount of radioactivity in the sample (to be used in the request for analysis form) and to determine whether any additional DOT requirements apply to the sample's shipment.

## Drilling Fluid Procedure

The drilling mud used on the project will be BioBore, manufactured by Baroid, who will supply a mud engineer (Rheologist) on site. This dry material will be mixed with water on site in a portable tank as directed by the site mud engineer with necessary changes made due to changing ground conditions. The use of additives may be necessary to stabilize the hole or mud due to site conditions. The addition or changing of drilling mud is at the discretion of the mud engineer as he sees fit to successfully complete the project.

In the event of lost circulation on the drill rig side while on the pilot run, it will be up to the mud engineer's discretion to continue drilling and making up additional drill mud. In the event that we have drill mud on the surface, we may elect to pull back the drill string in an attempt to clean the hole to regain returns. The mud engineer to achieve the returns may alter the viscosity and density of the drilling mud. After a reasonable amount of time attempting this procedure, at the discretion of the mud engineer, the pilot hole will continue. The frac out location will be contained and continuous recovery of the drilling fluids by vacuum trucks will be employed. The resulting material will be hauled off site to an approved disposal.

We have elected to use BioBore drilling mud because it contains 0% Bentonite. As a result, there will not be any induced interference, caused by bentonite's natural radioactivity, with the performance of the EMWD.

There seems to be a certain amount of confusion about the role of drilling fluids in horizontal directional drilling. The first misconception is in the drilling process itself. The process is perceived by some to be a jetting action where we are literally washing our way through the earth with water pressure. If this were true, it would be a valid concern. However, this is not the method used today in drilling installations. We are involved in fluid assisted mechanical cutting. We are cutting through the earth with a drill bit or reamer, and the only need for pressure it to keep the bit or reamer clean and maintain flow. The soil is blended with the fluid to form a slurry and enough of this slurry should be allowed to flow out of the bored pathway to make room for the product line. Unlike vertical drilling, there is never an "empty" hole completely devoid of cuttings. This slurry is what actually holds the bore path open.

The second misconception is that we are drilling with water. The fluids used have water as their base, but certain additives are added to the water to make the water user-friendlier for what we need to accomplish. These fluids are designed to do several things. They work as soil stabilizers lubricants, and in sand, they work as grouts to hold the sand in place and prevent caving. In clay or shale, they retard swelling and reduce sticking of the soil to the product line.

There are also specifications written requiring the use of minimal amounts of fluid. This, apparently, is in the mistaken belief that compaction of the soil is desirable. The use of compaction cones and compaction reamers were promoted during the early 1990's, as a preferred method of utility installation. This has since been proven to be an inferior installation method because it doesn't promote flow of the slurry created by the bit or reamer. Without flow, all we're doing is churning dirt.

What happens if we use too little fluid and don't produce a flowable slurry? If we're using an 8" reamer, we're dealing with 2.6 gallons of soil per linear foot. If we're pulling 5" product line, we're pulling 1 gallon of product line per linear foot. If we're in sand, we need *at least* one gallon of fluid per gallon of soil. However, let's say that in this situation we're only pumping one gallon of fluid per foot instead of the necessary minimum of 2.6 gallons. There is a definite possibility of creating an undesirable speed bump across our highway. Why? We don't have flow because we haven't created a flowable slurry and we're now trying to force 4.6 gallons of material (soil, product line and fluid) into a space that originally only had enough for 2.6 gallons.

# Bio-Bore™ Product Data Sheet

# BIO-BORE™

## Horizontal Directional Drilling Fluid Concentrate

THE Original DRILLING FLUIDS COMPANY.

**Description**

BIO-BORE is a free-flowing dry powder which when mixed with fresh water provides a clay-free, biodegradable drilling fluid for use in various drilling applications, particularly in the situation where clay-based drilling fluids are restricted.

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**Applications/Functions**

- Provide a clay-free drilling fluid
- Minimize formation damage
- Maximize recovery rate of contaminants during remediation
- Provide enhanced viscosity for hole cleaning
- Provide high yield point and gel strength for effective suspension and transport
- Reduce filtration rate in poorly consolidated formation
- Improve borehole stability for easy well installation

---

**Advantages**

- Soluble in water and disperses easily with moderate shear
- Compatible with wide range of make-up waters
- Does not form filter cake on the wellbore
- Stable and yet biodegradable within a reasonable time frame depending on the surrounding environment
- Preserve with addition of small quantity of sodium hypochlorite solution
- Breakdown chemically by calcium hypochlorite
- Non-toxic

---

**Typical Properties**

| | |
|---|---|
| • Appearance | white powder |
| • Bulk density (lb/ft$^3$) | 42.5 (as packaged) |
| • Specific gravity | 1.2 |
| • pH (4% solution or 15 lb/bbl) | 6.4 |

---

**Recommended Treatment**

- Add slowly and uniformly through a high-shear jet type mixer over one or more cycles of the volume of slurry. Continue to circulate and agitate the slurry until all materials are dispersed and dissolved.

- Recommended application amounts:
  - Normal consolidated formation:
    25 to 30 pounds per 100 gallons fresh water (10.5 to 12.6 lb/bbl)
  - Unconsolidated formation:
    30 to 35 pounds per 100 gallons fresh water (12.6 to 14.7 lb/bbl)

*Note:*

- Recommended degradation amounts:
  - One to two pounds calcium hypochlorite (65% active) per 100 gallons of BIO-BORE slurry

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**Safety**

Drilled cuttings exposed to the BIO-BORE should be treated with calcium hypochlorite to break down the polymers before the cuttings can be confined or stored in a vented, sealed container or drum.

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**Packaging**

BIO-BORE is packaged in a 50-lb (22.7-kg) white clay-coated, varnished bag. The bag is sturdy, moisture resistant and easy to handle and transport.

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**Availability**

BIO-BORE can be purchased through any QUIK-GEL® distributor, or by contacting the Customer Service Department in Houston.


**Baroid Division of Dresser Industries, Inc.**

**Industrial Drilling Products**

3000 N. Sam Houston Pkwy E.
Houston, TX 77032
(281) 871-4612 (800) 735-6075

410 17th Street, Suite 880
Denver, Colorado 80202
(303) 571-8270


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*QUIK-GEL is a registered trademark of Baroid Technology, Inc.*
*BIO-BORE is a trademark of Baroid Division of Dresser Industries, Inc.*



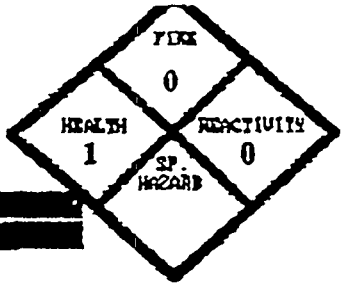
*Rev. 1/98 • IDP 037*



Because the conditions of use of this product are beyond the seller's control, the product is sold without warranty either express or implied and upon condition that purchaser make its own test to determine the suitability for purchaser's application. Purchaser assumes all risk of use and handling of this product. This product will be replaced if defective in manufacture or packaging or if damaged. Except for such replacement, seller is not liable for any damages caused by this product or its use. The statements and recommendations made herein are believed to be accurate. No guarantee of their accuracy is made, however.

# Bio-Bore™ Environmental, Safety and Transportation Data Sheet

# Baroid Environmental, Safety and Transportation Data Sheet




# BIO-BORE™

## I. PRODUCT IDENTIFICATION

| | |
|---|---|
| SUPPLIER<br>BAROID DRILLING FLUIDS, INC. | REGULAR TELEPHONE NUMBER 281/871-5900<br>EMERGENCY TELEPHONE NO. 800 424-9300 |
| ADDRESS<br>P.O. BOX 1675 HOUSTON, TX 77251 | |
| TRADE NAME<br>BIO-BORE | |
| GENERIC DESCRIPTION<br>HORIZONTAL DIRECTIONAL DRILLING FLUID CONCENTRATE | |

## II. HAZARDOUS INGREDIENTS

| MATERIAL OR COMPONENT | % | HAZARD DATA |
|---|---|---|
| NONE | | |
| | | |
| | | |
| | | |
| | | |
| | | |

## III. PHYSICAL DATA

| | | |
|---|---|---|
| BOILING POINT (Deg F)<br>NA | MELTING POINT<br>ND | FREEZING POINT<br>ND |
| SPECIFIC GRAVITY (H2O = 1)<br>1.2 | VAPOR PRESSURE (mm Hg)<br>NA | |
| VAPOR DENSITY (AIR = 1)<br>NA | SOLUBILITY IN WATER, % BY WT.<br>70% | |
| % VOLATILES BY VOLUME<br>NA | EVAPORATION RATE(BUTYL ACETATE = 1)<br>NA | |
| APPEARANCE AND ODOR<br>OFF WHITE TO YELLOW POWDER, NO ODOR | DENSITY @ 20 Deg C (Uncompacted)<br>42.5 pcf | |
| pH<br>4%soln 6.4 | | |

NA = Not Applicable ND = Not Determined

All information recommendations and suggestions herein concerning our product are based on tests and data believed to be reliable, however, it is the user's responsibility to determine the safety, toxicity, and suitability for his own use of the product described herein. Since the actual use by others is beyond our control, no guarantee, expressed or implied, is made by Baroid Corporation as to the effects of such use, the results to be obtained, or the safety and toxicity of the product nor does Baroid Corporation assume any liability arising from the use, by others, of the product referred to herein. Nor is the information herein to be construed as absolutely complete since additional information may be necessary or desirable when particular or exceptional conditions or circumstances exist or because of applicable laws or government regulations.

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Baroid Drilling Fluids, Inc.
P.O. Box 1675, Houston, Texas 77251

Baroid Division of
Dresser Industries, Inc.

## IV. FIRE AND EXPLOSION DATA

FLASHPOINT: PRODUCT IS NOT FLAMMABLE
FIRE EXTINGUISHING MEDIA: USE MEDIA APPLICABLE TO SURROUNDING FIRE.
FIRE FIGHTING PROCEDURE: WEAR FULL PROTECTIVE EQUIPMENT.
FIRE AND EXPLOSION HAZARDS: DUSTY CONDITIONS. MINIMUM EXPLOSIVE DUST CONCENTRATION IS APPROXIMATELY 0.05 CU/FT.

## V. HEALTH HAZARD INFORMATION

CARCINOGENICITY - NOT ON NTP, IARC OR OSHA LISTS

| ACUTE ORAL LD50 | ACUTE DERMAL LD50 | AQUATIC TOXICITY LC50 |
|---|---|---|
| ND | ND | ND |

ROUTES OF EXPOSURE AND EFFECTS

NONTOXIC
NUISANCE DUST, ALLERGEN TLV 10 mg/m3

EMERGENCY AND FIRST AID PROCEDURES

FLUSH ALL CONTACTED AREAS WITH WATER. IF IRRITATION PERSISTS, CONTACT A PHYSICIAN.

## VI. REACTIVITY DATA

**CONDITIONS CONTRIBUTING TO INSTABILITY**
STABLE, AVOID DUSTY CONDITIONS

**INCOMPATIBILITY**
NONE

**HAZARDOUS DECOMPOSITION PRODUCTS**
CARBON DIOXIDE, CARBON MONOXIDE

**CONDITIONS CONTRIBUTING TO HAZARDOUS POLYMERIZATION**
WILL NOT OCCUR

## VII. SPILL OR LEAK PROCEDURES

**STEPS TO BE TAKEN IF MATERIAL IS RELEASED OR SPILLED**
SWEEP UP, SALVAGE OR HOLD FOR DISPOSAL.

**NEUTRALIZING CHEMICALS**
NA

**WASTE DISPOSAL METHOD**
DISPOSE OF IN ACCORDANCE WITH ALL LOCAL, STATE AND FEDERAL REGULATIONS.

## VIII. INDUSTRIAL HYGIENE CONTROL MEASURES

**VENTILATION REQUIREMENTS**
MECHANICAL, GENERAL ROOM VENTILATION

**SPECIFIC PERSONAL PROTECTIVE EQUIPMENT**

**RESPIRATORY**
IF TLV EXCEEDED USE A NIOSH APPROVED DUST MASK

**EYE**
SAFETY GLASSES

**GLOVES**
WORK GLOVES

**OTHER CLOTHING AND EQUIPMENT**
EYEWASH

## IX. SPECIAL PRECAUTIONS

### PRECAUTIONARY STATEMENTS

AVOID INHALATION OF DUST.

### OTHER HANDLING AND STORAGE REQUIREMENTS

STORE IN SHELTERED AREA OR COVER FOR MOISTURE PROTECTION. USE WITH ADEQUATE VENTILATION. WEAR APPROPRIATE SAFETY EQUIPMENT. FLAMMABLE DUST WHEN FINELY DIVIDED AND SUSPENDED IN AIR.

## X. DEPARTMENT OF TRANSPORTATION INFORMATION

**PROPER SHIPPING NAME :**
NOT REGULATED AS HAZARDOUS

**PLACARDS :**
NONE

**HAZARD CLASS :**
NONE

**REPORTABLE QUANTITY :**
NONE

**HAZARDOUS SUBSTANCE :**
NONE

**ID NUMBER :**
NONE

**LABEL :**
NONE

## XI. REGULATORY INFORMATION

### STATUS ON SUBSTANCE LISTS

Comprehensive Environmental Response, Compensation and Liability Act of 1980, (CERCLA) requires notification of the National Response Center of release of quantities of Hazardous Substances equal to or greater than the reportable quantities (RQs) in 40 CFR 302.4.

Components present in this product which may require notification are:

| Chemical | CAS Number |
|---|---|
| NONE | |

Superfund Amendments and Reauthorization Act of 1986 (SARA) Title III requires emergency planning based on Threshold Planning Quantities (TPQs) and release reporting based on RQs.
Components present in this product at a level which could require reporting under the statute are:

NONE

SARA requires the submission of annual reports of toxic chemicals that appear in 40 CFR 372 (for SARA 313). This information must be included in all MSDS that are copied and distributed for this material.
Components present in this product at a level which could require reporting under the statute are:

NONE

Toxic Substances Control Act (TSCA)
The ingredients of this product are on the TSCA inventory.

## XII. STATE RIGHT TO KNOW

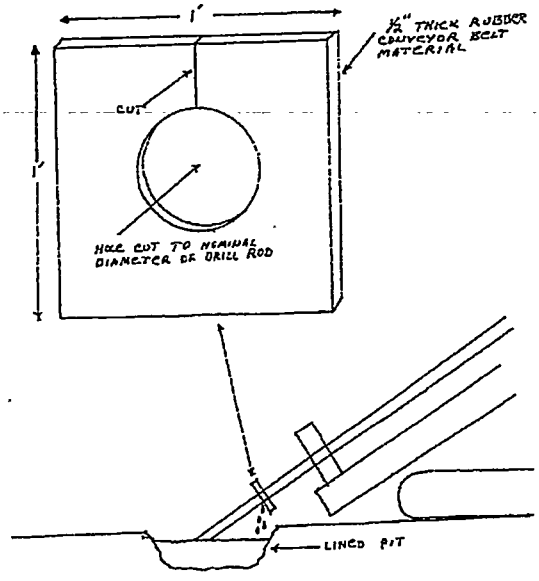
NOT ON ANY STATE LISTS.

