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7. Abstract

This test report describes the field demonstration, conclusions, and recommendations for the DITCH WITCH[1] Directional Boring System used at Hanford. Primary funding was obtained through the Volatile Organic Compounds-Arid Integrated Demonstration. Other development funding sources included the Mixed Waste Landfill Integrated Demonstration, the Non-Arid Site Integrated Demonstration, and Charles Machine Works, Inc. The purpose of this test was to determine the viability in drilling glacial fill soils containing significant amounts of gravel and cobbles. A successful test would lead to future use on environmental restoration projects at Hanford and other U.S. Department of Energy sites with similar geologic conditions.

The X-810 and P-80 Ditch Witch systems were tested at the Hanford Site. The X-810 is a prototype boring system, and the P-80 is utilized commercially for utilities installations. The testing consisted of attempting two horizontal boreholes with the X-810 system and a single boring with the P-80 system. No further testing is recommended, pending development of drilling and steering tools for the X-810 system. It is recommended that any environmental use of the P-80 system remain shallow (less than 25 feet [7.6 meters]) subsurface activities to allow use of the P-80 tracking system.

[1]DITCH WITCH is a registered trademark of the Charles Machines Works, Inc.

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Results of Testing the Directional Boring System at the Hanford Site

B. W. Volk
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Science Applications International Corporation

June 1994

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EXECUTIVE SUMMARY

This test report describes the March 1993 field test of the DITCH WITCH[1] Directional Boring System primarily funded by the Volatile Organic Compounds-Arid Integrated Demonstration. Other development funding sources included the Mixed Waste Landfill Integrated Demonstration, the Non-Arid Site Integrated Demonstration, and the Charles Machine Works, Inc. The Directional Boring Systems were tested at the Hanford Site to determine the viability in drilling unsaturated, loosely consolidated, arid soils containing significant amounts of gravel and cobbles. Previous tests of the prototype machinery in clay and sand formations at the U.S. Department of Energy Savannah River Site and Sandia National Laboratory have proven successful. This test was designed to evaluate the performance limits of the Directional Boring System for possible future use on environmental restoration projects at the Hanford Site and other U.S. Department of Energy sites with similar geologic conditions.

The two DITCH WITCH systems tested at the Hanford Site were the X-810 and the P-80. The X-810 is a prototype DITCH WITCH boring system, and the P-80 is a proven boring system widely used for utilities installation.

The objectives of the Directional Boring System test were outlined in the *Integrated Test Plan for Directional Boring* (Volk 1993). The general objectives were to: (1) test the drilling and steering capabilities of the X-810 at Hanford, and (2) determine the boring and sampling capabilities of the P-80 at Hanford. Specific objectives are outlined in the test plan.

The results of testing the Directional Boring System at the Hanford Site are summarized below and are discussed in further detail in the text of this report.

X-810 TEST

The X-810 test plan included the installation of two horizontal boreholes with horizontal lengths of 200 to 250 feet (61 to 76 meters) and vertical depths of 15 feet (4.6 meters) and 25 feet (7.6 meters). The test was conducted at the Drilling Technology Test Site located north of the 200 Areas Fire Station.

The X-810 was able to penetrate the gravel and cobbles at the site; however, directional steering control was unsuccessful. Three drilling attempts were made with the X-810. The X-810 test was terminated after damage occurred to the drill pipe.

Because of the inability to steer the X-810 in Hanford soils, no further testing is recommended. If a method to case the borehole while drilling is devised and air percussion tools can be used to steer the tool, the X-810 may warrant additional testing at Hanford.

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[1]DITCH WITCH is a registered trademark of the Charles Machine Works, Inc.

P-80 Test

Following the X-810 test, the DITCH WITCH P-80 rod pushing system was used to test sampling and steering capabilities. The P-80 was used to pierce a 116-foot (35.4-meter) horizontal borehole through gravel at depths ranging from 6 to 8 feet (1.8 to 2.4 meters). The planned course was maintained, and the drill bit exited the ground at the intended location. Four soil samples were attempted. Sample recovery was 100% on one sample and less than 5% on two samples. The sampler broke on the final sample. The sampler used, however, was only 1.1875 inches (3.0 centimeters) in diameter and 7.5 inches (19 centimeters) in length and retrieved an 8.3 cubic inch (136 cubic centimeters) sample. This was a standard samples configuration used in the soil mechanics industry, but in comparison, the standard 5-inch (12.7-centimeter) split spoon sampler used at Hanford for vertical boreholes retrieves a 300 cubic inch (4,916 centimeter) sample.

If larger sampling tools could be devised, further testing of the P-80 may be appropriate. However, the P-80 is depth- and size-limited. Machinery with larger sampling capabilities is being developed for future environmental applications.

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1.0 INTRODUCTION

1.1 PURPOSE AND SCOPE

This report describes the results and conclusions from the engineering test of the DITCH WITCH directional boring system (DBS) at the Hanford Site. The DBS was tested to determine its viability for drilling in unsaturated, loosely consolidated, glacial fill soils containing significant amounts of gravel and cobbles. This test was used to evaluate the performance of the directional boring system for future use on environmental restoration projects at the Hanford Site and other U.S. Department of Energy (DOE) sites having similar geologic conditions. Shallow horizontal boreholes are needed for monitoring and characterization, and to install barriers under waste disposal cribs and trenches at the Hanford Site.

Two DITCH WITCH systems were tested at the Hanford Site: the X-810 and the P-80. The X-810 is a prototype boring system, and the P-80 is used commercially for utilities installations. The test consisted of attempting two horizontal boreholes with the X-810 at the Drilling Technology Test Site (DTTS) (Figure 1), and completing a second borehole at the alternate test site also shown in Figure 1.

1.2 BACKGROUND

The test was conducted in conjunction with DITCH WITCH [Charles Machine Works (CMW)] and Sandia National Laboratory (SNL). A 3-year partnership between CMW and SNL has been extended through fiscal year 1994. The X-810 has been tested in the past year at the DOE Savannah River Site (SRS) in conjunction with the Volatile Organic Compounds in Non-Arid Soils Integrated Demonstration. The X-810 was also tested at the SNL site in conjunction with the Mixed Waste Landfill Integrated Demonstration. Previous tests of the DBS prototype machinery in clay and sand formations at the DOE SRS and SNL have proven successful (Wemple et al. 1993).