## Decontamination Procedures

An acceptable external contamination level for the drill pipe and an acceptable exposure rate for the boring area will be established. A lay down area for the equipment will be designated next to the rig, and covered with 6-mil plastic sheeting. As much as possible, the rig will be covered with plastic sheeting to minimize splashing of potentially contaminated mud onto the rig. As the drill pipes are withdrawn from the bore, they will be surveyed to confirm the contamination level and the exposure rate. If the contamination level of the pipe and exposure rate are less than the maximum acceptable levels, the pipe will be staged on the plastic sheeting for further use in the boring. If the contamination level and exposure rate are greater than the maximum acceptable levels, the drill pipe will be placed in six mil sheeting cut to size, wrapped in the plastic, and closed with duct tape. The wrapped equipment will be isolated in the boring area to minimize personnel exposure until it is transported to the decon area. The worker's gloves will also be surveyed during the withdrawal of the drill pipe, to ensure that the accumulated contamination level stays acceptably low. If they exceed acceptable levels, they will be changed before handling any additional pipe or other equipment. Used PPE will be collected in approved containers for ultimate disposal.

The wrapped equipment will be transported in accordance with site procedures. The equipment will be cleaned at the Hanford facility designated for decontamination of heavy equipment..

The drill pipe and other equipment will be placed on racks in the decon pad and washed with high pressure steam, hot water, and detergent solution. Alconox brand laboratory cleaner detergent will be used for this purpose. After testing and declared to be contamination free, they will be placed on and covered with plastic until needed.




**Drill Rod Wiper (not to scale)**

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# APPENDIX D

## PLANNED DRILL PROFILE

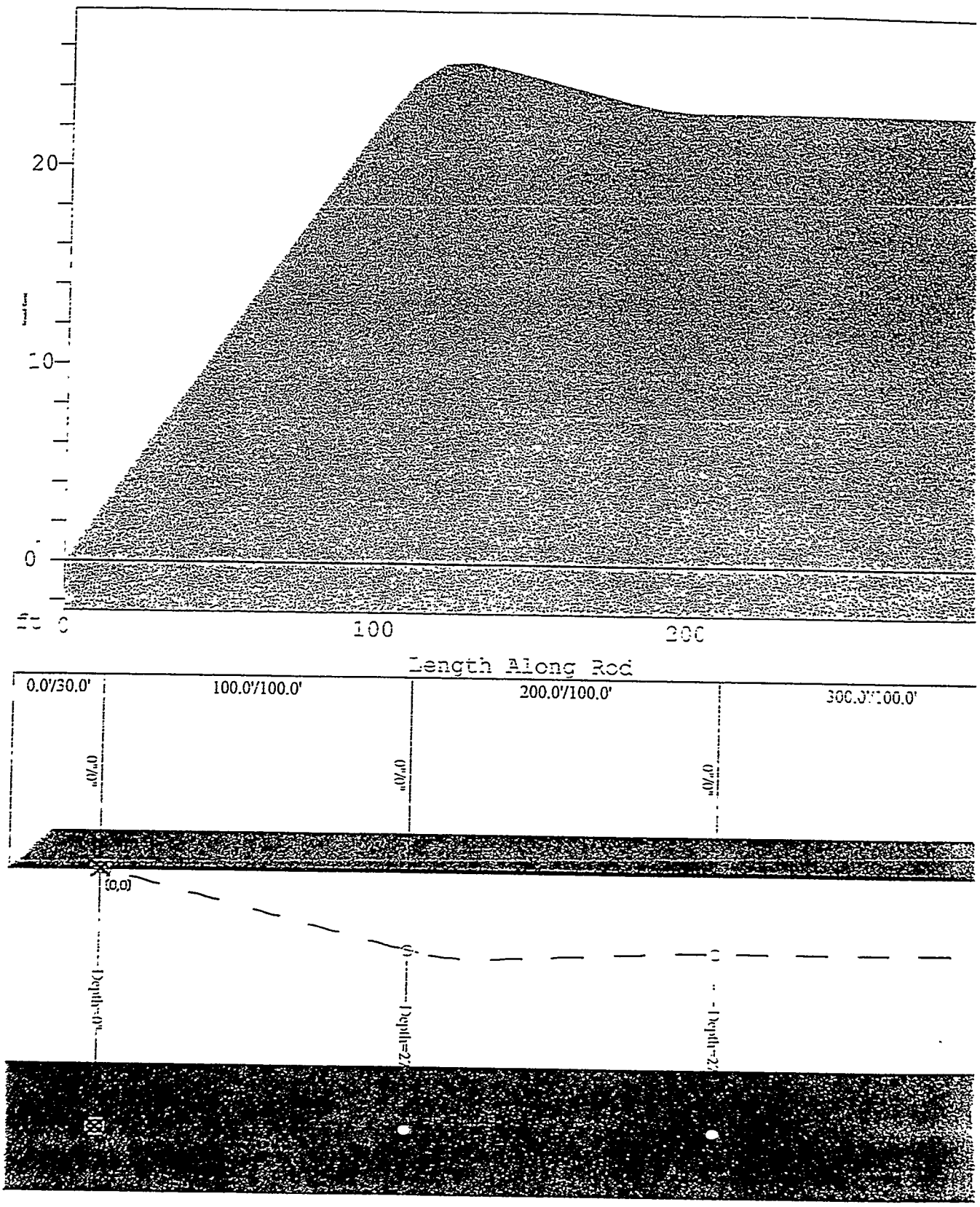
## Mock Tank Test Site Planned Drill Profile

Pilot Hole Volume: 455 gallons
Backreamed Hole Volume: 455 gallons

Set up Distance: 0.0 ft.
Set Up Left/Right: 0.0 ft.

| ROD | Length | Dist. | Depth | L/R | Pitch | Azimuth |
|---|---|---|---|---|---|---|
| | ft | ft | in | ft | % | % |
| 1 | 10.0 | 9.7 | 29.0 | 0.0 | -23.3 | 0.0 |
| 2 | 20.0 | 19.4 | 56.0 | 0.0 | -23.3 | 0.0 |
| 3 | 30.0 | 29.2 | 83.0 | 0.0 | -23.3 | 0.0 |
| 4 | 40.0 | 38.9 | 109.0 | 0.0 | -23.3 | 0.0 |
| 5 | 50.0 | 48.7 | 136.0 | 0.0 | -23.3 | 0.0 |
| 6 | 60.0 | 58.4 | 162.0 | 0.0 | -23.3 | 0.0 |
| 7 | 70.0 | 68.2 | 188.0 | 0.0 | -23.3 | 0.0 |
| 8 | 80.0 | 78.0 | 215.0 | 0.0 | -23.3 | 0.0 |
| 9 | 90.0 | 87.7 | 242.0 | 0.0 | -23.3 | 0.0 |
| 10 | 100.0 | 97.4 | 268.0 | 0.0 | -23.4 | 0.0 |
| 11 | 110.0 | 107.3 | 291.0 | 0.0 | -14.9 | 0.0 |
| 12 | 120.0 | 117.2 | 303.0 | 0.0 | -5.5 | 0.0 |
| 13 | 130.0 | 127.2 | 304.0 | 0.0 | 3.7 | 0.0 |
| 14 | 140.0 | 137.2 | 299.0 | 0.0 | 3.9 | 0.0 |
| 15 | 150.0 | 147.2 | 295.0 | 0.0 | 3.9 | 0.0 |
| 16 | 160.0 | 157.2 | 290.0 | 0.0 | 3.9 | 0.0 |
| 17 | 170.0 | 167.2 | 285.0 | 0.0 | 3.9 | 0.0 |
| 18 | 180.0 | 177.2 | 281.0 | 0.0 | 3.7 | 0.0 |
| 19 | 190.0 | 187.2 | 277.0 | 0.0 | 2.4 | 0.0 |
| 20 | 200.0 | 197.2 | 275.0 | 0.0 | 0.6 | 0.0 |
| 21 | 210.0 | 207.2 | 275.0 | 0.0 | 0.0 | 0.0 |
| 22 | 220.0 | 217.2 | 275.0 | 0.0 | 0.0 | 0.0 |
| 23 | 230.0 | 227.2 | 275.0 | 0.0 | 0.0 | 0.0 |
| 24 | 240.0 | 237.2 | 275.0 | 0.0 | 0.0 | 0.0 |
| 25 | 250.0 | 247.2 | 275.0 | 0.0 | 0.0 | 0.0 |
| 26 | 260.0 | 257.2 | 275.0 | 0.0 | 0.0 | 0.0 |
| 30 | 300.0 | 297.2 | 275.0 | 0.0 | 0.0 | 0.0 |
| 31 | 310.0 | 300.0 | 275.0 | 0.0 | 0.0 | 0.0 |

# *Mock Tank Test Site Planned Drill Profile*



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# APPENDIX E

## FIELD NOTES

## Field Notes from Hanford Field Engineers

### *Demonstration Borehole #1: Mock Tank Test Site*

| DATE | TIME | | DURATION (min.) | | | DESCRIPTION OF ACTIVITIES |
|---|---|---|---|---|---|---|
| | Start | Finish | Drilling | Other | Total | |
| | | | | | | |
| 9/15 | 0800 | 1900 | | 660 | 660 | Mobilized equipment to the tank simulation site (Mock Tank Site) located in 200 East area. A pre-condition RAD survey was conducted on A&L Underground drilling equipment prior to rigging up. No contamination was found on any of the equipment. Built spill containment and began setting up rig and equipment. Welded extended platform to rig to accommodate use of the EMWD tool. Lines were surveyed in for aligning drill rig and running wires for directional survey tool. A safety inspection was performed. Need to replace hydraulic hoses was identified. |
| 9/16 | 0700 | 1900 | | 720 | 720 | Continued to set up equipment. Location survey identified a buried line directly in front of rig and approximately 3" from point of entry. Moved rig back 10'. Return pit dug and lined. Safety inspection of setup conducted. Hoses have been replaced or on order. Safety issues identified were readily addressed and fixed. Pre-job meeting conducted. Mud tank filled with water. Drilling sub for installing casing required to be fabricated (sent to local fab shop). |
| 9/17 | 0700 | 1420 | | 440 | 440 | Continued rigging up equipment and setting up site. Initiated daily equipment inspections and pre-job safety briefings. Completed hydraulic hose replacements. A 4500 gallon water tank was delivered to site and filled. Mixed drilling mud (Bio Bore and BarZand-D Plus. Had to trouble shoot mud mixing system. Mixed up total of 2500 gallons of drilling mud. Composition is .25 #/gal of BioBore and .01#/gal of BarZan. No testing of mud parameters to be made.<br>Efforts extended to run wire through the EMWD tool assembly with no success. Decision made to initiate drilling without the EMWD tool in the drill string. |
| | 1420 | 1422 | 2 | | 2 | Started drilling. Running jetting tool assembly with tricone bit. Directional tool located 6.5' behind bit. Water swivel started leaking. |
| | 1422 | 1440 | | 18 | 18 | Shut down to repair water swivel. Mud coming to ground surface and not flowing from entry hole into the return pit. Built dirt burms to direct the mud into the return pit. |
| | 1440 | 1442 | 2 | | 2 | Finished drilling in the bottom hole assembly (bit and jet assembly with bent sub, directional tool and monel). With drill head down, Monel and jetting assembly approximately 5' into the ground |
| | 1442 | 1538 | | 56 | 56 | Experiencing mechanical problems with mud shaker as well as the mud return pump. Made connection. Repaired mud shaker. Replaced hydraulic sump pump with a large centrifugal trash pump for transferring mud from the return pit to the mud shaker. |
| | 1538 | 1543 | 5 | | 5 | Drilled down #1 rod.. A total of 25.1' drilled in (~12' below surface). While drilling, encountered an obstacle (large rock), but was able to work around it. |
| | 1543 | 1600 | | 17 | 17 | Making up connection (added #2 rod) |
| | 1602 | 1605 | 3 | | 3 | Started drilling down rod #2. Rotating at approximately 48 RPM |

| DATE | TIME | | DURATION (min.) | | | DESCRIPTION OF ACTIVITIES |
|---|---|---|---|---|---|---|
| | Start | Finish | Drilling | Other | Total | |
| | | | | | | |
| | | | | | | while jetting. |
| | 1605 | 1627 | | 22 | 22 | Stopped drilling to transfer mud from return pit. Pump transfer still not working properly. Due to the large rocks and cobbles, rig pull down is causing the rig to slide backwards. Positioned and anchored the backhoe to the front of the rig. |
| | 1627 | 1628 | 1 | | 1 | Rod #2 drilled down. Rotated at ~48-50 RPM while jetting. Continued having problems transferring mud from return pit. |
| | 1628 | 1643 | | 15 | 15 | Making connection. Currently 9.25' below surface at probe with 40` of pipe in the ground. |
| | 1643 | 1720 | | 33 | 33 | Started drilling but had to shut down after less than 30 sec. due to inability to transfer mud. Worked on pump and hoses until transfer system working again. |
| | 1720 | 1737 | 17 | | 17 | #3 rod drilled down. Encountered large rock but was able to push around it (or push it aside). |
| | 1737 | 1747 | | 10 | 10 | Made connection. |
| | 1747 | 1755 | 8 | | 8 | #4 rod drilled down. Tool depth is now at 14' below surface. Still experiencing problems with transferring mud. Loosing mud to formation. Adding water to mud tank and mixing mud. |
| | 1755 | 1825 | | 30 | 30 | Got a pump working and transferred mud. Made connection. |
| | 1825 | 1830 | 5 | | 5 | #5 rod drilled down. |
| | 1830 | 1834 | | 4 | 4 | Circulated hole, transferred mud. |
| | 1834 | 1838 | | 4 | 4 | Made connection. |
| | 1838 | 1852 | | 14 | 14 | Circulated hole to clean out cuttings. |
| | 1852 | 1856 | 4 | | 4 | #6 rod drilled down. Currently 110' from point of entry, ~23' in depth. |
| | 1856 | 1904 | | 8 | 8 | Made connection. |
| | 1904 | 1914 | | 10 | 10 | Broke circulation. Working on mud transfer. Cleaning hole. |
| | 1914 | 1916 | 2 | | 2 | #7 rod drilled down. Shift end. |
| | | | | | | |
| 9/18 | 0700 | 0750 | | 50 | 50 | Crew on location. Start up equipment. Conduct equipment safety inspections and daily safety meeting/plan of the day. Pumped return pit. |
| | 0750 | 0800 | | 10 | 10 | Making connection. Added #7 rod. |
| | 0800 | 0829 | 29 | | 29 | #8 rod drilled down. Rotating at ~60 rpm with torque between 1000-1800. Mud transfer working. |
| | 0829 | 0837 | | 18 | 18 | Making connection. |
| | 0837 | 0840 | | 3 | 3 | Break circulation and wash hole. |
| | 0840 | 0859 | 19 | | 19 | #9 rod drilled down. Alternated between rotating and pushing. Had to pull back and wash to bottom to clean hole and restore full circulation as hole was plugging off. |
| | 0859 | 0910 | | 11 | 11 | Making connection. |
| | 0910 | 0922 | 12 | | 12 | #10 rod drilled down. Lost circulation for a short period. |
| | 0922 | 0937 | | 15 | 15 | Making connection. Pumped return pit. |
| | 0937 | 0947 | 10 | | 10 | #11 rod drilled down. |
| | 0947 | 1000 | | 13 | 13 | Making connection. |
| | 1000 | 1009 | 9 | | 9 | #12 rod drilled down. |
| | 1009 | 1023 | | 14 | 14 | Making connection. |
| | 1023 | 1032 | 9 | | 9 | #13 rod drilled down. Deviation within 2.69' of center line. |
| | 1032 | 1315 | | 163 | 163 | Circulated hole clean, setup new pump for transferring mud from return pit, tripped tools out of hole. |
| | 1315 | 1336 | | 21 | 21 | Remove directional tool and add EMWD tool. |

| DATE | TIME | | DURATION (min.) | | | DESCRIPTION OF ACTIVITIES |
|---|---|---|---|---|---|---|
| | Start | Finish | Drilling | Other | Total | |
| | | | | | | |
| | 1336 | 1750 | | 254 | 254 | Run tools back to bottom taking readings from the EMWD tool every 5-10 minutes. Mixing and circulating hole plug abandonment fluid. |
| | 1750 | 1940 | | 110 | 110 | Trip the tools from hole and displace hole with abandonment fluid. Shift end. |
| | | | | | | |
| 9/19 | 0700 | 1900 | | 720 | 720 | Demobilizing from Mock Tank site and mobilizing to Drilling Test Site. |
| | | | | | | |
| 9/20 | | | | | 0 | No work. |
| | | | | | | |
| **Total Duration:** | | | 137 | 3463 | 3600 | Total of 2.28 actual hours of drilling. Total of 60 hours on job. |
| | | | | | | |