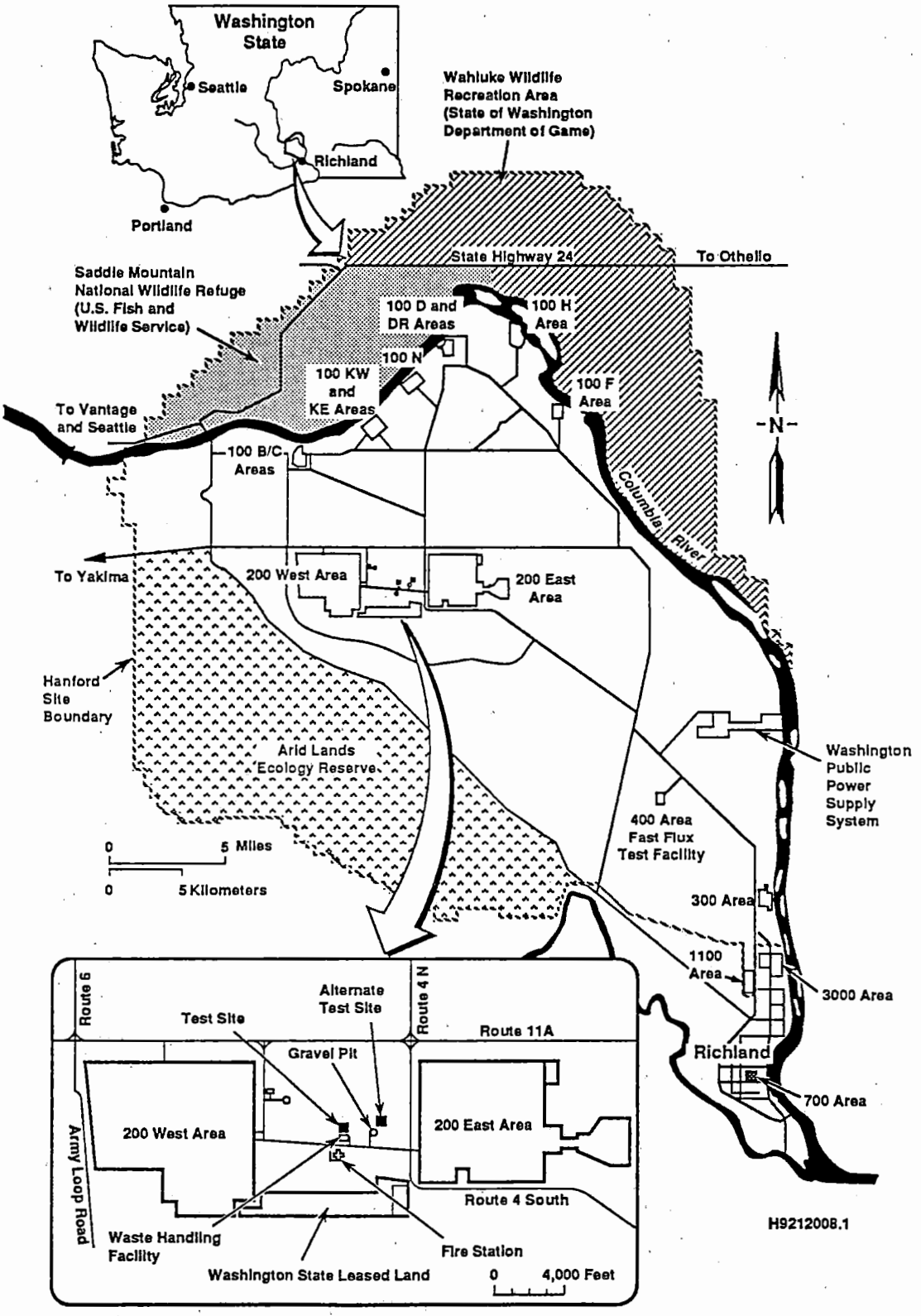
The test was conducted via the Drilling Technology Development Technical Task Plan ([TTP] #RL-421103), which is part of the Volatile Organic Compound-Arid Integrated Demonstration (VOC-Arid ID). The VOC-Arid ID is one of several integrated demonstrations throughout the DOE complex which is funded by DOE's Office of Technology Development, and designed to support the development and testing of emerging environmental restoration technologies.

CMW provided the test equipment through its industrial partnership with SNL. CMW and SNL also provided funding to conduct this testing.

1.3 DESCRIPTION OF THE TEST SITES

The X-810 test was conducted at the DTTS, which is approximately 2,000 feet (610 meters) northwest of the 200 Areas fire station, between the 200 East and 200 West Areas of the Hanford Site, as shown in Figure 1 (S1-1,2 Test Site). Previous testing has been performed on the same location

Figure 1. Drilling Technology Test Site.



with the Dual Wall Percussion Hammer Method (McLellan 1990) and the Cone Penetrometer System (Cassem 1992). An existing drilling pad measuring 75 feet by 170 feet (22.9 meters by 51.8 meters) was expanded to approximately 100 feet by 250 feet (30.5 meters by 76.2 meters) for the X-810 test. The P-80 test was conducted at the alternate test site shown in Figure 1 (S1-3 Test Site). Both test sites were located in areas that were neither radiologically nor chemically contaminated.

1.4 DESCRIPTION OF THE DIRECTIONAL BORING SYSTEM

1.4.1 X-810 System

The X-810 directional boring technology combines pushing technology from the utility/road crossing industry with rotary drilling technology. The system (Figures 2 and 3) weighs approximately 11,000 pounds (5,000 kilograms) and has a base frame 16 feet (4.9 meters) long by 6 feet (1.8 meters) wide. The borehole is advanced by thrusting (in excess of 80,000 pounds [36,300 kilograms]) and rotating (up to 50 revolutions per minute) a drill bit into the soil using hydraulic power. The soil is compacted as the drill bit is advanced. Hydraulic power and coolant (water) are supplied to the X-810 via a remote diesel-powered motor. The power skid is attached to the X-810 via hydraulic hoses. The X-810 is anchored to the ground and pushed from within a pit to counteract the force vector created by the pushing of the drill rod.

The bottomhole assembly for the X-810 (Figure 4) consists of the drill bit, steering tool, flex sub, and four Nitronic (non-magnetic) collars. The drill bit has a flat face, which allows steering of the tool. The bit face incorporates water outlets, which permits water to be pumped through the bit, and if necessary, to aid in penetration of the soil and cooling of the bit. The magnetic steering tool measures azimuth, inclination, and tool-face orientation. This data is transmitted back to the surface via a wire routed through the center of the drill rod. The flex sub is made of a slightly ductile steel that allows flection to occur between the bit and the drill rod. Finally, four Nitronic collars (5 feet [1.5 meters] each) isolate the steering tool from the magnetic effect of the steel drill pipe.

The borehole is drilled by orienting the face of the drill bit with the steering tool. Once the face of the bit is pointing in the desired direction, it is thrust into the soil by the X-810 system using hollow steel rods that are 3 inches (7.6 centimeters) outside diameter and 1.5 inches (3.8 centimeters) inside diameter. The clearance through the pinned connections of the drill rod is 0.75 inches (1.9 centimeters). To drill straight, without building any angle, the bit is simply rotated and thrust forward. Using rotation and thrust, the bit and drill rod are turned and oriented approximately 2.29°/10 feet (3.0 meters) until the borehole reaches the horizontal position.

The borehole is then extended horizontally to a pre-determined point. Next, the bit is oriented upward to drill the exit hole at approximately the same inclination as the entrance hole was drilled. Once the bit exits the

Figure 2. X-810 Directional Boring System Schematic.