## *Demonstration Borehole #2: Drilling Technology Test Site*

| DATE | TIME | | DURATION | | | DESCRIPTION OF ACTIVITIES |
|---|---|---|---|---|---|---|
| | Start | Finish | Drilling | Other | Total | |
| | | | | | | |
| 9/19 | 0700 | 1900 | | 720 | 720 | Demobilizing from Mock Tank site and mobilizing to Drilling Test Site. |
| | | | | | | |
| 9/20 | | | | | 0 | No work. |
| | | | | | | |
| 9/21 | 0700 | 1900 | | 720 | 720 | Continue setting up equipment, containment and instrumentation at the Drilling Test Site (located north of Route 3 between 200 E and 200 W). Directional line surveyed. Return pit dug. |
| | | | | | | |
| 9/22 | 0700 | 0740 | | 40 | 40 | Start up equipment. Conduct equipment inspections and plan of the day/safety meeting. Found that the return pit had been placed `1/2 ft. off center. Decided to drill ahead using directional capabilities to come back on line. Started mixing mud at 0725. Composition is .25 #/gal of BioBore and .01#/gal of BarZan. Brought over mud tanks full (~1800 gal.). |
| | 0740 | 0743 | 3 | | 3 | Drilled in bit and sub assembly (only 5' drilled in ground). |
| | 0743 | 0748 | | 5 | 5 | Making connection. Not running the EMWD tool. Plan to run it following sampling activities. |
| | 0748 | 0756 | 8 | | 8 | Drilling down #1 rod. Going slow due to large cobbles at surface. Drilled down ~10'. Repaired a broken wire to directional tool. Backed rod out. |
| | 0756 | 0914 | | 78 | 78 | Shut down to repair PTO controlling mud system. Having difficulties transferring mud from return pit. |
| | 0914 | 0943 | 29 | | 29 | Drilled in #1 rod. Very difficult drilling. Jetting tool making slow progress through cobbles. Had to work tools back and forth to get rod drilled in. Total of 3750 gallons of water placed in reserve water tank (in addition to 1800 gallons of mud in mud tanks). |
| | 0943 | 0953 | | 10 | 10 | Making connection. Adding #2 rod. Tool string currently consists of jetting assembly, directional tool, monel, and 2 drill rods. |
| | 0953 | 1020 | 27 | | 27 | Drilling down #2 rod. Jetting to advance with occasional back and forth rotational motions (skipping). Cobbles making forward progress slow and difficult. Occasionally pull back and work tools back down. Had a breakout (mud coming to ground surface) at 1003 located ~10' out and 5' off center line. Burmed flow and directed it back to return pit. |
| | 1020 | 1031 | | 11 | 11 | A second breakout occurred ~15' past the first. Brought in backhoe to build burm to redirect flow. Stopped drilling and circulating. |
| | 1031 | 1034 | 3 | | 3 | Continued to work drill tools and circulate hole. |
| | 1034 | 1043 | | 9 | 9 | Stopped drilling to make electrical connection repairs at drill head. |
| | 1043 | 1050 | | 7 | 7 | Started circulation and working tools. Another breakout occurred on opposite to first with a significant mud flow. Continued drilling while burms are built to redirect the mud flow to the return pit. |
| | 1050 | 1130 | | 40 | 40 | Shut down drilling. Mud system PTO problems again. Attempted to repair. |

| DATE | TIME | | DURATION | | | DESCRIPTION OF ACTIVITIES |
|---|---|---|---|---|---|---|
| | Start | Finish | Drilling | Other | Total | |
| | | | | | | |
| | 1130 | 1700 | | 330 | 330 | Transmission to motor driving mud system found to be damaged and not repairable. Removed the transmission. Drilling shut down for the day while waiting on a new transmission. Crew remained on site pulling maintenance and cleanup. While down, crew replaced mud pump swabs. |
| | | | | | | |
| 9/23 | | | | | 0 | Down all day locating a replacement transmission. Due to the difficult drilling conditions, a mud motor was flown in for use when drilling resumed. |
| | | | | | | |
| 9/24 | 0700 | 1700 | | 600 | 600 | Replacement transmission installed. Drive shaft required shortening, which caused additional delays. Removed jetting tool and replaced it with the mud motor. |
| | 1700 | 1722 | | 22 | 22 | Reentered hole with mud motor and drilled down tool assembly and rod #1. |
| | 1722 | 1745 | | 23 | 23 | Made connection. |
| | 1745 | 1845 | | 60 | 60 | Reamed in rod #2. Pulled tools from the hole prior to shut down. Had to ream tools out, couldn't pull them back without rotating entire string. Another breakout occurred. Estimate that only ½ returns from hole to return pit, remainder coming out of breakouts or being lost to formation. Have been steadily adding water and mixing mud. End of shift at 1845. |
| | | | | | | |
| 9/25 | 0700 | 0720 | | 20 | 20 | Started up equipment, conducted equipment inspections and plan of the day meeting. Determined that the mud motor was causing the tool string to rise. Decided to raise rig angle to 18 degrees to compensate. Also decided to set 60' of casing after drilling out of the cobbles to try and regain circulation and keep the upper portion of the hole open. |
| | 0720 | 0945 | | 145 | 145 | Got rig repositioned to 16 degrees (most it could be raised). Had to move return pit to accommodate new angle of entry. |
| | 0945 | 1025 | | 40 | 40 | Prepared to reenter hole. |
| | 1025 | 1109 | | 44 | 44 | Reaming down mudmotor and directional assembly. With mud motor attached, directional tool is located 25' behind the bit. In moving the return pit back, the point of entry is now backfill. Drilling mud is breaking through the backfill and having to be redirected to the pit. Having trouble reaming back down hole even with mud motor in string. Drilling mud is exiting ~8' from pint of entry with no returns from hole. Having to advance slowly to ensure a new hole is drilled (don't want to follow old hole). Mud loss to formation increasing. Pumping at ~150 gpm. Mud motor and 5' of directional tool drilled in at 1109. |
| | 1109 | 1119 | | 10 | 10 | Making connection (adding rod #1). |
| | 1119 | 1135 | 16 | | 16 | Started drilling. At 1126 lost circulation completely. Shut down once all mud pumped. A total of 5500 gallons of mud have been lost to the formation. |
| | 1135 | 1415 | | 160 | 160 | Waiting on water delivery. Had 5250 gallons delivered. While down, drove rig anchors to prevent rig from skidding back. |
| | | | | | | Mixed mud. Mixing Quickgel (bentonite/polymer mix) to attempt to regain circulation. |
| | 1415 | 1450 | 35 | | 35 | Rod #1 drilled in. Still losing mud to formation. Additional |

| DATE | TIME | | DURATION | | | DESCRIPTION OF ACTIVITIES |
|---|---|---|---|---|---|---|
| | Start | Finish | Drilling | Other | Total | |
| | | | | | | |
| | | | | | | breakouts occurring. |
| | 1450 | 1500 | | 10 | 10 | Making connection. Made directional survey now that directional tool is in the ground. |
| | 1500 | 1540 | | 40 | 40 | Found wire connection to directional tool to be broken. Removed rod #2, reamed out rod #1 and removed it to repair wire connection. |
| | 1540 | 1545 | | 5 | 5 | Redrilled rod #1. |
| | 1545 | 1555 | | 10 | 10 | Making connection. Resurveying. |
| | 1555 | 1614 | 19 | | 19 | Resumed drilling with rod #2. Several more breakouts occurring. Loss of mud to formation continuing. Out of water at 1410 hrs.. Still have 1500 gallons of mud mixed in tanks. Drilling difficult. Had to anchor rig with backhoe to keep it from pushing back (driven anchors working out of ground). At 1613 the chain between the rig and the backhoe broke. Stopped drilling. |
| | 1614 | 1630 | | 16 | 16 | Stopped drilling while anchors were driven deeper. A load of 3750 gallons of water delivered. |
| | 1630 | 1645 | | 15 | 15 | Continued drilling down rod #2. Stopped after 15' drilled in. |
| | 1645 | 1655 | | 10 | 10 | Driving anchors deeper. |
| | 1655 | 1706 | 11 | | 11 | Rod #2 drilled down. Continued to lose mud to formation. Another delivery of 3750 gallons of water. |
| | 1706 | 1725 | | 19 | 19 | Making connection and taking survey. |
| | 1725 | 1800 | 35 | | 35 | Rod #3 drilled down. |
| | 1800 | 1816 | | 16 | 16 | Making connection and taking survey. Bit coming up. Made necessary adjustments to redirect bit to bring it back on line. |
| | 1816 | 1855 | 39 | | 39 | Rod #4 drilled down. Drilling still slow. Mud returns improving, but still losing a considerable amount to the formation and up through breakouts. No mud returns from borehole point of entry. All returns coming from breakouts. Shift end. |
| | | | | | | |
| 9/26 | 0700 | 0845 | | 105 | 105 | Started equipment. Conducted equipment inspection and plan of the day/safety meeting. Mixed mud. |
| | 0845 | 0850 | 5 | | 5 | Drilled in last 2' of rod #4. |
| | 0850 | 0900 | | 10 | 10 | Making connection. |
| | 0900 | 0919 | 19 | | 19 | Rod #5 drilled down. Delivery of 3750 gallons of water. Still losing mud. No returns for a while. Circulation returning slightly at the end of rod #5 drill down. Drilling has improved. Currently 17.6' in depth and 130' out. Appears that may have drilled out of the cobbles. |
| | 0919 | 0929 | | 10 | 10 | Making connection. |
| | 0929 | 0939 | 10 | | 10 | Rod #6 drilled down. Regaining some returns, mostly from breakouts. |
| | 0939 | 0952 | | 13 | 13 | Making connection. |
| | 0952 | 1003 | 11 | | 11 | Rod #7 drilled down. |
| | 1003 | 1017 | | 14 | 14 | Making connection. |
| | 1017 | 1027 | 10 | | 10 | Rod #8 drilled down. Getting fairly good returns from breakout located ~8' directly in front of point of entry. All other breakouts have healed. |
| | 1027 | 1040 | | 13 | 13 | Making connection. |
| | 1040 | 1058 | 18 | | 18 | Rod #9 drilled down. |

| DATE | TIME | | DURATION | | | DESCRIPTION OF ACTIVITIES |
|---|---|---|---|---|---|---|
| | Start | Finish | Drilling | Other | Total | |
| | | | | | | |
| | 1058 | 1107 | | 9 | 9 | Making connection. |
| | 1107 | 1117 | 10 | | 10 | Rod #10 drilled down. |
| | 1117 | 1128 | | 11 | 11 | Making connection. |
| | 1128 | 1134 | 6 | | 6 | Rod #11 drilled down. Good drilling. Appears to be drilling in sand and silts. Decision made to pull tools and run casing. After casing is set, will run in with sampler and attempt to collect a soil sample. Returns from forward breakout fluctuating. Mud flows appearing again at other breakouts. Still no returns from point of entry. |
| | 1134 | 1436 | | 182 | 182 | Remove drill string and lay down mud motor. Put on jet sub assembly. |
| | 1436 | 1644 | 10 | 118 | 128 | Reamed back in hole. Added rod #12 and drilled it down. Had no difficulty following hole back to bottom. Hole stayed open. |
| | 1644 | 1807 | | 83 | 83 | Prepared to run casing. 12 drill rods (240') and bottom hole assembly (25') in hole. |
| | 1807 | 2000 | | 113 | 113 | Ran casing. 1st joint of casing run in 2 minutes. 2nd joint was difficult to make up and took 3 minutes to ream down. 3rd joint had to be welded, took 3 minutes to ream. 4th joint also had to be welded and took 3 minutes to ream. Getting full returns through casing. |
| | 2000 | 2030 | | 30 | 30 | Cleaned up and shut down. Note: 7500 gallons of water delivered today. |
| | | | | | | |
| 9/27 | | | | | 0 | No Work. |
| | | | | | | |
| 9/28 | 0700 | 0920 | | 140 | 140 | Started equipment. Conducted equipment inspections and plan of the day/safety meeting. Cut off casing collar to remove drilling sub. Tied on to drill rods. Made connection. |
| | 0920 | 0930 | 10 | | 10 | Rod #13 drilled down. |
| | 0930 | 1100 | | 90 | 90 | Tripped tools out of hole to run sampler. Length of hole at ~265' from point of entry. |
| | 1100 | 1120 | | 20 | 20 | Out of hole with tools. Removed bottom hole assembly and attached sampler. |
| | 1120 | 1140 | | 20 | 20 | Ran 6 rods into the hole before encountering an obstruction. Worked tools back and forth, but didn't make much forward progress. Can't circulate mud through sampler to jet tool down, can only push. Decision made to come back out of the hole with the sampler. |
| | 1140 | 1210 | | 30 | 30 | Out of hole with tool string. Sampler body had snapped off at sub and was left in the hole. |
| | 1210 | 1318 | | 68 | 68 | Picked up bottom hole assembly (BHA) and removed top sub. Attached the EMWD tool and added to the BHA along with an additional monel. New BHA is 39.93'. The directional tool is 6.6' from the bit. New BHA would not make up to the drill rods. Crossover sub has wrong threads. |
| | 1318 | 1900 | | 342 | 342 | Took the EMWD tool out of BHA and returned it to original configuration. Started tripping tools back into borehole, reaming to get them to go. End of shift. |
| | | | | | | |
| 9/29 | 0700 | 0730 | | 30 | 30 | Start equipment. Conduct equipment inspections and plan of the day/safety meeting. |

| DATE | TIME | | DURATION | | | DESCRIPTION OF ACTIVITIES |
|---|---|---|---|---|---|---|
| | Start | Finish | Drilling | Other | Total | |
| | | | | | | |
| | 0730 | 1130 | | 240 | 240 | Reaming back into hole. Having difficulty. All 13 rods reamed to bottom. Made connection. Delivery of 3750 gallons of water. |
| | 1130 | 1140 | 10 | | 10 | Rod #14 drilled down. |
| | 1140 | 1330 | | 110 | 110 | Survey showed bit had kicked out. Pull back 5 joints and redrill. |
| | 1330 | 1430 | | 70 | 70 | Reamed back to bottom. |
| | 1430 | 1530 | 20 | 40 | 60 | Rods #15 and #16 drilled down. Back on line but ~5 ' deeper. Took a nose dive after Rod #10. Rather than trip back out and try to get on line, will use directional capabilities to steer tools back to intersect the line. Current line is 5' deeper and 12' to the right of the target. |
| | 1530 | 1610 | | 20 | 20 | Making connection. |
| | 1610 | 1620 | 10 | | 10 | Rod #17 drilled down. Line almost flat. |
| | 1620 | 1630 | | 10 | 10 | Making connection. |
| | 1630 | 1648 | 18 | | 18 | Rod #18 drilled down. |
| | 1648 | 1702 | | 14 | 14 | Making connection. |
| | 1702 | 1725 | 23 | | 23 | Rod #19 drilled down. Good mud returns. Approaching target line. Approximately 3' below, but still moving out. Now 18' out from center. May have lost a tool face. |
| | 1725 | 1740 | | 15 | 15 | Making connection. |
| | 1740 | 1755 | 15 | | 15 | Drilling rod #20. Transfer pump quit |
| | 1755 | 1805 | | 10 | 10 | Attempting to fix transfer pump. |
| | 1805 | 1813 | 8 | | 8 | Rod #20 drilled down. Now 3' below and 19.5' out. |
| | 1813 | 1823 | | 10 | 10 | Making connection. |
| | 1823 | 1831 | 8 | | 8 | Rod #21 drilled down. This rod was rotated down. Pump pressure has been running at 250 psi, and pumping at 120-150 gpm. Thrust has been 20K-45K psi. Drill line is being held. Last survey didn't change. End of shift. |
| | | | | | | |
| 9/29 | 0700 | 0850 | | 110 | 110 | Started equipment. Conducted equipment inspections and plan of the day/safety meeting. Mixed abandonment mud. Dumped existing drilling fluid. |
| | 0850 | 1155 | | 185 | 185 | Tripping drill string out of hole, pumping abandonment fluid as rods are pulled. |
| | 1155 | 1240 | | 45 | 45 | Removed directional tool. Placed EMWD tool in BHA. |
| | 1240 | 1814 | | 334 | 334 | Running tools back into hole. Ran in 8 drill rods. Had trouble with mud transfer, and solids control equipment. Making measurements as tools tripped into hole. After rod #8 was run, lost connection with tool. |
| | 1814 | 1850 | | 36 | 36 | Attempted to regain connection with EMWD tool. Unsuccessful. Shut down. |
| | | | | | | |
| 10/01 | 0800 | 0845 | | 45 | 45 | Started equipment. Conducted safety inspection and plan of the day/safety meeting. |
| | 0845 | 1130 | | 165 | 165 | Tripped tools out of hole. |
| | 1130 | 1900 | | 450 | 450 | Rigged down and started cleanup and loading out equipment. |
| | | | | | | |
| 10/02 | 0700 | 1900 | | | | Continued rigging down and cleanup. |
| | | | | | | |
| 10/03 | 0700 | 1900 | | | | Continued rigging down and cleanup. |
| | | | | | | |
| 10/04 | | | | | | Demobilization completed. Site cleaned up. |

| DATE | TIME | | DURATION | | | DESCRIPTION OF ACTIVITIES |
|---|---|---|---|---|---|---|
| | Start | Finish | Drilling | Other | Total | |
| | | | | | | |
| | | | | | | |
| **Total Duration:** | | | 446 | 6595 | 7041 | Total of 7.4 actual hours of drilling. Total of 117.3 hours on job. |
| | | | | | | Did not include last 2 days of demob. |

## Sandia National Laboratories Hanford Demonstration Field Notes

| Date | Location | Status |
|---|---|---|
| 9/13/98<br>(Sunday) | ABQ to SLC | Delta Flt to SLC late departure<br>Late arrival in SLC, missed connection to Pasco<br>Overnight in SLC on Delta |
| 9/14/98<br>(Monday) | SLC to Pasco<br>Charge as Mobilize | Depart SLC ~11:30 AM MST arrive Pasco 12:08 PM<br>Problem with car, exchange for Blazed<br>Arrive @ Hanford training Center, completed site training ~ 2:15 PM<br>Met Marty Gardner (WM ), drillers at Hill St. facility.<br>EMWD package arrived at Emery, not yet delivered.<br>Drilling equipment @ Hill street site---not at site, 25 mi. away<br>Marty Gardner, Waste Management NW |
| 9/15/98<br>(Tuesday) | Mock Tank Test Site<br>Drilling Day # 1 | All equipment & EMWD package moved to site,<br>Package works (not work when next to 4140 housing)<br>File: HAD_1tst.PCM w/Th-W rods for signal: in SS housing<br>Drillers weld platform on back for pulling cable.<br>Surveyors: elevation survey, center of tank, bearing of drilling line<br>Using a DWG sampler, need sub, not here, Fri?? |
| 9/16/98<br>(Wednesday) | Mock Tank Test Site<br>Drilling Day # 2 | NO WATER<br>2 wires, GPR survey: move rig back 10 feet to new entry to miss wire<br>mounting the battery pack & coil<br>Safety briefing<br>Expert panel<br>Mounting T for Batt back not rotate, will try stationary,<br>Vermeer Part on order<br>Pickupcoil mount not ready<br>HAD_2sts.pcm using 4 ~3.5 in ThW rods, in SS housing<br>Will mount ThW rods to package for signal |
| 9/17/98<br>(Thursday) | Mock Tank Test Site<br>Drilling Day # 3 | Ss sub galled, ruined housing<br>4140 housing has a bad thread at coil end, RAN filed, repaired<br>Cannot get wire through package<br>Start drill,7 rods in ground, quit @ 7PM<br>Rig Problems<br>small frac out, build burm to contain<br>As bit hits cobbles & wag through, rig moves back;<br>anchor rig with backhoe<br>Breakout cylinder seal breaks, hydraulic fluid spill, replace cylinder<br>mud pump not working, changing motor, belts cover on shaker<br>Ran & GJL to shop, got wire through all but coil endcap<br>GJL & Dale take SS & subs to Machine shop, had 4140 coil end sub |

| | | |
|---|---|---|
| 9/18/98<br>(Friday) | Mock Tank Test Site<br>Drilling Day # 4 | holes modified to push wire through<br>RAN & GJL got wire through but unable to pull Tensor wire.<br>A & L completed hole by ~10:30 AM, ttl of 12 (?) rods,<br>Went back in hole with our package.<br>12 bags of Biobore & 1 bag Xantham<br>Signal okay to start, got noisy; reterminate coil wire,<br>better bur still noisy<br>Ran as is: coil seems to be okay<br>Occasionally saw peak, may be K<br>A&L crew took over coil connections after 5 rods, 13 total<br>Tripped out & grouted with bentonite<br>pitch good , final Mag: ~26.7, TruTracker ~24<br>& EMWD ~22.3 (26.9) |
| 9/19/98<br>(Saturday) | Mock Tank Test Site<br>Drilling Day # 5 | Tool off rig, battery pack in trailer, works great, TH & K cal<br>GJL pound on housing to cause noise, okay<br>Check coax cable to rig----Bad; will use all new cables<br>Removed package, mud at both ends, flanges kept center clean<br>Used coil: end cap fell off--functioned okay<br>Installed new cable spool<br>Cal on Bench: Th, K |
| 9/21/98<br>(Monday) | Directional Drilling<br>Test Range<br>Drilling Day # 6 | Mtg. with D. Myers<br>Site set up: use deadman pins (4" x 10 ')<br>RAN & GJL pulled wire through, check system, not working<br>Checking battery: new pack<br>ThW: Th_dr2a.pcm<br>K: K-dr2a.pcm<br>Tensor Rotational, Inclination Check: 0 @ high side 76.3 degrees<br>90 = 76.2<br>180 =76.4<br>270= 76.5 |
| 9/22/98<br>(Tuesday)<br><br><br><br><br><br><br>9/23/98<br>(Wednesday) | Directional Drilling<br>Test Range<br>No Charge<br>Repair<br><br><br><br><br><br>Directional Drilling<br>Test Range | Start drill 0.7 ft. left<br>6 ft. in ground PTO for mud & shaker broken<br>Monel & first rod in ground, ~ 45 min.<br>Much grinding throughout the cobble<br>Paul: pull out , frac out 1 ft.<br>Terry back at it, 2nd frac out, rt.<br>~2 ft. off, pull out & go back in, 3rd frac out, rt.<br>Mud Pump blow: transmission gone<br>Gone to Spokane to fix<br><br>Waiting for pump |

| | | |
|---|---|---|
| 9/24/98<br>(Thursday) | Directional Drilling<br>Test Range<br>No Charge | Pump Installation<br>Mud motor hooked up<br>Casing: welded carbide tipped drag bit inserts on end of casing (both directions) purpose; get casing In/out of hole<br>~ 5PM system check. Push in mud motor & monel<br>Monel @ 10 degrees<br>Lft frac out bubbling, new frac out right<br>tough drilling, moving the rig<br>Rig set @ 14 degrees, mud motor in, rise to 7.7 degrees<br>That is 2 degrees/rod, the rising up is causing the frac outs<br>Still in cobble, pull out<br>Will set rig @ 18 degrees to spend less time in cobble zone |
| 9/25/98<br>(Friday) | Directional Drilling<br>Test Range<br>Drilling Day # 7 | Rig set @16 degrees (74)<br>Short in wireline<br>One report indicates that cobble is down to ~30-35 ft.<br>cos74=35 ft./h, h=35/cos74=127 ft. (at 30 ft, h=108ft)<br>Mud motor 21.75 ft., Monel 21.25 ft.,<br>Therefore need to push 4.2 rods to get through<br>Monel in @ 14.3 degrees, much better shape<br>Another log says cobble down to ~12-15 ft.<br>cos74=15 ft./h, h=15/cos74= ~55 ft. (at 12 ft., h=44 ft.)<br>Therefore need to push ~1 rod to get through<br>New frac, tracking package in hole ~ 11AM<br>Next joint, lost returns, run out water, waiting for water<br>Anchor rig with backhoe<br>Took ~2.5 hours to get water!<br>Start up again ~ 2:15 PM, using gel 9bentonite & polymer)<br>Two new fracs<br>43 ft. in ground, Monel @12.4 degrees (77.6) (78.70<br>Break in wireline, pull out & re-crimp<br>Pushing 1st Fe rod<br>Stabilizing chain to bachhoe broke<br>Pound in deadman pins, drill , pund in deadman pins more<br>Rain<br>Mud motor, monel & 3 rods in ground |

| | | |
|---|---|---|
| 9/26/98<br>Saturday | Directional Drilling<br>Test Range<br>Drilling Day # 8 | Wait for mud<br>Start at ~8:45AM, first rod drilled in ~20min<br>starting to get returns, still fracing out<br>Appear to be throughout the Bolder zone, in sand & gravel ~20 deep<br>Drilling going much faster, but above projected drilling line by ~10 ft.<br>8 Fe rods ~2.5 hours (M Motor, monel + 11 rods)<br>11:35 AM Pulling out to pull casing<br>Remove Mud motor, put on jet, replace cable to tensor Tool<br>Start up @ 2:30, will run to bottom & pull casing<br>12 rods + monel to get to bottom to get on bottom, 2 hrs<br>running drill rod back in easy, circulation good<br>Last rod not able to jet, rig moving, need to anchor rig<br>Break off to run casing (5:15 PM)<br>Start 6;07, Finish 8PM<br>Casing drive sub: need to remove breakout clamps<br>Casing 1, 2, 3 drive very easy ~ 2min each<br>Casing 4 ~10 min<br>More trouble getting casing set: Thread problems on #1<br>2-3 & 2-4 had to weld<br>64 ft. casing |
| 9/28/98<br>(Monday) | Directional Drilling<br>Test Range<br>Drilling Day # 9 | Rig up, cut collar to remove casing sub<br>Broke joint, add drill pipe, tag bottom & trip out (9:30-11)<br>Good Circulation<br>Sampler on, start drill ~11:20, sampler bottoming out ~on 6th rod,<br>There may be trouble with sampler (11:42)<br>Set up monel & EMWD--1:30, cannot mate, work to 2:30,<br>Bda threads<br>Take off, will put on 4140, Ran & John Mores try to Pull wire:<br>Not Work<br>Crew will drill out to 70 ft. depth., using jet, start @ 3:45PM<br>Rods in:7; on line & high (may be due to casing) Quit @ 7PM |

| | | |
|---|---|---|
| 9/29/98<br>(Tuesday) | Directional Drilling<br>Test Range<br>Drilling Day # 10 | Safety briefing<br>Start at 7:30 AM:<br>Continue High & on line<br>Rod 13:Still high & to left & moving left (2.6 ft. left & 2.5 ft. high)<br>Rod 14: 4.8 left & 4.5 ft. high<br>Now 5 ft. left: Makes the window greater than 10 ft.<br>Back out & resteer<br>Back out 5 rods & re-drill to kick out of the hole<br>Rod 10 redrill<br>Joint # 10 glanced off boulder: sent right & down<br>Joint # 14 (~285 ft. ) incl. rose 5.8 degrees,<br>As shifted left 5.2 degrees.<br>----glanced off something such as a boulder, sent back left<br>----low 6 ft., on line but looking left<br>It will move left, will let go left & concentrate on elevation, b<br>bring to left -70 ft.<br>Braced with the semi & backhoe<br>rod 17: 7 ft. below line & 12 ft. left<br>21 rods in, @ 73 depth & 19.93 ft. to left: |
| 9/30/98<br>(Wednesday) | Directional Drilling<br>Test Range<br>Drilling Day # 10 | Start pull out & grouting @ 8:50<br>Cal: Th---dr2_Th1.pcm<br>Cal: bentonite--bentin.pcm<br>Cal: K--dr2_K.pcm<br>Complete grouting @ ~10 AM<br>Resurvey rods 9-4, new data in agreement with previous survey.<br>To Monel 11:10 AM, slight bow in monel<br>Start rigging EMWD @ 11:30<br>Replace connector & pigtail, starr @ 1:20<br>Running in casing only background signal.<br>Stop to mix mud, looks like we lost the hole, will have to drill (1:46)<br>Start to pump mud, not enough, air lock, now mud hopper clogged.<br>Start up 3 P looks like the holeic loosed<br>Rod 3 out of casing was tough<br>4 & 5 easier<br>rod 6 fast, asked Driller to slow down<br>Rod 7 down at a slower rate<br>Rod 8 set----mud pump having problem 4:15 PM<br>Left EMWD running, unplug after ~20 minutes<br>Repaired, ready to start @ ~5:45 PM<br>Plug EMWD in, not work, RAN & CVW look for problem, no luck<br>---checked battery pack, coax cable coil connection, there appears<br>to be a short in the cable from battery pack to computer,<br>We have ~165 ft. of data<br>We lack 3 rods to bottom, push to bottom, will grout Thursday. |

# Daily Activity Log, Horizontal Technology, Inc

ORIZONTAL
ECHNOLOGY, INC.
Phone (888) 556-5511
Fax (713) 774-5593

# DAILY ACTIVITY

| TECHNICIAN: | JOE GRESS | CUSTOMER: | A+L | LOCATION: | RICHLAND, WA |
|---|---|---|---|---|---|
| JOB # | 98208 | DATE: | 9-13-98 | M T W T F S S | |

| TIME | NOTES |
|---|---|
| 9-13 11:50 | FLIGHT LEAVES HOUSTON TO PORTLAND TO RICHLAND (PASCO) WA. |
| 4:00 | ARRIVE IN PASCO, WA. — RENT CAR + COLLECT BAGS — DRIVE TO HOTEL |
| 9-14 | |
| 6:30 | MEET TERRY + CREW AT RESTURANT (IN HOTEL) |
| 7:00 | DRIVE TO AIRPORT (RICHLAND) FOR TRAINING |
| 12:00 | TRAINING COMPLETE DRIVE TO HANFORD SITE BADGE OFFICE FOR I.D. |
| | BADGES |
| 14:00 | AT RIG STAGING AREA - CREW LOOKING OVER R. |
| 15:00 | BACK AT HOTEL (READ SPECS) |
| 9-15 | |
| 7:00 | MEET AT RIG STAGING AREA - I WILL RIDE WITH DALE (LICENSED DRILLER) |
| | TO LOCATE SURVEY EQPT. ALSO OVERALL. |
| 11:00 | AT STAGING AREA THE ONLY SURVEYING I NEED. WE COULD LOCATE IT |
| | BUILDERS TRANSIT. I AM CONCERNED THIS WILL NOT BE ACCURATE |
| | ENOUGH TO PROVIDE THE QUALITY OF DATA THEY NEED TO CALL THIS |
| | TEST A SUCESS. |
| 11:30 | AT LOCATION - CREW WORKING ON RIG THIS LOCATION IS A |
| | MOCK TANK FARM (TO SIMULATE DRILLING UNDER A REAL TANK FARM) |
| 13:00 | SANDIA (ALL'S CLIENT) CALLED FOR A SURVEY CREW TO HELP SURVEY |
| | (FOR PROFILE + COIL) THEY ARRIVE + WE START SURVEY |
| 15:00 | SURVEYORS FINISHED - LAY OUT COIL |
| 17:30 | LEAVE LOCATION |
| 9-16 | |
| 7:00 | AT LOCATION CREW CONTINUES RIGGING UP (SURVEYOR ABOUT THE MIDDLE |
| | OF MONITOR WELL LOCATED IN AND AROUND THE TANK) LOCATE WELL HEADS |
| | OUTSIDE OF TANK - WILL NEED LADDERS TO GET INTO TANK - IF THEY WELLS |
| | ARE DEEP |

DAILY COST ESTIMATES: (This is not an invoice. Estimates for customer information only.)

| TECH. | PER DIEM | LODGING | AUTO | AIR FARE | FREIGHT | STEERING TOOL | TRANSIT | MISC. |
|---|---|---|---|---|---|---|---|---|
| 175/DAY | 40/DAY | 65/DAY | [illegible] | | [illegible] | 300/DAY | — | |

TECHNICIAN SIGNATURE: _____ CUSTOMER SIGNATURE: _____

WHITE COPY: OFFICE PINK COPY: CUSTOMER YELLOW COPY: TECHNICIAN

ORIZONTAL
ECHNOLOGY, INC.