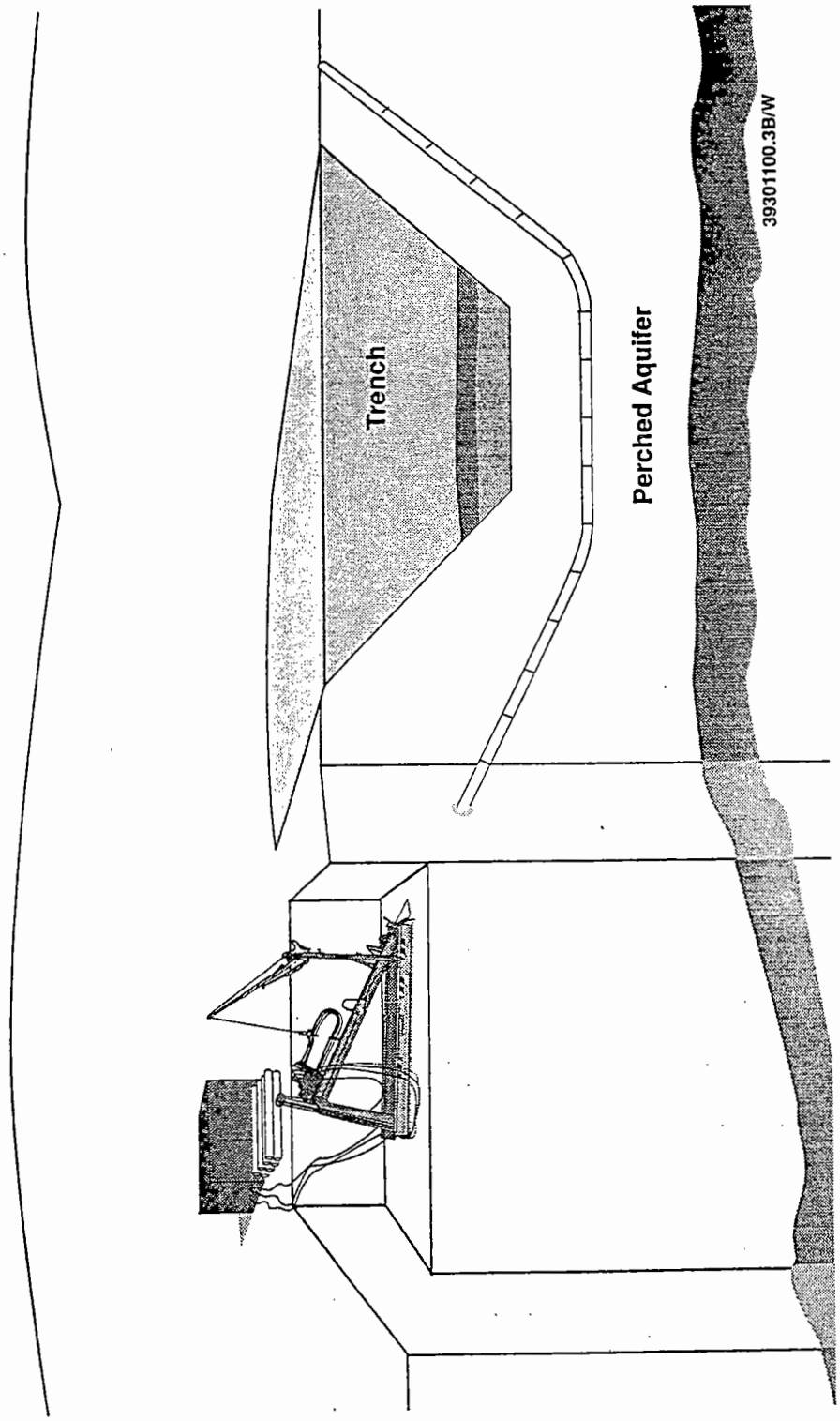


Figure 3. Photograph of the X-810 at the Drilling Technology Test Site.

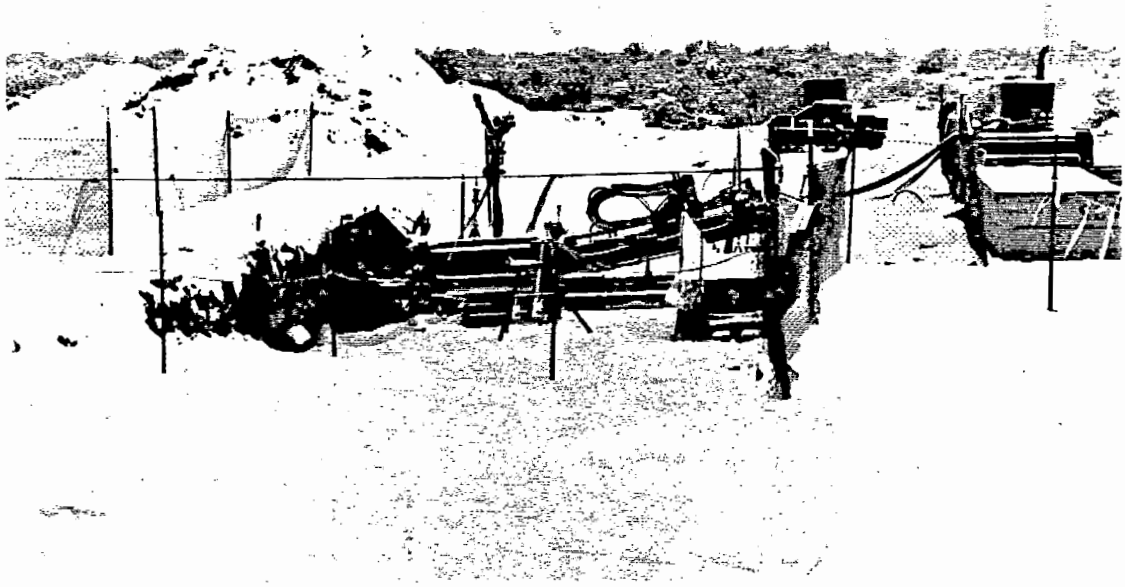
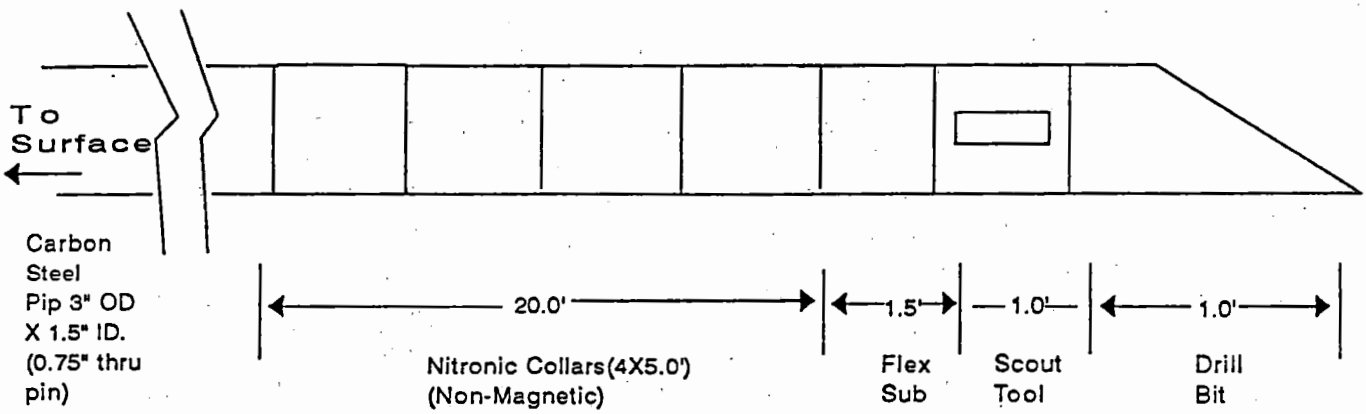


Figure 4. X-810 Bottomhole Assembly.



ground, it is replaced with an expander cone or reamer, and a pulling plug that is connected to the casing. The casing is then pulled into the exit end of the borehole as the drill rod is removed from the entrance point.

Although the X-810 requires the occasional addition of water at a rate of 1 to 2 gallons (3.8 to 7.6 liters) per minute during drilling, the water does not return to the surface. In addition, cuttings generated during the drilling process are simply compacted to the sides of the borehole.

1.4.2 P-80

The P-80 Directional Rod/Pipe Pusher, a commercially available rod pushing system for shallow (12 feet [3.7 meters] deep with trench box, up to 20 feet [6 meters] in open excavations) applications, was used at the S1-3 site. The P-80 was launched horizontally from a pit. A sketch of the P-80 is shown in Figure 5, and photographs are shown in Figures 6a and 6b. The P-80 uses 1.75-inch (4.5-centimeter) solid rods to push a steel push point bit through the soil with up to 80,000 pounds (36,288 kilograms) thrust. The bit may be replaced with a sampling tool to retrieve 1-inch- (2.5 centimeters-) diameter in situ soil samples. The sampler is pushed to the previous position attained by the steering bit and opened, and a sample is retrieved. The sampler used for the P-80 system was a punch-core type sampler with a recovered sample diameter of 1.2 inches (3 centimeters), a length of 7.5 inches (19 centimeters), and a volume of 0.0048 cubic feet (0.0001359 cubic meters). The P-80's sample size is small compared to Hanford's conventional split spoon sample size of 5 inches (13 centimeters) by 24 inches (61 centimeters) and a volume of 300 cubic inches (4,916 cubic centimeters). The P-80's sample volume, even if obtaining 100%, will not provide adequate soil volume to perform physical or chemical analysis. In addition, the P-80's size limits sample particle size that it can throat (Figure 7).

Power is supplied to the P-80 via a hydraulic supply. No waste is generated by the P-80; in addition, the P-80 can bring soil samples to the surface. The completion methods for the P-80 are the same as those for the X-810. The P-80 is normally used for installing electrical and telecommunication cables under roadways.

The steering method and push point for the P-80 are similar to those of the X-810. However, a (Subsite[tm2]) walk-over tracking system is used to track the position of the borehole and orient the drill bit.

The pit for the P-80 is 3 feet (0.9 meters) wide by 8 feet (2.4 meters) long by 4 feet (1.2 meters) deep. Normally, a pit is dug with a backhoe, the P-80 is laid in the pit, and the soil is back-filled in around the P-80 trench box. Trench boxes can be stacked up to 12 feet (3.7 meters) for deeper targets.

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[2]Subsite is a registered trademark of the Charles Machine Works, Inc.

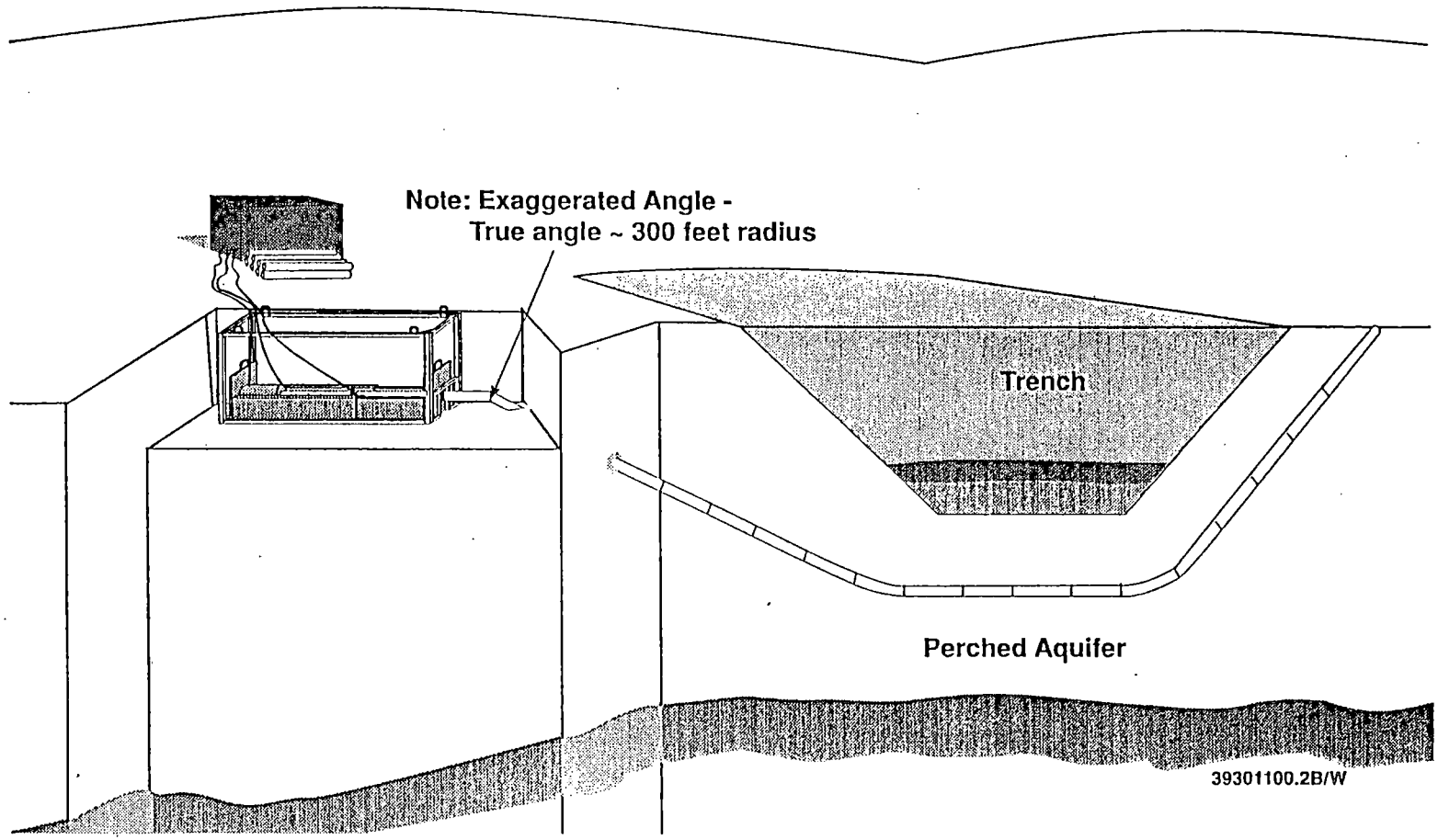

Figure 5. P-80 Directional Boring System Schematic.

Figure 6a. Photograph of the P-80 Directional Boring System.

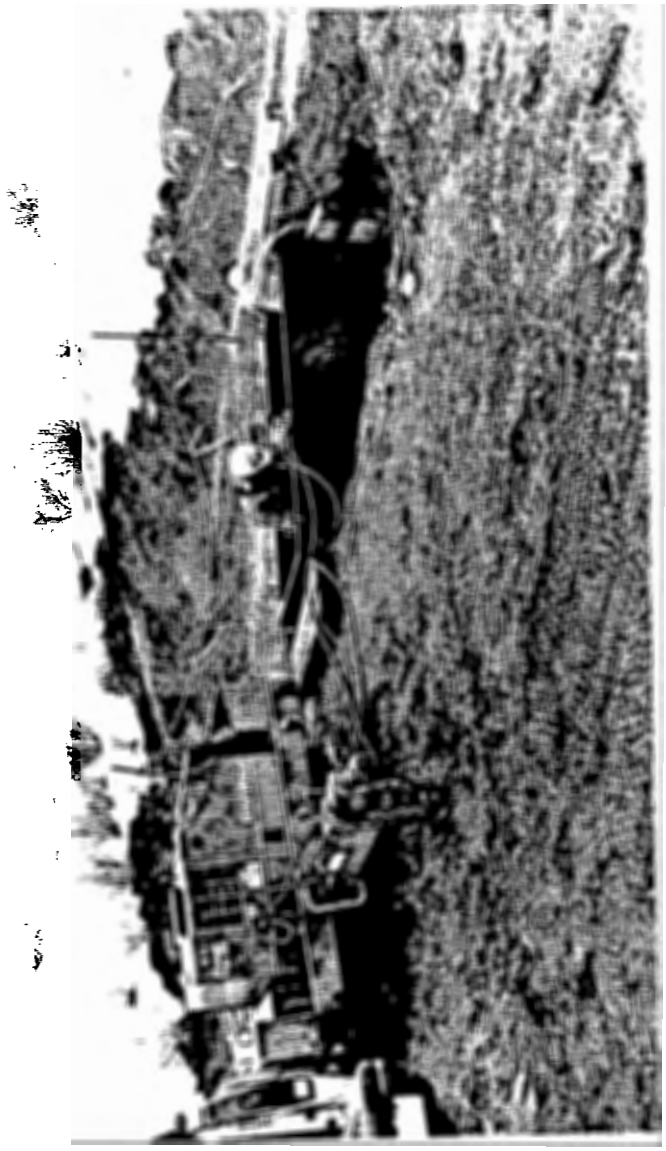

Figure 6b. Photograph of the P-80 Directional Boring System.

Figure 7. Photograph of the P-80 Sampler (right).

1.5 DESCRIPTION OF BASELINE TECHNOLOGY

The X-810 or P-80 tests conducted at Hanford provide the only horizontal directional activities to date.