Phone (888) 556-5511
Fax (713) 774-5593

# DAILY ACTIVITY

| TECHNICIAN: | JOE GRESS | CUSTOMER: | AT L | LOCATION: | RICHLAND, WA |
|---|---|---|---|---|---|
| JOB # | 96208 | DATE: | 9-16 | M T W T F S S | |

| TIME | NOTES |
|---|---|
| 9-16 12:00 | MONITOR WELLS INSIDE OF TANK ARE NOT DEEP ENOUGH TO BE A PROBLEM |
| | CREW CONTINUES RIGGING UP |
| 18:30 | LEAVE LOCATION |
| 9-17 | |
| 7:00 | AT LOCATION - CREW CONTINUES RIGGING UP (PROBLEMS WITH |
| | AIR LINE IN SANDIA TOOL TO ACCOMODATE OUR WIRE) (THEIR TOOL WILL |
| | BE IN BACK OF OUR TOOL) |
| 14:00 | DECIDE TO RUN OUR TOOL FIRST (ALONE) TO SURVEY HOLE |
| 15:30 | SPUD IN & CONTINUE |
| 19:00 | TF = 7 DOWN (1410' MD) STOP DRILLING FOR NIGHT |
| 9-18 | |
| 7:00 | AT LOCATION - RIG UP |
| 8:00 | CONTINUE DRILLING |
| 10:21 | AT TARGET - LAST SURVEY [illegible] |
| | (TO CLEAR DATA) |
| [illegible] | SANDIA TOOL ON BOTTOM - RU MUD LINE TO TRIP OUT |
| 18:00 | HOLE FULL STOP FOR NIGHT |
| 9-19 | |
| 7:00 | PLANNED TO ARRIVE AT LOCATION LATE (TO MAIL HAZ WASTE BOOK TO |
| | OFFICE) CALL FROM TOWN WANTS PHYSICAL ADDRESS FOR MOTEL |
| | DRIVE TO LOCATION - TOOL SAYS SHIP TO MOTEL DRIVE TO TOWN |
| | & CALL TOWN - MAIL BOOK - BACK TO LOCATION (CREW RIGGING |
| | DOWN) |
| 12:00 | DRIVE TO NEW LOCATION - KEEP STARTING OVER |
| 16:00 | ALL OUT AT NEW LOCATION - LEAVE OUT HOTEL |
| | |
| | |

DAILY COST ESTIMATES: (This is not an invoice. Estimates for customer information only.)

| TECH. | PER DIEM | LODGING | AUTO | AIR FARE | FREIGHT | STEERING TOOL | TRANSIT | MISC. |
|---|---|---|---|---|---|---|---|---|
| 425/DAY | 40/DAY | 125/DAY | 76.24/DAY 420.00/WEEK | | 125 | 300/DAY | — | |

TECHNICIAN SIGNATURE: _____ CUSTOMER SIGNATURE: _____

WHITE COPY: OFFICE PINK COPY: CUSTOMER YELLOW COPY: TECHNICIAN

(5)

ORIZONTAL ECHNOLOGY, INC.

# DAILY ACTIVITY

Phone (888) 556-5511
Fax (713) 774-5593

| TECHNICIAN: | JOE GRESS | CUSTOMER: | AT L | LOCATION: | RICHLAND LOA |
|---|---|---|---|---|---|
| JOB # | 98208 | DATE: | 9-28 | M T W T F S S | |

| TIME | NOTES |
|---|---|
| 19:00 | TTB 7 DOWN STAP FOR THE NIGHT - LEAVE LOCATION |
| 1:29 | |
| 7:00 | AT LOCATION (SAFETY MEETING |
| 7:45 | CONTINUE TRIP IN (WE ARE OUTAF OUR EXISTING HOLE - DRILL |
| | TO FIND HOLE) |
| 10:10 | START NEW SURVEY FILE (TT #12) |
| 12:20 | #14 DOWN & MOVING TO CAR LEFT - PULL BACK 5 JTS & KICK |
| | OFF |
| 14:30 | T.T # 14 DOWN & MOVING LEFT AGAIN - CONTINUE & STEER MORE RT. |
| | (SAUDIA & AT L DECIDE TO CONTINUE & CONCENTRATE ON FLEX. TO INTERSECT PROPER |
| | LINE |
| 16:30 | LEAVE LOCATION (TT # 01 DOWN END OF BORE |
| 9-30 | |
| 7:00 | AT LOCATION RIG UP & SAFETY MEETING |
| 7:30 | MIX MUD CAP TRIP OUT (NEED 6 SURVEYS ON THE WAY OUT RETRIEVE |
| | TT # 4 & TT # 10) |
| | |
| 10:00 | SURVEY COMPLETE - MERGE FILES & RUN REPORTS |
| 13:45 | LEAVE LOCATION - DRIVE TO TOWN |
| | |
| | |
| | |
| | |
| | |
| | |
| | |
| | |

DAILY COST ESTIMATES: (This is not an invoice. Estimates for customer information only.)

| TECH. | PER DIEM | LODGING | AUTO | AIR FARE | FREIGHT | STEERING TOOL | TRANSIT | MISC. |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | |

TECHNICIAN SIGNATURE: _____ CUSTOMER SIGNATURE: _____

WHITE COPY: OFFICE PINK COPY: CUSTOMER YELLOW COPY: TECHNICIAN

## Kaiser Engineering Field Survey Notes:

***Horizontal Drilling Demo #1 - Mock Tank Test Site***

| KAISER ENGINEERS HANFORD | FIELD SURVEY NOTES | Date 9/15/98 | 1 \| 2 |
|---|---|---|---|
| | | File No. | |
| Title HORIZONTAL DRILLING DEMO #1 | | Req. No. | |
| Crew NF-LM | Weather | | |
| Inst. LIETZ SET 2B | Temp. | Bar. | PPM |

1

T.O. STA. 0+00 (GUARD STAKE)

STE TANK 105 (TEST TANK)

| | X,Y | H.DIST |
|---|---|---|
| LEFT EDGE | 00° 00' 00" | 212.33' |
| RIGHT EDGE | 13° 28' 20" | 212.33' |
| ℄ TANK / FACE | 6° 44' 10" | 189.45' + 0.28' TO FACE = 189.73' |

CONTRACTOR'S ALIGN STAKE ℄ 7°41'24"

T.O. 0+00

STE CONTRACTOR'S ℄

| STA | DIFF EL. | ELEV. | |
|---|---|---|---|
| 0+00 | | 100.00 | |
| 0+25 | +0.2' | 100.2' | |
| 0+50 | +0.5' | 100.5' | |
| 0+75 | +0.8' | 100.8 | |
| 1+00 | +0.6' | 100.6 | |
| 1+25 | +0.7' | 100.7 | |
| 1+50 | +1.3' | 101.3 | |
| 1+59.8 SHLD | +1.0' | 101.0 | |
| 1+72.7 TOE | -2.8' | 97.2 | |
| 1+88 EDGE CABLE TRENCH | -2.9' | 97.1 | |
| 1+90.0 | -2.9' | 97.1 | OUTSIDE FACE OF TANK |
| 1+90.0 | -5.9' | 94.1 | INSIDE FACE OF TANK |

| KAISER ENGINEERS HANFORD | FIELD SURVEY NOTES | Date 9/15/98 | Z | Z |
|---|---|---|---|---|
| | | File No. | | |
| Title HORIZONTAL DRILLING DEMO #1 | | Req. No. | | |
| Crew NF-LM | Weather | | | |
| Inst. LIETZ SET 28 | Temp. Bar. PPM | | | |

Z

T.P. STA 0+00 (STAKE)
SITE CONTRACTOR'S ℄

| STA | EL. DIFF. | ELEV. | |
|---|---|---|---|
| 2+39 73 | -2.61' | 97.4' | OUTSIDE FACE OF TANK / SW SIDE OF TANK |
| 2+43 9 | -3.00' | 97.0' | GRADE BREAK |
| 2+50 | -2.8' | 97.2' | GRND |
| 2+64 1 | -1.5' | 98.5' | GRND |
| 2+75 9 | 0.0' | 100.0' | GRADE BREAK |
| 2+90 5 | -0.2' | 99.8' | " |
| 3+00 | -0.1' | 99.9' | GROUND |
| 3+25 | -0.6' | 99.4' | " |
| 3+50 | -0.6' | 99.4' | " |
| 3+75 | -0.8' | 99.2' | " |
| 3+90 | -1.0 | 99.0' | " |
| WELL 348°23'04" | 114.16' | +1.60' 101.60' | WELL B-2429 7-26-95 BRASS CAP IN CASE |

*Horizontal Bore Test #2 - Drilling Technology Test Site*

| KAISER ENGINEERS HANFORD | FIELD SURVEY NOTES | Date 9/21/98 | 1 / 1 |
|---|---|---|---|
| | | File No. 2ENE-028 | |
| Title HORIZONTAL BORE TEST #2 | | Req. No. 984-220 | |
| Crew NF-RT | Weather CLEAR, CALM | | |
| Inst. LIETZ SET 2 | Temp. 80°F Bar. — PPM — | | |

– PROFILE & CONTRACTOR'S ALIGNMENT –

1

HI = 5.42

HP = 5.42

HP = 9.16

① TBE STA. 0+00 (CONTRACTOR'S STAKE) N: 10000; E: 10,000 EL = 100.00

② FS ℄ BASELINE (CONTRACTOR'S STAKES) SOUTH EASTERLY

③ FS ~~PRIMARY CONTROL~~ ℄ STORM LINE VERTICAL RISE N. SIDE RUNTS 5

④ FS ALUM MON "616-3"

⑮ 5+05.2 / 34.8' LEFT
99.1

⑭ 5+00.4
100.2

⑯ 4+95.2 / 34.6' RIGHT
100.6

⑬ 4+46.7
100.6

⑫ 4+00.4
100.0

⑪ 3+52.2
99.6

⑩ 3+00.2
99.9

⑨ 2+51.3
100.5

⑰ 2+01.2 / 25.0' LEFT
100.1

⑧ 2+00.1
100.3

⑱ 1+99.4 / 25.0' RIGHT
100.7

⑦ 1+50.4
100.2

⑥ 1+00.0
100.1

⑤ 0+50.1
100.0

① RESET
STA 0+00
EL = 100.0

# APPENDIX F

## Horizontal Technology, Inc. Survey Data for the HDD-EMWD Hanford Demonstration

## Mock Tank Test Site

Survey Tabulation Sheet
Directional Survey Report
TruTrucker Survey Report
Data Verification Report
Field Survey Data Plot

# SURVEY TABULATION SHEET

HORIZONTAL TECHNOLOGY, INC.

TOLL FREE 1-888-556-5511

TELE (713) 774-5594 ❄ FAX (713) 774-5593

LOCATION HANFORD SITE (RICHLAND, WA MOCK TANK FARM

CUSTOMER AYL

JOB NO. 98208 SHT _____ OF _____

GROUND ELEVATION, ENTRY 0 EXIT NO EXIT

ENGINEER JOE GRESS

AWAY (STATIONS) ENTRY 0+00 EXIT _____

PROBE NO. 2433 SHOOT AZIMUTH _____ MAG _____ DIP _____ RIG AZIMUTH _____ SURVEY FILE HANFORD1

BIT-SENSOR 6.6

VICE-ENTRY 18

TF OFFSET 16.7

DHA LENGTH 25.1

CROSSING LENGTH _____

COIL FILE _____

| DATE | JT. JOB | TIME | PIPE LENGTH CL | PIPE LENGTH MD | INCLINATION | AZIMUTH RAW | AZIMUTH AVG | MAG | DIP | STATION AWAY | ELEVATION SURVEY | ELEVATION TT | LEFT/RIGHT SURVEY | LEFT/RIGHT TT | NOTES |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 9-17 | D/A | 15:36 | | -5 | | | | | | | | | | | |
| | 1 | | 20 | 20.5 | 77.3 | 222.9 | Pg 226 | 57242 | 67.6 | 11.95 | 95.27 | 97.39 | 0 | .75 | (224.5 |
| | 2 | 16:09 | 20 | 40.5 | 76.4 | 227.5 | | 55106 | 69.0 | 31.42 | 90.72 | 91.49 | .25 | .64 | |
| | 3 | 17:17 | 20 | 60.5 | 78.3 | 226.9 | | 55048 | 68.9 | 50.93 | 86.35 | 87.15 | .64 | .57 | |
| | 4 | 17:37 | 20 | 80.5 | 80.8 | 225.5 | | 55137 | 69.0 | 70.6 | 82.72 | 83.78 | .71 | 0.64 | |
| | 5 | 18:12 | 20 | 100.5 | 81.9 | 225.9 | | 55192 | 69.0 | 90.37 | 79.71 | 80.99 | .60 | -.36 | |
| | 6 | 18:36 | 20 | 120.5 | 83.6 | 225.9 | | 55294 | 69.1 | 110.21 | 77.19 | 78.66 | 0.57 | -.62 | |
| | 7 | 18:58 | 20 | 140.5 | 85.7 | 226.3 | | 55306 | 69.0 | 130.13 | 75.32 | 77.10 | .63 | -.80 | |
| 9-18 | 8 | 8:17 | 20 | 160.5 | 88.0 | 226.5 | | 55367 | 68.9 | 150.09 | 74.21 | 76.17 | -1.06 | -.88 | ~~.77~~ |
| | 9 | 8:48 | 20 | 180.5 | 88.1 | 226.6 | | 56317 | 68.4 | 170.08 | 73.54 | 75.7 | -1.13 | -.11 | .77 + 2.2 |
| | 10 | 9:14 | 20 | 200.5 | 90.1 | 224.5 | | 59868 | 68.8 | 190.07 | 73.22 | 76.17 | -1.54 | +.06 | .17 + 1.5 |
| | 11 | 9:37 | 20 | 220.5 | 89.9 | 234 | | 60134 | 72.4 | 210.07 | 73.21 | 76.57 | -1.29 | +.17 | .11 + .3 |
| | 12 | 9:58 | 20 | 240.5 | 89.7 | 232.3 | | 56187 | 73.3 | 230.01 | 73.15 | 76.88 | 1.53 | +.78 | .61 + 1.75 |
| | 13 | 10:21 | 20 | 260.5 | 90.1 | 228.6 | | 54057 | 70.9 | 249.96 | 73.12 | 75.81 | 1.64 | +.80 | .02 |