2.0 TEST OBJECTIVES/MEASURES OF SUCCESS

The test was broken down into two series in the *Integrated Test Plan for Directional Boring* (Volk 1993). Based on the performance of the system, Series 2 testing was not conducted. The test objectives and measures of success for the Series 1 testing are outlined in the following sections.

2.1 TEST OBJECTIVES

2.1.1 X-810 System

The primary focus of the test was to determine the drilling capabilities of the X-810 under Hanford Site conditions. Specific objectives included the following:

1. Test the capability to drill and complete horizontal boreholes at Hanford to depths up to 25 feet (7.6 meters) below ground level (BGL) and 100 feet (30.5 meters) horizontal length.

2. Test the ability to maintain directional control.

3. Test the ability to complete boreholes with fiberglass casing.

4. Test the ability to maintain contamination control and minimize generated waste.

5. Test the ability of the directional boring system to install boreholes that comply with Washington State Department of Ecology (Ecology) variances to the Washington Administrative Codes (WAC).

2.1.2 P-80 System

A secondary focus of the demonstration/test was to determine the sampling capabilities of the P-80 directional boring system at the Hanford Site. The P-80 was used to drill borehole S1-3. The specific objectives were as follows:

- Test the ability of the P-80 to penetrate Hanford soils.
- Test the steering capabilities of the P-80 system.
- Test the ability of the P-80 to obtain in situ soil samples.
- Test the use of the walk-over tracking used with the P-80.

2.2 MEASURES OF SUCCESS

Because this was the first time this system has been tried at the Hanford Site for operations, other than very shallow utility crossings under roadways, measured parameters were recorded. The drilling data was documented by the Field Team Leader in controlled notebook #EFL-1075, "Directional Boring Test".

2.2.1 X-810 System

Measures of success are as follows.

1. Ability to drill horizontal wellbores with 100- to 200-foot (30.5- to 61-meter) horizontal sections and up to 25-foot (7.6-meter) vertical depth in the Hanford formation. Specific parameters measured include the following:

   - Penetration rates
   - Downtime for equipment repair
   - Borehole stability (caving of the borehole walls)
   - Pipe handling time
   - Time required to install the boreholes.

2. Ability to steer the directional boring system to allow accurate placement of the wellbore. Parameters measured include the following:

   - Azimuth (left-right orientation) and dip (angle from horizontal) of the borehole
   - Comparison of calculated exit point to actual exit point of the borehole
   - Ability of the steering tools to continue functioning when heating of the borehole results from the friction of the bit against the borehole wall
   - Trajectory measured by the steering system as compared to a survey of the boreholes using an independent tracking system such as the Sharewell True Tracker[3]. The goal for the test was ±3 feet (±0.9 meters) between the measured and independent survey.

3. Ability to complete the boreholes with fiberglass screen and casing. Parameters measured include the following:

   - Ability to install fiberglass screen and casing
   - Time required to install the screen and casing.

4. Ability to minimize waste generation and provide contamination control at the wellbore. Parameters include the following:

   - Amount of material requiring drumming
   - Control of samples being removed from the borehole.

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[3]Sharewell True Tracker is a tradename of Sharewell, Inc, Stafford, Texas.

5. Ability to protect human health and demonstrate operational safety. Specific parameters include the following:

   - No reportable accidents
   - Minimal first aid cases.

6. Ability to comply with variances specified by Ecology. These variances include waiving the requirement for 2-inch (5.1-centimeter) annular seals and filter packs. Specific parameters to be recorded include the following:

   - Screen length and placement depth
   - Size and placement location of surface seal.

2.2.2 P-80 System

The primary focus of the P-80 test was to obtain samples. The following characteristics/parameters were recorded:

- Ability to describe the geology of the soil being drilled
- Volume of sample retrieved (percent of sampler filled)
- Time to obtain samples.

3.0 TEST RESULTS

3.1 TEST DESCRIPTION

3.1.1 X-810 System

A detailed description of the drilling operation is shown in Appendix A. Three attempts were made to drill borehole S1-1 at the DTTS. The X-810 was mobilized to the drill site on March 2, 1993 and prepared for drilling. The intended trajectory for borehole S1-1 is shown in Figure 8. The borehole was drilled to 35 feet (10.7 meters) measured depth (7.5 feet [2.3 meters] vertical depth) at an inclination from horizontal of 12.4°. At 35 feet (10.7 meters) depth, the penetration angle of 12.4° could not be maintained; the drill bit was tending toward horizontal. The target trajectory versus the actual trajectory is shown in Figure 9. Attempts to steer the bit and continue to build angle into the formation were unsuccessful. Each time the drill bit was pulled back, the soft Hanford formation would cave. Each subsequent push would then cause the bit to continue to trend toward horizontal and/or start curving back toward the surface. Because of the difficult drilling conditions, the bottomhole assembly was removed from the borehole to check for damage to the tools. The flexible sub in the assembly had been bent approximately 2° and had to be taken to a machine shop to be straightened.

On the second attempt of borehole S1-1, the flex sub was not used. It was anticipated that this would provide a more stiff bottomhole assembly and allow penetration of the loosely consolidated soils. As shown in Figure 10,

Figure 8. Borehole S1-1 Intended Trajectory for X-810 System.

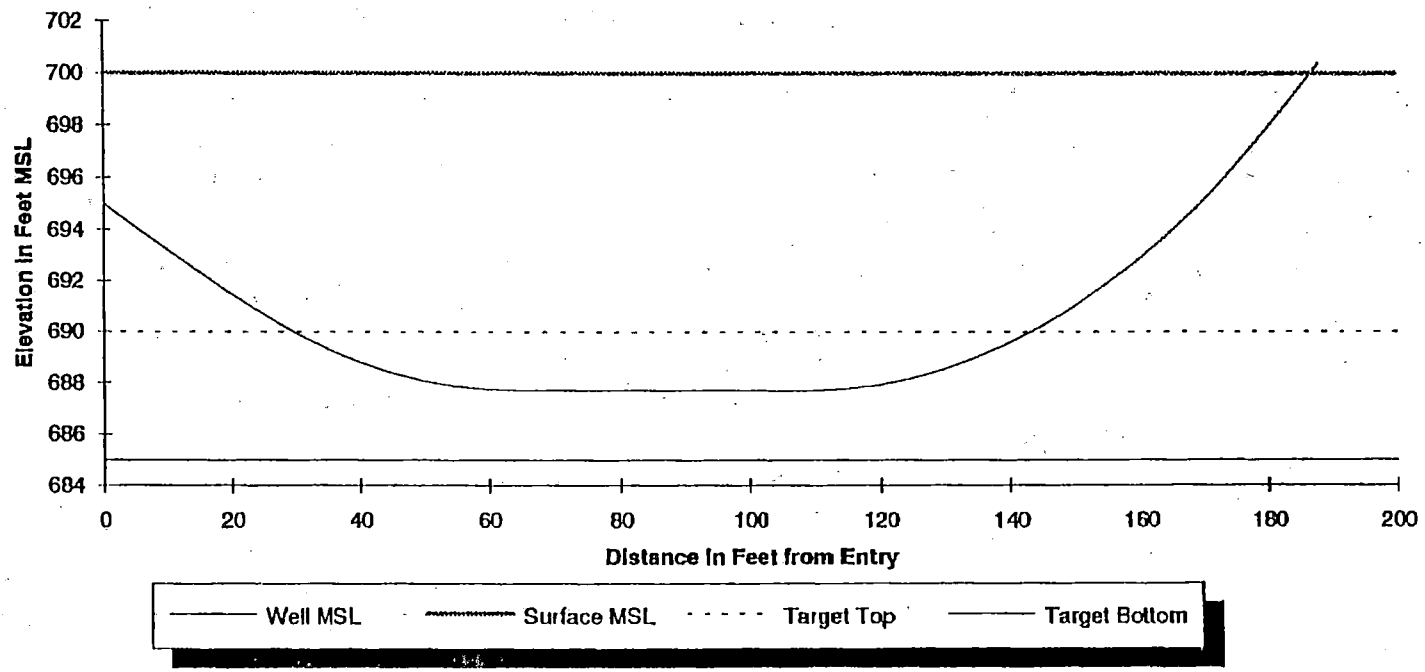


Figure 9. Borehole S1-1 (Try #1) Intended Versus Actual Trajectory for X-810 System.

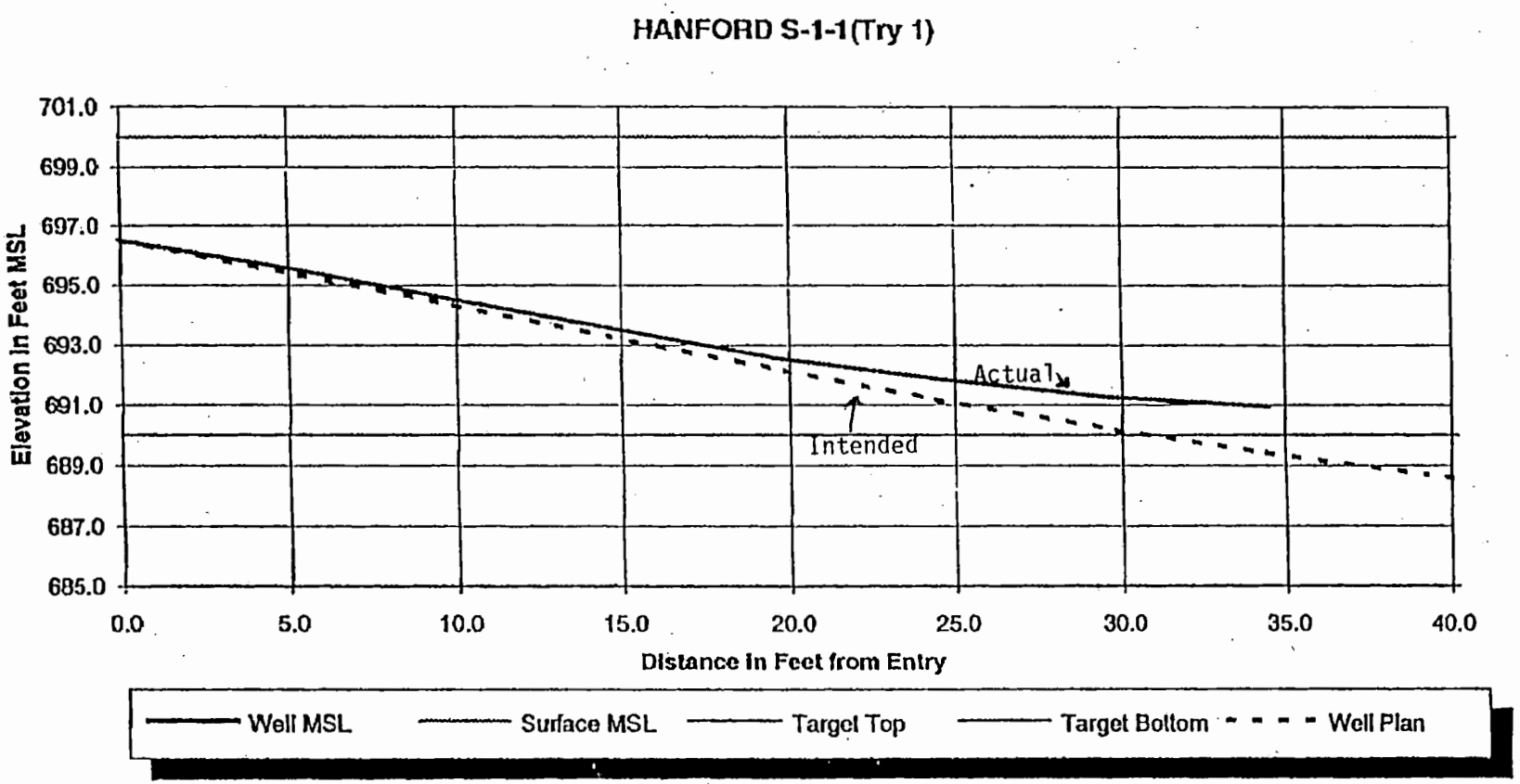
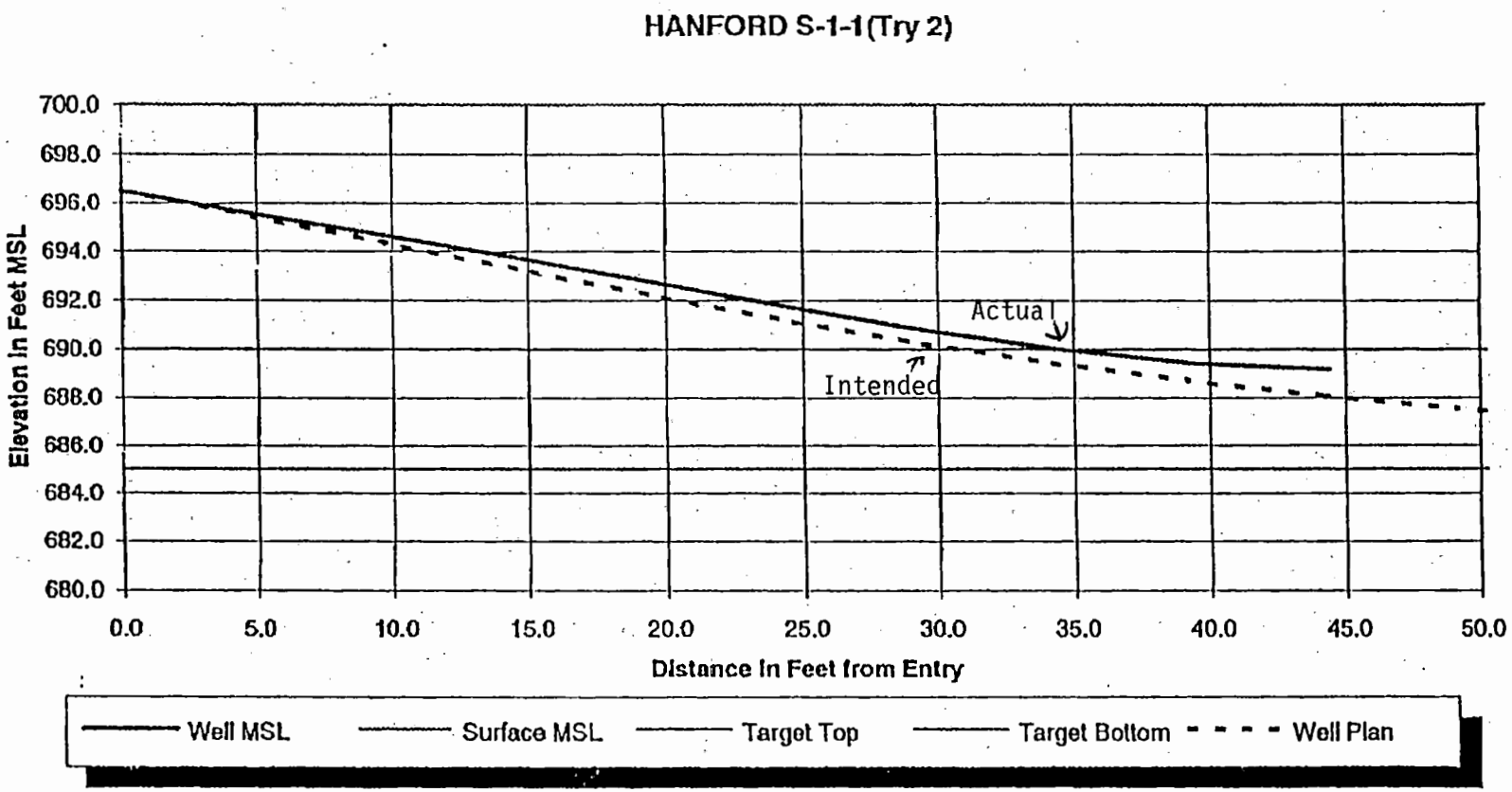


Figure 10. Borehole S1-1 (Try #2) Intended Versus Actual Trajectory for X-810 System.



at a measured depth of 49 feet (15 meters) (10.5 feet [3.2 meters] vertical depth), the drill continued to trend toward horizontal and veer toward the right. The target depth was 14 feet (4.3 meters) vertical depth, thus the inability to steer the bit at 10.5-feet (3.2 meters) measured depth was unacceptable. After several attempts to correct the borehole deviation, the bottomhole tools were withdrawn, and the borehole was abandoned.