Horizontal Technology Inc.
Directional Survey Report
Version 3.3

Company: A&L
Well: MOCK TANK FARM
Location: RICHLAND
Field: WA.
Operator: JOE GRESS
Job No.: 98208

Survey File -> HANFORD1
18 Sep 1998
Probe 2433
Depth Units: Feet
Dec: 0.0
Line Az: 226.7

VS Azimuth = 0.0
VS Origin Away = 0.00
VS Origin Right = 0.00

Method: Average Angle

| Station | MD | Inc | Az | Away | Right | Elev | VS | DL | DS |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 0.00 | 76.0 | 226.7 | -8.00 | 0.00 | 100.00 | 0.00 | 0.0 | TI |
| 1 | 20.50 | 77.3 | 226.0 | 11.95 | -0.12 | 95.27 | -8.28 | 7.2 | PG |
| 2 | 40.50 | 76.4 | 227.5 | 31.42 | -0.11 | 90.72 | -21.63 | 8.5 | ST |
| 3 | 60.50 | 78.3 | 226.9 | 50.94 | 0.04 | 86.35 | -34.90 | 10.1 | ST |
| 4 | 80.50 | 80.8 | 225.5 | 70.61 | -0.13 | 82.72 | -48.52 | 13.9 | ST |
| 5 | 100.50 | 81.9 | 225.9 | 90.37 | -0.48 | 79.71 | -62.33 | 5.9 | ST |
| 6 | 120.50 | 83.6 | 225.9 | 110.21 | -0.75 | 77.19 | -76.13 | 8.3 | ST |
| 7 | 140.50 | 85.7 | 226.3 | 130.12 | -0.95 | 75.32 | -89.93 | 10.6 | ST |
| 8 | 160.50 | 88.0 | 227.5 | 150.09 | -0.88 | 74.21 | -103.58 | 13.1 | PG |
| 9 | 180.50 | 88.1 | 228.9 | 170.08 | -0.35 | 73.54 | -116.90 | 7.0 | PG |
| 10 | 200.50 | 90.1 | 227.2 | 190.07 | 0.12 | 73.22 | -130.27 | 12.9 | PG |
| 11 | 220.50 | 89.9 | 227.0 | 210.07 | 0.26 | 73.21 | -143.88 | 1.3 | PG |
| 12 | 240.50 | 89.7 | 228.4 | 230.06 | 0.61 | 73.15 | -157.33 | 7.3 | PG |
| 13 | 260.50 | 90.1 | 226.8 | 250.06 | 0.94 | 73.12 | -170.81 | 8.5 | PG |

Horizontal Technology Inc.
TruTracker Survey Report
Version 3.3

Company: A&L
Well: MOCK TANK FARM
Location: RICHLAND
Field: WA.
Operator: JOE GRESS
Job No.: 98208

Survey File -> HANFORD1
18 Sep 1998

Depth Units: Feet

Line Az: 226.7

| MD | Away | Right | Elev | Total Cur | Rad Angle | Rad Intens | Ax Intens | AxMis | Coil |
|---|---|---|---|---|---|---|---|---|---|
| 20.50 | 11.95 | 0.75 | 97.39 | 172.9 | 270.5 | 21977 | -3013 | -7 | MOCKTANK |
| 40.50 | 31.42 | 0.64 | 91.44 | 166.0 | 268.7 | 11666 | -796 | 0 | MOCKTANK |
| 60.50 | 50.93 | 0.57 | 87.15 | 176.7 | 266.4 | 8668 | -728 | 0 | MOCKTANK |
| 80.50 | 70.60 | 0.04 | 83.78 | 169.0 | 263.5 | 6584 | -611 | 1 | MOCKTANK |
| 100.50 | 90.37 | -0.36 | 80.99 | 169.7 | 262.1 | 5673 | -562 | 1 | MOCKTANK |
| 120.50 | 110.21 | -0.62 | 78.66 | 170.4 | 261.6 | 5117 | -521 | 0 | MOCKTANK |
| 140.50 | 130.13 | -0.80 | 77.10 | 171.3 | 261.8 | 4856 | -501 | 0 | MOCKTANK |
| 160.50 | 150.09 | -0.88 | 76.17 | 193.6 | 262.9 | 5400 | -582 | 0 | MOCKTANK |
| 180.50 | 170.08 | -0.11 | 75.70 | 178.0 | 266.6 | 5010 | -530 | -0 | MOCKTANK |
| 200.50 | 190.07 | 0.06 | 76.17 | 177.3 | 269.5 | 5178 | -445 | -1 | MOCKTANK |
| 220.50 | 210.07 | 0.17 | 76.57 | 177.9 | 271.5 | 5281 | -230 | -2 | MOCKTANK |
| 240.50 | 230.01 | 0.78 | 76.88 | 177.1 | 273.8 | 5290 | -96 | -4 | MOCKTANK |
| 260.50 | 249.96 | 0.80 | 75.81 | 176.4 | 275.4 | 5158 | 85 | -6 | MOCKTANK |

Horizontal Technology Inc.
Data Verification Report
Version 3.3

Company: A&L
Well: MOCK TANK FARM
Location: RICHLAND
Field: WA.
Operator: JOE GRESS
Job No.: 98208

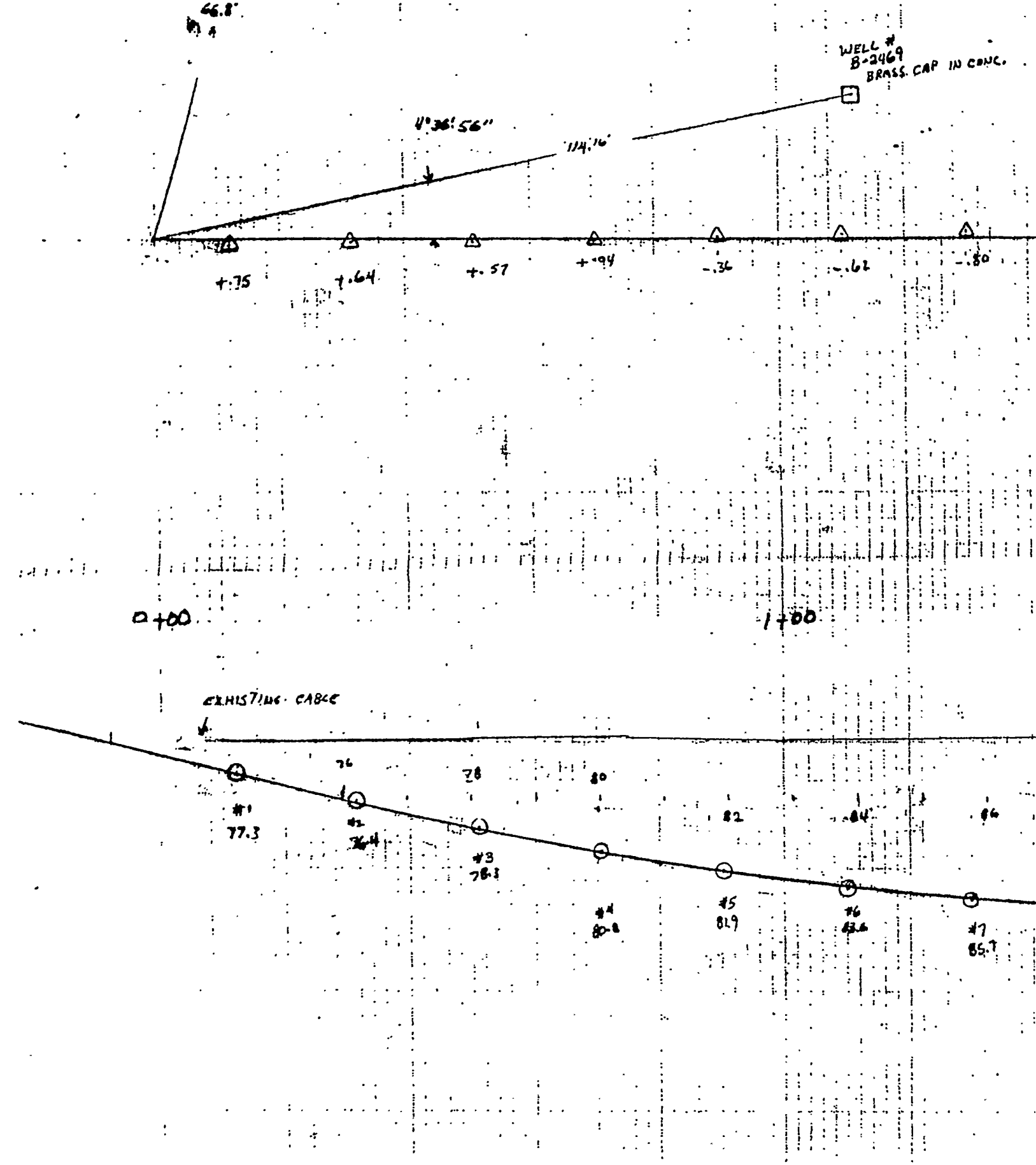
Survey File -> HANFORD1
18 Sep 1998
Probe 2433
Depth Units: Feet
Dec: 0.0
TF Offset: 16.7

| Station | MD | Inc | Az | Hs | Mtf | GTotal | HTotal | Dip | Tp(F) | WV |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 20.50 | 77.3 | 222.9 | 10.8 | 233.7 | 1001.1 | 57242 | 67.64 | 90 | 35 |
| 2 | 40.50 | 76.4 | 227.5 | 353.6 | 221.1 | 1001.1 | 55106 | 69.03 | 89 | 35 |
| 3 | 60.50 | 78.3 | 226.9 | 349.9 | 216.8 | 1001.2 | 55048 | 68.94 | 89 | 35 |
| 4 | 80.50 | 80.8 | 225.5 | 359.7 | 225.3 | 1001.1 | 55137 | 69.01 | 89 | 34 |
| 5 | 100.50 | 81.9 | 225.9 | 5.2 | 231.1 | 1001.0 | 55192 | 69.05 | 89 | 37 |
| 6 | 120.50 | 83.6 | 225.9 | 14.7 | 240.6 | 1001.2 | 55294 | 69.11 | 88 | 37 |
| 7 | 140.50 | 85.7 | 226.3 | 10.0 | 236.4 | 1001.2 | 55306 | 69.04 | 87 | 38 |
| 8 | 160.50 | 88.0 | 226.5 | 357.6 | 224.2 | 1000.9 | 55367 | 68.90 | 78 | 32 |
| 9 | 180.50 | 88.1 | 226.6 | 10.1 | 236.7 | 1001.1 | 56317 | 68.38 | 80 | 31 |
| 10 | 200.50 | 90.1 | 224.5 | 346.2 | 210.7 | 1001.2 | 59868 | 68.77 | 79 | 31 |
| 11 | 220.50 | 89.9 | 230.4 | 355.7 | 226.1 | 1001.1 | 60134 | 72.39 | 79 | 31 |
| 12 | 240.50 | 89.7 | 232.3 | 6.2 | 238.4 | 1001.1 | 56187 | 73.30 | 79 | 32 |
| 13 | 260.50 | 90.1 | 228.6 | 1.7 | 230.4 | 1001.0 | 54057 | 70.93 | 79 | 32 |

H Total Max = 60134 Gammas @ Station 11
H Total Min = 54057 Gammas @ Station 13
H Total Spread = 6077 Gammas

G Total Max = 1001.2 Milligees @ Station 10
G Total Min = 1000.9 Milligees @ Station 8
G Total Spread = 0.3 Milligees

Dip Max = 73.30 Degrees @ Station 12
Dip Min = 67.64 Degrees @ Station 1
Dip Spread = 5.66 Degrees


46.8'
WELL #
B-2469
BRASS CAP IN CONC.
4°36'56"
114.16'
+.75
+.64
+.57
+.94
-.36
-.62
-.80
0+00
1+00
EXISTING CABLE
#1
77.3
#2
#3
78.3
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80.8
#5
81.9
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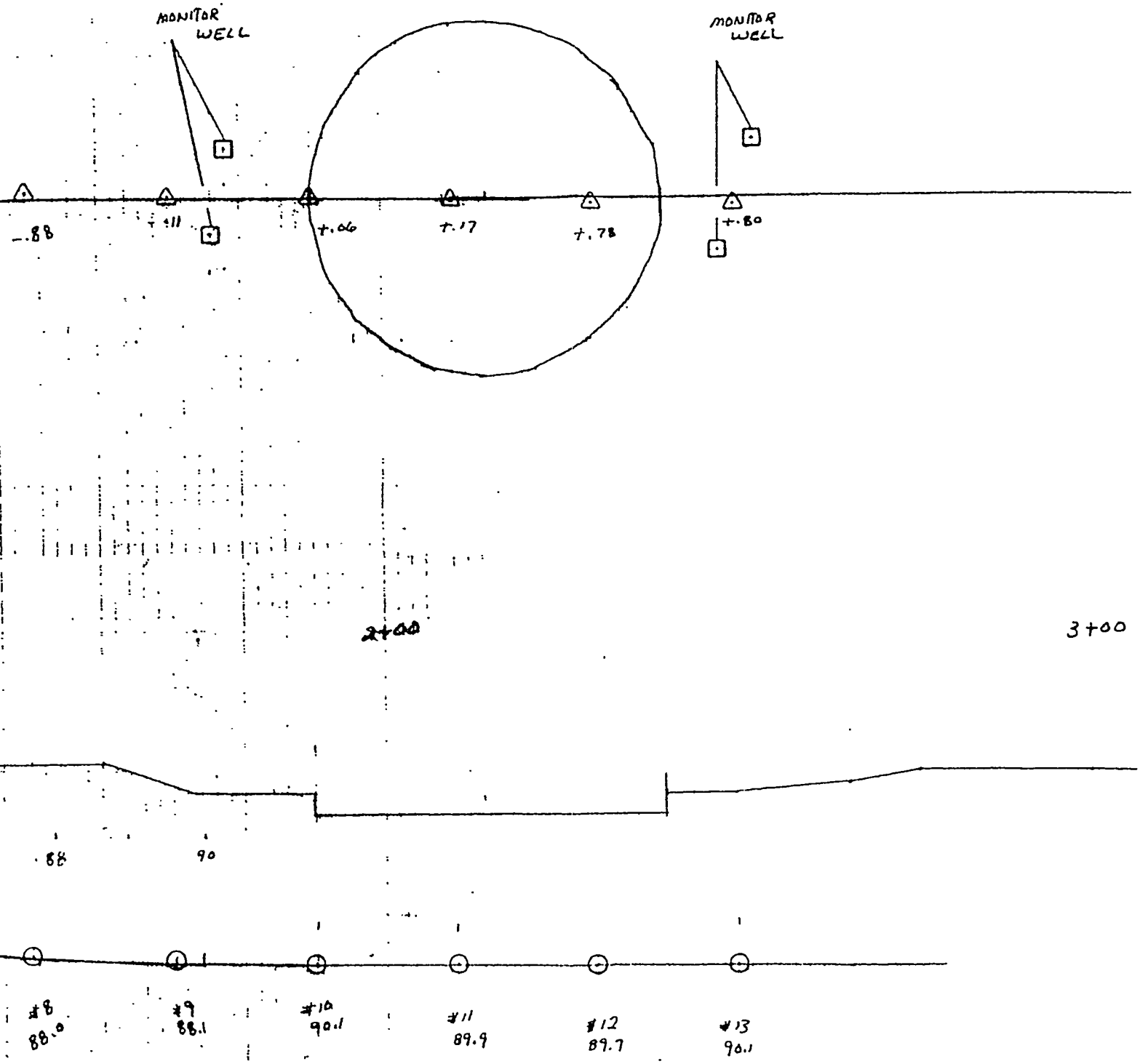
84
86


MONITOR WELL
MONITOR WELL
-.88
+.11
+.06
+.17
+.78
+.80
2+00
3+00
88
90
#8
88.0
#9
88.1
#10
90.1
#11
89.9
#12
89.7
#13
90.1

## Drilling Technology Test Site

Survey Tabulation Sheet
Directional Survey Report
TruTrucker Survey Report
Data Verification Report
Field Survey Data Plot

0: 76.3
90 76.2

# SURVEY TABULATION SHEET

HORIZONTAL TECHNOLOGY, INC.