The attempt to drill borehole S1-2 (Figure 11) with the X-810 was initiated on March 3, 1993. The penetration angle of the drill frame was raised to 22.0° to attempt to cut through the formation. It was surmised that increasing the penetration angle would improve the chances of penetrating beyond the 10.5 foot (3.2 meter) vertical depth level. The drill rod was pushed to 25 feet (7.6 meters) measured depth (9.4 feet [2.9 meters] vertical depth). The drilling from 20 to 25 feet (6.1 to 7.6 meters) was extremely difficult. The bit appeared to have travelled across the top of a large rock and made a substantial direction change in a 5-foot (1.5 meters) interval. Because the steel drill pipe was not designed to handle the degree of severity of the turn, it broke off in the borehole. The actual trajectory is shown in Figure 12. After the broken drill pipe was retrieved with a backhoe, it was decided by Westinghouse Hanford Company, CMW, and SNL personnel to stop the X-810 test.

One additional test was run at the X-810 site using the Pierce Airrow[4] percussion hammer tool. The Pierce Airrow was shown to penetrate Hanford soils at a rate of approximately 30 feet (9.1 meters) per hour. Possible adaptation of the Pierce Airrow could be used to improve the penetration and steering capabilities of the X-810 system.

The X-810 was shown to be unable to complete boreholes up to 25 feet (7.6 meters) in depth and unable to maintain directional control. Because no boreholes were completed with the X-810, independent surveys were not performed. Objective 3, ability to complete boreholes with fiberglass casing, was never tested because a borehole was not completed. The ability to maintain contamination control was proven. Finally, Objective 5, the ability to install boreholes that meet WAC was not demonstrated. However, the limits of the X-810 as currently configured, were established for the first time.

3.1.2 P-80 System

The P-80 was successfully used at the S1-3 site to drill a horizontal borehole approximately 114 feet (35 meters) long and 1.75 inches (4.5 centimeters) in diameter. The entry point of the borehole was at the base of a gravel mound, and the exit borehole was on the other side of the mound. A cross-section of the actual borehole trajectory is shown in Figure 13.

The S1-3 borehole was sampled at intervals of 10, 20, 30, and 39 feet (3, 6.1, 9.1, and 11.9 meters) using a modified, commercial soil mechanics type sampler; however, an acceptable sample was only recovered from the 39-foot (11.9-meter) interval. Sample recovery was 100% at the 39-foot (11.9-meter)

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[4]Pierce Airrow is a registered trademark of Oklahoma Airrow, Inc.

Figure 11. Borehole S1-2 Intended Trajectory for P-80 System.

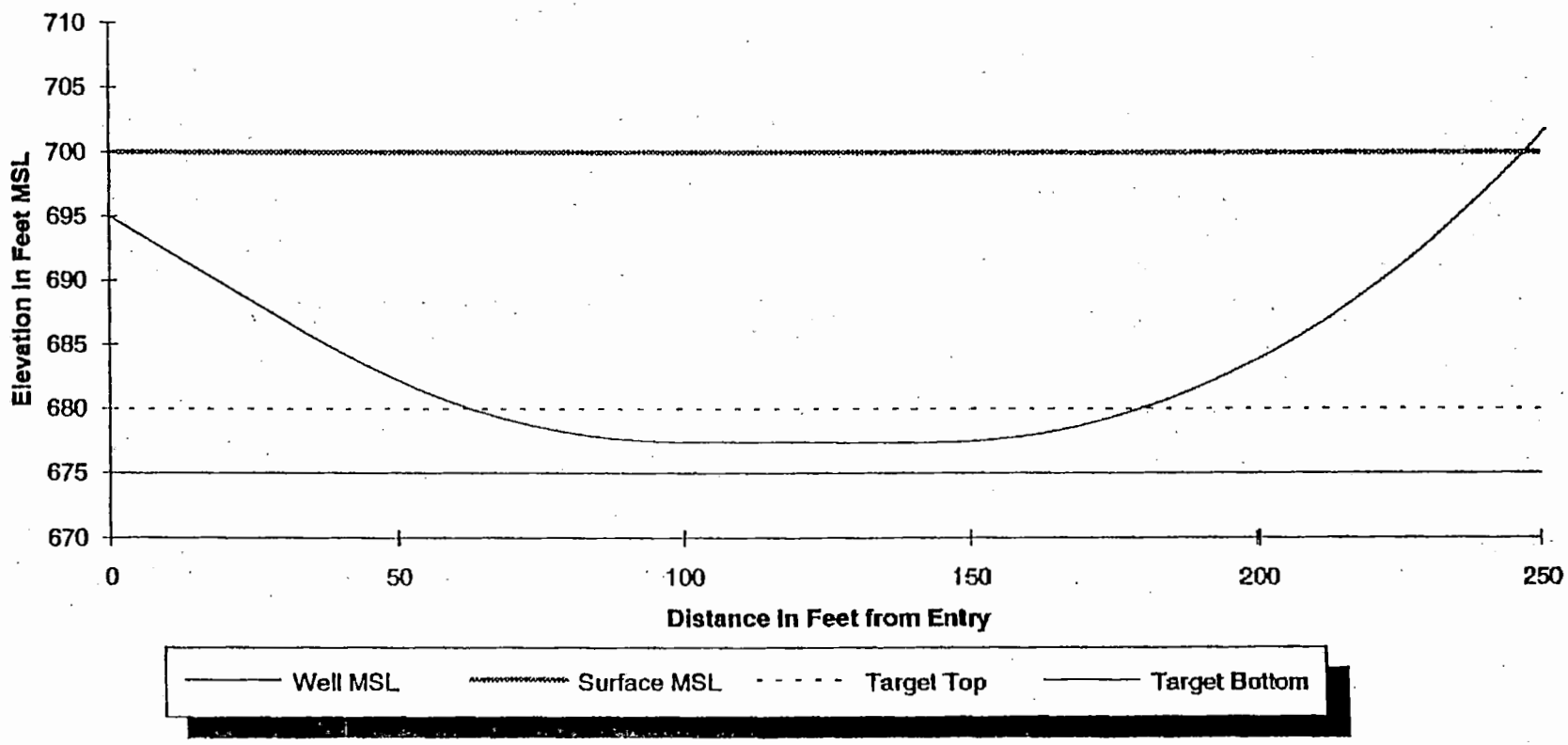


Figure 12. Borehole S1-2 Actual Versus Intended Trajectory for P-80 System.