TOLL FREE 1-888-556-5511

TELE (713) 774-5594 ❖ FAX (713) 774-5593

LOCATION RICHLAND WA. HANFORD SITE DEEP WELL TEST

CUSTOMER AVL

JOB NO. 98208 SHT 1 OF

GROUND ELEVATION, ENTRY 100 EXIT

ENGINEER JOE GRESS

AWAY (STATIONS) ENTRY 0100 EXIT NO EXIT

PROBE NO. 2433 SHOOT AZIMUTH 88.5 MAG 55300 DIP 69.6 RIG AZIMUTH 88.5 SURVEY FILE HANFORD 2

BIT-SENSOR 6.6

VICE-ENTRY 17.3

TF OFFSET 38.9 (MOTOR) 175.3 (JET) 29.9

DHA LENGTH 25.1

CROSSING LENGTH

COIL FILE

| DATE | JT. JOB | TIME | PIPE LENGTH CL | PIPE LENGTH MD | INCLINATION | AZIMUTH RAW | AZIMUTH AVG | MAG | DIP | STATION AWAY | ELEVATION SURVEY | ELEVATION TT | LEFT/RIGHT SURVEY | LEFT/RIGHT TT | NOTES |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 9-17 | DHA | 7:40 | 1.2 | | | | | | | | | | | | |
| | | 9:25 | 20 | 21.2 | 80.41 | 87.0 | | 55[illegible] | 68.1 | 20.9 | 96.46 | — | -1.24 | — | |
| | | | | | | | | | | | | | | | |
| 9-24 | 1 | 17:59 | | 20.7 | 82.3 | 72 | PG 88.5 | 55563 | 69.6 | 20.[illegible] | 77.24 | — | .7 | — | |
| | | | | | | | | | | | | | | | |
| 9-25 | 1 | 14:40 | 241.7 | 241.7 | 78.7 12.0 | 70.6 | [illegible] | 556[illegible] | 68.3 | 241.21 | 95.11 | 94.96 | -1.33 | -.66 | |
| | 2 | 16:08 | 20 | 441.7 | 79.4 80.0 | 72.4 | PG 88.5 | 55445 | 67.3 | [illegible] | 91.45 | 90.62 | | -.42 | |
| | 3 | 17:41 | 20 | 641.7 | 82.2 81.9 | 72.9 | PG 88.5 | 56181 | 69.0 | 63.68 | 88.75 | 87.47 | | 1.04 | |
| | 4 | 20:33 | 20 | 841.7 | 81.8 81.9 | 68.8 | PG 88.5 | 56686 | 69.3 | 83.08 | 5588 | 84.76 | | .20 | |
| | 5 | 9:15 | 20 | 1041.7 | 80.0 78.5 | 67.7 | PG 88.5 | 57038 | 69.1 | 103.17 | 82.41 | 81.61 | | .51 | |
| | 6 | 9:36 | 20 | 1241.7 | 78.4 78.3 | 68.0 | PG 88.5 | 57401 | 68.7 | 123.24 | 78.28 | 77.65 | | .87 | [illegible] |
| | 7 | 10:02 | 20 | 1441.7 | 78.5 77.8 | 68.0 | PG 88.5 | 56978 | 68.5 | 142.36 | 74.39 | 73.3 | | 1.08 | 5[illegible] |
| | 8 | 10:23 | 20 | 1641.7 | 78.1 78.0 | 68.5 | PG 88.5 | 56991 | 68.5 | 161.93 | 70.27 | 69.40 | | 1.23 | 3 ↓ 7 RoT 2 ↓ 8 RoT |
| | 9 | 10:53 | 20 | 1841.7 | 77.2 77.3 | 67.8 | PG 88.5 | 57181 | 68.5 | 181.43 | 65.84 | 64.65 | | 1.04 | [illegible] 270 → RoT |
| | 10 | 11:12 | 20 | 2041.7 | 77.1 76.7 | 67.3 | PG 88.5 | 57252 | 68.5 | 200.93 | 61.39 | 60.19 | | .98 | RoT |
| | 11 | 11:30 | 20 | 2241.7 | 76.9 76.6 | 67.7 | PG 88.5 | [illegible] | [illegible] | [illegible] | 56.81 | 55.8 | | .94 | RoT |
| | 12 | 16:40 | 20.5 | 2462 | 76.6 | 87.2 | | 55357 | 69.4 | [illegible] | 52.07 | 51.32 | | 1.10 | |
| 9-29 | 13 (1) | 10:40 | 20 | 2662 | 81.7 | 76.9 | | 55328 | 69.4 | 259.69 | 48.44 | 47.34 | | -2.58 | |
| | 14 (2) | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | |
| | 10 (1) | 12:39 | 20 | 2641.7 | 68.8 | 85.2 | | 55389 | 69.4 | 200.05 | 61.03 | 61.9 | 6.23 | 7.42 | 20' ↓ |
| | 11 (3) | 13:10 | | 2241.7 | 64.9 | 86.3 | | 55386 | 69.4 | 218.15 | 52.54 | 53.77 | 5.54 | 7.11 | 10↓ RoT |
| | 12 (4) | 13:40 | | 2441.7 | 64.5 | 84.7 | | 55464 | 69.5 | 236.16 | 43.94 | 45.45 | [illegible]4.33 | 6.21 | RoT in ↑ in |
| | 13 (9) | 14:00 | | 2641.7 | 67.9 | 79.3 | | 55412 | 69.5 | 254.45 | 36.4 | 37.42 | +1.38 | 1.89 | ↑ |
| | 14 (5) | 14:29 | | 2841.7 | 73.7 | 74.1 | | 55418 | 69.5 | 273.41 | 30.78 | 30.96 | -3.35 | .84 | ↑ |
| | 15 (6) | 15:04 | | 3041.7 | 79.3 | 73.2 | | 55404 | 69.3 | 292.9 | 27.08 | 26.86 | | -1.38 | [illegible] 45° |

# SURVEY TABULATION SHEET

HORIZONTAL TECHNOLOGY, INC.

TOLL FREE 1-888-556-5511

TELE (713) 774-5594 ❄ FAX (713) 774-5593

LOCATION RICHLAND, WA HANFORD SITE (DEEP WELL TEST) CUSTOMER A+L

JOB NO. 9820B SHT 2 OF _____ GROUND ELEVATION, ENTRY 100 EXIT NO EXIT

ENGINEER JOE GRESS AWAY (STATIONS) ENTRY 0+00 EXIT _____

PROBE NO. 2433 SHOOT AZIMUTH _____ MAG _____ DIP _____ RIG AZIMUTH _____ SURVEY FILE _____

BIT-SENSOR 6.6

VICE-ENTRY 13.3

TF OFFSET 29.7

DHA LENGTH 25.1

CROSSING LENGTH _____

COIL FILE _____

| DATE | JT. JOB | TIME | PIPE LENGTH CL | PIPE LENGTH MD | INCLINATION | AZIMUTH RAW | AZIMUTH AVG | MAG | DIP | STATION AWAY | ELEVATION SURVEY | ELEVATION TT | LEFT/RIGHT SURVEY | LEFT/RIGHT TT | NOTES |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 9.29 | 16 (7) | 15:30 | 20 | 324.7 | 84.6 | 75.3 | | 55374 | 69.3 | 311.38 | 25.19 | 23.94 | -13.12 | -8.65 | 20@45° |
| | 17 (8) | 16:18 | 20 | 304.7 | 88.1 | 76.9 | | 55326 | 69.2 | 290.97 | 24.54 | 23.02 | -17.13 | -12.0 | 20@60° |
| | 18 (9) | 16:49 | 20 | 364.7 | 92.1 | 79.6 | | 55277 | 69.4 | 350.71 | 25.23 | 23.31 | -20.20 | -15.01 | 20@60 |
| | 19 (10) | 17:28 | 20 | 384.7 | 94.2 | 81.7 | | 55208 | 69.2 | 370.52 | 24.74 | 24.67 | -22.56 | -17.74 | 10@75 10@120 |
| | 20 (11) | 18:16 | 20 | 404.7 | 90.7 | 85.5 | | 55266 | 69.3 | 390.49 | 26.99 | 25.49 | 23.61 | -19.25 | 20 @ 150 - 180 |
| | 21 (12) | 18:34 | 20 | 424.7 | 90.0 | 85.9 | | 55288 | 69.3 | 410.47 | 27.00 | 24.47 | -24.5 | -19.93 | " |
| | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | |
| | 9 | | 20 | 184.7 | 74.2 | 90.3 | | 55110 | 69.3 | 181.17 | | 68.62 | | 7.25 | |
| | | | | | | | | | | | | | | | |
| | 8 | | 20 | 164.7 | 78.6 | 93.2 | | 55320 | 69.2 | 161.9 | | 73.19 | | 5.73 | |
| | | | | | | | | | | | | | | | |
| | 7 | | 20 | 144.7 | 81.7 | 92.8 | | 55480 | 69.4 | 142.49 | | 76.63 | | 3.73 | |
| | | | | | | | | | ~~69~~ | | | | | | |
| | 6 | | 20 | 124.7 | 82.7 | 90.9 | | 55301 | 69.5 | 122.99 | | 79.21 | | 2.01 | |
| | | | | | | | | | | | | | | | |
| | 5 | | 20 | 104.7 | 82.7 | 88.4 | | 55331 | 69.6 | 103.32 | | 81.58 | ~~81~~ | .66 | |
| | | | | | | | | | | | | | | | |
| | 4 | B | 20 | 84.7 | 84.1 | 86.5 | | 55577 | 70.1 | 83.56 | 86.68 | — | | — | |

Meters ; Pits ; Reamers ; Hole Openers ; Steering Tools ; Guidance Service ; Non-Mag Coll

Horizontal Technology Inc.
Directional Survey Report
Version 3.3

Company: A&L
Well: DEEP TEST
Location: RICHLAND
Field: WA.
Operator: JOE GRESS
Job No.: 98208

Survey File -> HANFORD3

Probe 2433
Depth Units: Feet
Dec: 0.0
Line Az: 87.2

VS Azimuth = 0.0
VS Origin Away = 0.00
VS Origin Right = 0.00

Method: Tangential

| Station | MD | Inc | Az | Away | Right | Elev | VS | DL | DS |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 0.00 | 76.0 | 26.0 | 0.00 | -0.70 | 100.00 | 0.00 | 0.0 | TI |
| 1 | 24.70 | 78.7 | 87.6 | 24.22 | -0.57 | 95.14 | 1.73 | 242.7 | PG |
| 2 | 44.70 | 79.4 | 88.2 | 43.87 | -0.26 | 91.45 | 2.36 | 4.5 | PG |
| 3 | 64.70 | 82.2 | 88.8 | 63.68 | 0.27 | 88.75 | 2.79 | 14.8 | PG |
| 4 | 84.70 | 81.8 | 88.0 | 83.47 | 0.53 | 85.88 | 3.49 | 4.7 | PG |
| 5 | 104.70 | 82.7 | 88.4 | 103.31 | 0.91 | 83.35 | 4.06 | 5.1 | PG |
| 6 | 124.70 | 82.7 | 90.9 | 123.11 | 2.17 | 80.80 | 3.75 | 12.6 | ST |
| 7 | 144.70 | 81.7 | 92.8 | 142.80 | 4.10 | 77.92 | 2.77 | 10.9 | ST |
| 8 | 164.70 | 78.6 | 93.2 | 162.30 | 6.12 | 73.96 | 1.68 | 15.7 | ST |
| 9 | 184.70 | 74.2 | 90.3 | 181.52 | 7.16 | 68.52 | 1.57 | 25.8 | ST |
| 10 | 204.70 | 68.8 | 85.2 | 200.16 | 6.48 | 61.30 | 3.15 | 36.4 | ST |
| 11 | 224.70 | 64.9 | 86.3 | 218.27 | 6.18 | 52.82 | 4.31 | 20.4 | ST |
| 12 | 244.70 | 64.5 | 84.7 | 236.30 | 5.37 | 44.21 | 5.99 | 7.7 | ST |
| 13 | 264.70 | 67.9 | 79.3 | 254.65 | 2.82 | 36.67 | 9.42 | 29.5 | ST |
| 14 | 284.70 | 73.7 | 74.1 | 273.35 | -1.54 | 31.05 | 14.67 | 38.0 | ST |
| 15 | 304.70 | 79.3 | 73.2 | 292.41 | -6.31 | 27.35 | 20.35 | 28.6 | ST |
| 16 | 324.70 | 84.6 | 75.3 | 311.89 | -10.43 | 25.46 | 25.41 | 28.2 | ST |
| 17 | 344.70 | 88.1 | 76.9 | 331.56 | -14.01 | 24.81 | 29.93 | 19.6 | ST |
| 18 | 364.70 | 92.1 | 79.6 | 351.37 | -16.66 | 25.55 | 33.53 | 24.0 | ST |
| 19 | 384.70 | 94.2 | 81.7 | 371.22 | -18.58 | 27.02 | 36.39 | 14.9 | ST |

Horizontal Technology Inc.
Directional Survey Report
Version 3.3

Company: A&L
Well: DEEP TEST
Location: RICHLAND
Field: WA.
Operator: JOE GRESS
Job No.: 98208

Survey File -> HANFORD3

Probe 2433
Depth Units: Feet
Dec: 0.0
Line Az: 87.2

VS Azimuth = 0.0
VS Origin Away = 0.00
VS Origin Right = 0.00

Method: Tangential

| Station | MD | Inc | Az | Away | Right | Elev | VS | DL | DS |
|---|---|---|---|---|---|---|---|---|---|
| 20 | 404.70 | 90.7 | 85.5 | 391.21 | -19.19 | 27.26 | 37.96 | 25.8 | ST |
| 21 | 424.70 | 90.0 | 85.9 | 411.20 | -19.64 | 27.27 | 39.37 | 4.0 | ST |

Horizontal Technology Inc.
TruTracker Survey Report
Version 3.3

Company: A&L
Well: DEEP TEST
Location: RICHLAND
Field: WA.
Operator: JOE GRESS
Job No.: 98208

Survey File -> HANFORD3

Depth Units: Feet

Line Az: 87.2

| MD | Away | Right | Elev | Total Cur | Rad Angle | Rad Intens | Ax Intens | AxMis | Coil |
|---|---|---|---|---|---|---|---|---|---|
| 24.70 | 24.21 | -0.66 | 94.89 | 103.8 | 267.8 | 10145 | -711 | -2 | HANFORD2 |
| 44.70 | 43.86 | -0.42 | 90.62 | 109.6 | 268.4 | 7315 | -469 | -1 | HANFORD2 |
| 64.70 | 63.68 | 0.04 | 87.47 | 108.9 | 270.1 | 5643 | -386 | -0 | HANFORD2 |
| 84.70 | 83.48 | 0.20 | 84.76 | 109.5 | 270.6 | 4697 | -335 | -0 | HANFORD2 |
| 104.70 | 103.32 | 0.66 | 81.58 | 164.0 | 271.9 | 5815 | -406 | 1 | HANFORD2 |
| 124.70 | 122.99 | 2.01 | 79.21 | 316.0 | 275.7 | 9893 | -652 | 1 | HANFORD2 |
| 144.70 | 142.49 | 3.73 | 76.63 | 326.0 | 279.9 | 9028 | -510 | 3 | HANFORD2 |
| 164.70 | 161.90 | 5.73 | 73.19 | 331.0 | 284.0 | 7890 | -374 | 4 | HANFORD2 |
| 184.70 | 181.17 | 7.25 | 68.62 | 328.0 | 286.2 | 6529 | -309 | 4 | HANFORD2 |
| 204.70 | 200.05 | 7.42 | 61.90 | 319.5 | 284.8 | 5002 | -296 | 2 | HANFORD2 |
| 224.70 | 218.15 | 7.11 | 53.77 | 318.5 | 282.5 | 3837 | -234 | 2 | HANFORD2 |
| 244.70 | 236.16 | 6.71 | 45.45 | 319.0 | 280.4 | 3030 | -201 | 2 | HANFORD2 |
| 264.70 | 254.45 | 4.89 | 37.43 | 320.0 | 276.6 | 2488 | -207 | -0 | HANFORD2 |
| 284.70 | 273.04 | 0.84 | 30.96 | 319.0 | 270.5 | 2155 | -140 | 1 | HANFORD2 |
| 304.70 | 292.00 | -4.38 | 26.86 | 317.5 | 263.7 | 1981 | -70 | 3 | HANFORD2 |
| 324.70 | 311.38 | -8.65 | 23.94 | 314.0 | 258.7 | 1860 | -15 | 5 | HANFORD2 |
| 344.70 | 330.97 | -12.00 | 23.02 | 320.0 | 254.9 | 1882 | 53 | 7 | HANFORD2 |
| 364.70 | 350.71 | -15.01 | 23.39 | 319.0 | 251.5 | 1912 | 68 | 6 | HANFORD2 |
| 384.70 | 370.52 | -17.74 | 24.67 | 321.0 | 248.3 | 1997 | 128 | 6 | HANFORD2 |
| 404.70 | 390.49 | -19.25 | 25.49 | 328.0 | 246.8 | 2101 | 172 | 5 | HANFORD2 |
| 424.70 | 410.47 | -19.93 | 24.47 | 332.0 | 246.9 | 2093 | 307 | 6 | HANFORD2 |

Horizontal Technology Inc.
Data Verification Report
Version 3.3

Company: A&L
Well: DEEP TEST
Location: RICHLAND
Field: WA.
Operator: JOE GRESS
Job No.: 98208

Survey File -> HANFORD3

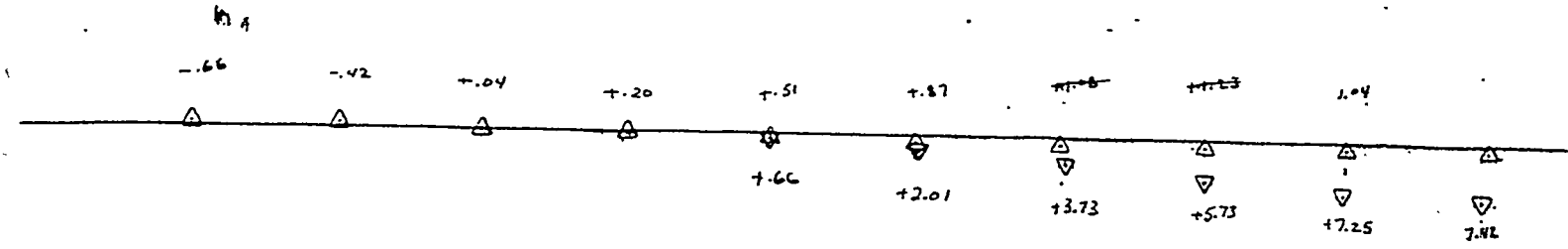
Probe 2433
Depth Units: Feet
Dec: 0.0
TF Offset: 29.9

| Station | MD | Inc | Az | Hs | Mtf | GTotal | HTotal | Dip | Tp(F) | WV |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 24.70 | 78.7 | 70.0 | 319.0 | 29.1 | 1001.1 | 55387 | 67.97 | 77 | 38 |
| 2 | 44.70 | 79.4 | 72.4 | 330.5 | 43.0 | 1001.2 | 56445 | 67.34 | 79 | 39 |
| 3 | 64.70 | 82.2 | 72.9 | 313.7 | 26.7 | 1000.9 | 56181 | 69.00 | 78 | 32 |
| 4 | 84.70 | 81.8 | 68.8 | 147.1 | 215.9 | 1001.5 | 56686 | 69.80 | 79 | 38 |
| 5 | 104.70 | 82.7 | 88.4 | 5.2 | 93.6 | 1001.3 | 55331 | 69.60 | 72 | 33 |
| 6 | 124.70 | 82.7 | 90.9 | 4.8 | 95.7 | 1001.0 | 55301 | 69.55 | 72 | 34 |
| 7 | 144.70 | 81.7 | 92.8 | 12.2 | 105.1 | 1001.2 | 55432 | 69.41 | 71 | 34 |
| 8 | 164.70 | 78.6 | 93.2 | 8.6 | 101.8 | 1001.1 | 55320 | 69.20 | 71 | 34 |
| 9 | 184.70 | 74.2 | 90.3 | 7.2 | 97.5 | 1000.7 | 55110 | 69.26 | 69 | 34 |
| 10 | 204.70 | 68.8 | 85.2 | 359.2 | 84.4 | 1000.1 | 55389 | 69.54 | 77 | 34 |
| 11 | 224.70 | 64.9 | 86.3 | 3.9 | 90.2 | 1000.6 | 55384 | 69.41 | 79 | 33 |
| 12 | 244.70 | 64.5 | 84.7 | 1.1 | 85.7 | 1000.7 | 55464 | 69.53 | 81 | 35 |
| 13 | 264.70 | 67.9 | 79.3 | 3.2 | 82.5 | 1001.3 | 55493 | 69.50 | 81 | 35 |
| 14 | 284.70 | 73.7 | 74.1 | 352.8 | 67.0 | 1001.4 | 55448 | 69.45 | 80 | 34 |
| 15 | 304.70 | 79.3 | 73.2 | 7.9 | 81.1 | 1001.5 | 55404 | 69.33 | 80 | 34 |
| 16 | 324.70 | 84.6 | 75.3 | 3.5 | 78.8 | 1001.4 | 55374 | 69.32 | 80 | 35 |
| 17 | 344.70 | 88.1 | 76.9 | 16.9 | 93.8 | 1001.5 | 55326 | 69.25 | 82 | 33 |
| 18 | 364.70 | 92.1 | 79.6 | 357.5 | 77.2 | 1001.6 | 55277 | 69.36 | 83 | 34 |
| 19 | 384.70 | 94.2 | 81.7 | 4.2 | 86.0 | 1001.3 | 55208 | 69.22 | 83 | 33 |
| 20 | 404.70 | 90.7 | 85.5 | 16.8 | 102.3 | 1001.1 | 55266 | 69.31 | 83 | 33 |
| 21 | 424.70 | 90.0 | 85.9 | 1.4 | 87.3 | 1001.6 | 55288 | 69.31 | 83 | 31 |

H Total Max = 56686 Gammas @ Station 4
H Total Min = 55110 Gammas @ Station 9
H Total Spread = 1576 Gammas

G Total Max = 1001.6 Milligees @ Station 18
G Total Min = 1000.1 Milligees @ Station 10
G Total Spread = 1.6 Milligees

Dip Max = 69.80 Degrees @ Station 4
Dip Min = 67.34 Degrees @ Station 2
Dip Spread = 2.46 Degrees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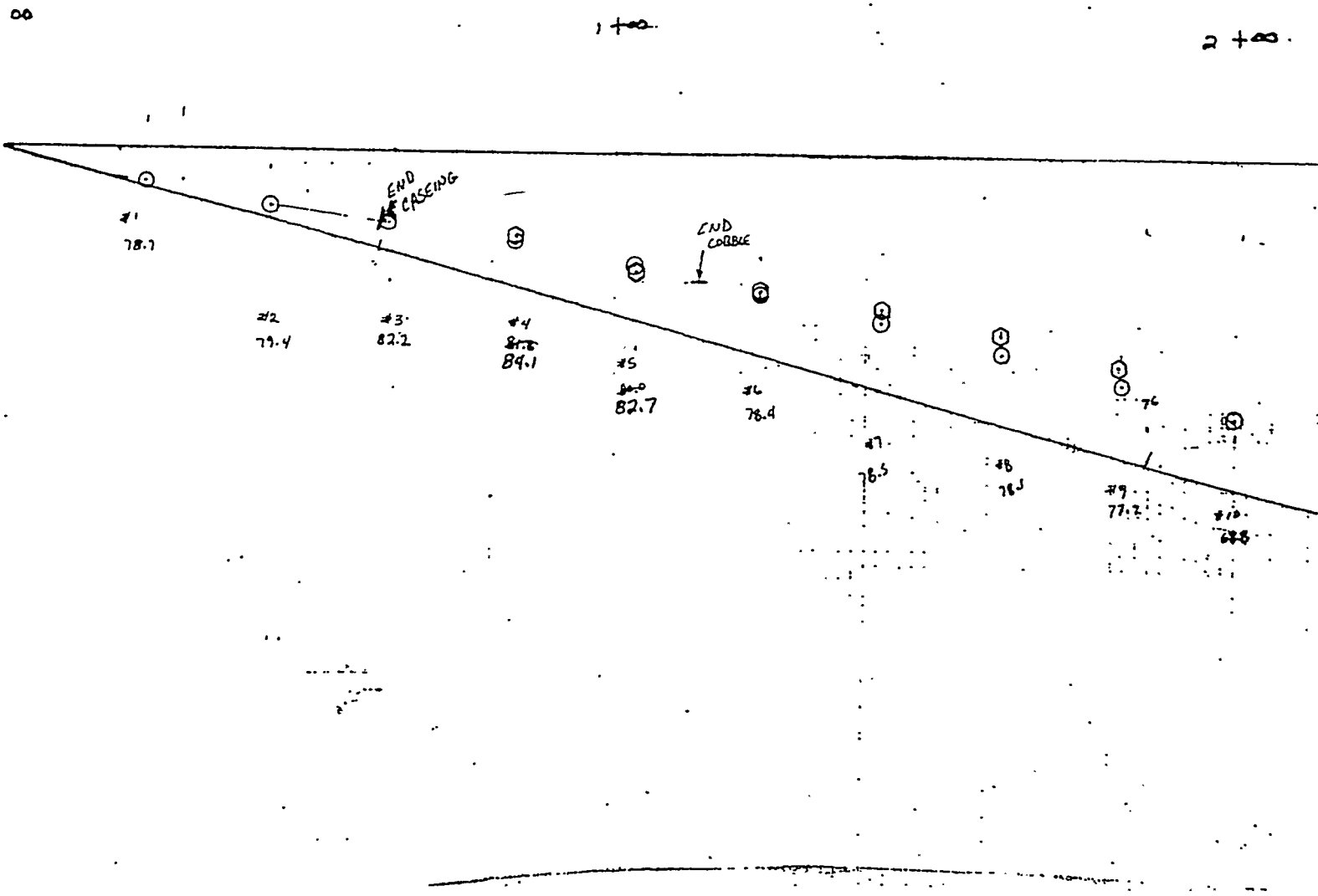
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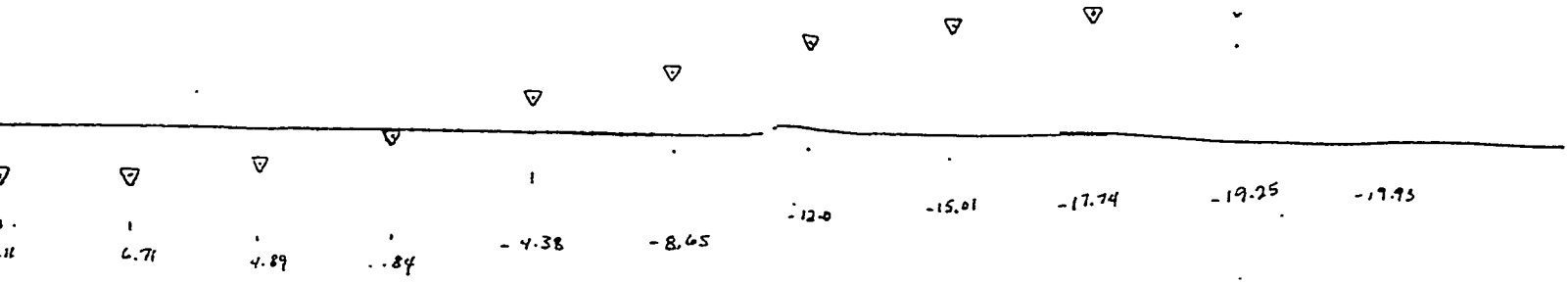
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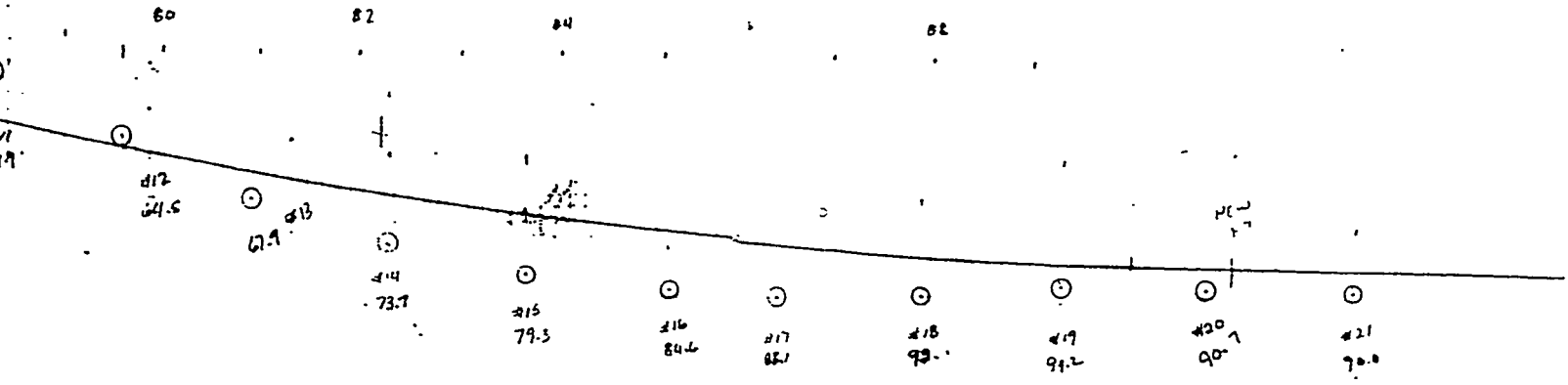
4 +∞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#18
#19
91.2
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90°
#21

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