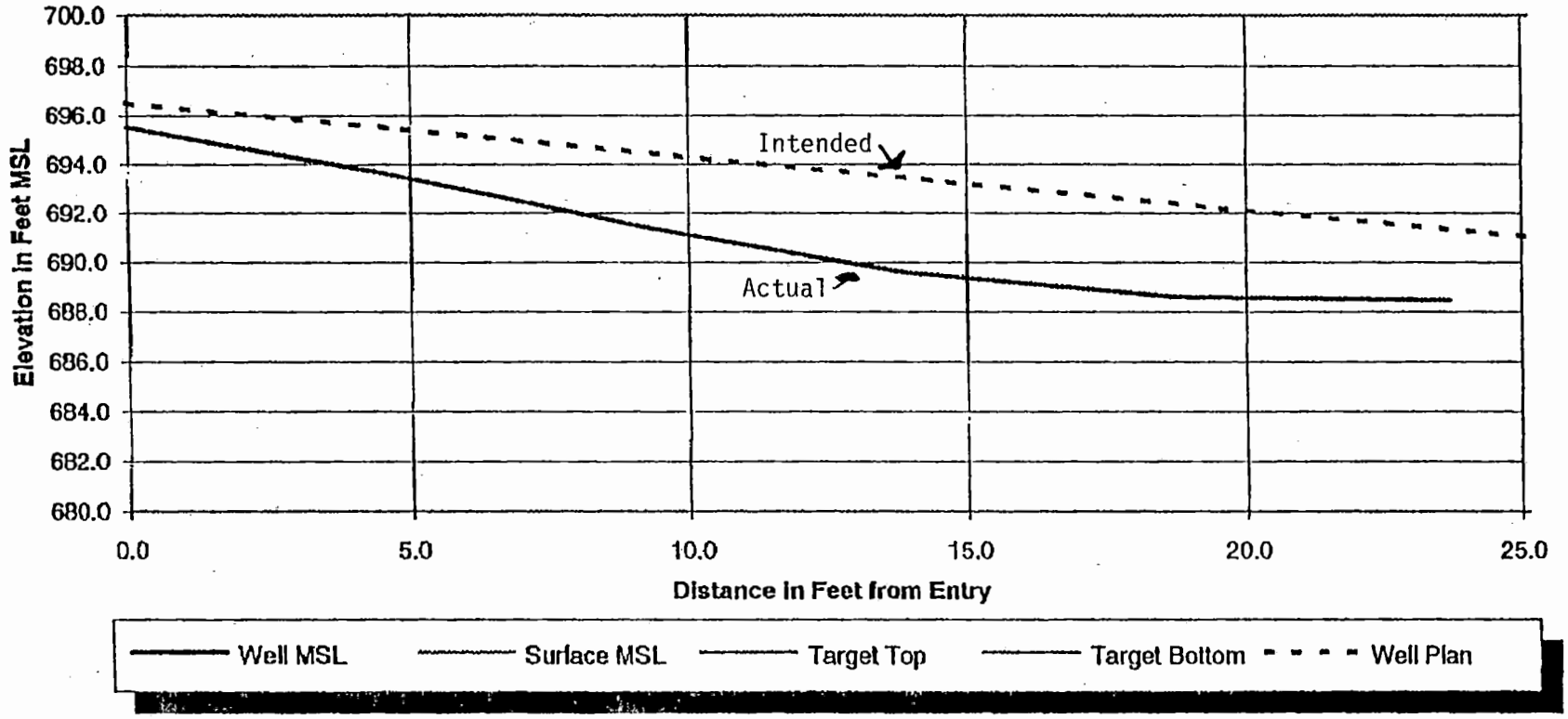
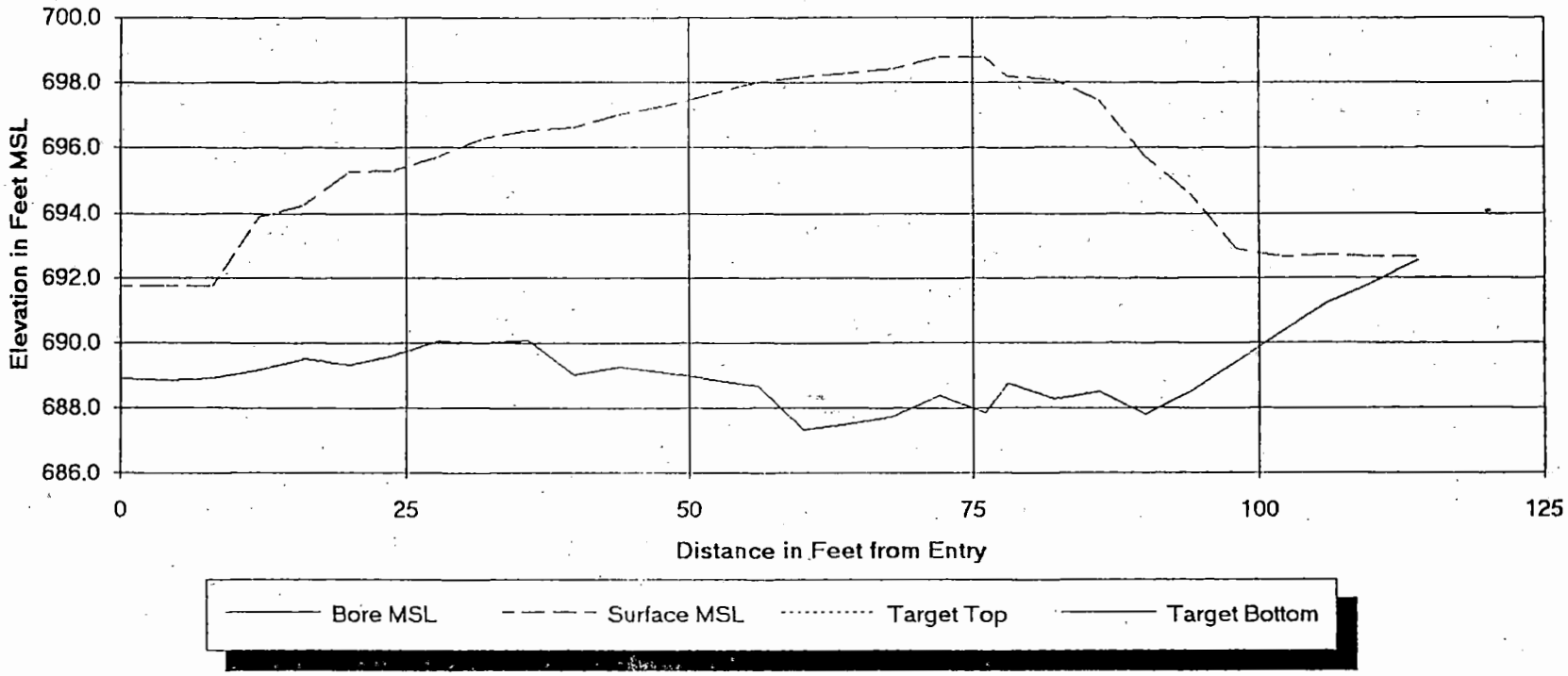


Figure 13. Borehole S1-3 Actual Trajectory for P-80 System.



interval and less than 5% on the 10-foot (3.1-meter) and 20-foot (6.1-meter) samples. The sampler broke on the 30-foot (9.1-meter) sample. The sampler broke off at the 30-foot (9.1 meter) interval failed at the rod thread where it screws into the rod adapter. The sampler used was only 1.1875 inches (3 centimeters) in diameter and 7.5 inches (19.1 centimeters) in length and retrieved an 8.3 cubic inch (136 cubic centimeter) sample. In comparison, the standard 5-inch (13-centimeter) split spoon sampler used at Hanford retrieves a 300 cubic inch (4,916 cubic centimeter) sample.

Steering the P-80 was accomplished using a DITCH WITCH patented drill bit and a walk-over tracking system. Steering control was excellent along the length of the 114-foot (34.7-meter) borehole, and the exit point of the borehole was in the intended location.

The test objectives mentioned previously were accomplished by the field testing. Depending on sample strategies, an evaluation would need completed to determine if sampling tools are of adequate size. It would be beneficial for the sampling tools to be enlarged and made stronger to be used for environmental sampling in soils similar to Hanford. The P-80 was very successful in directional control and penetration of Hanford soils. In addition, the walk-over tracking provided accurate measurements of the borehole trajectory.

3.2 PENETRATION RATES AND PIPE HANDLING TIME

3.2.1 X-810 System

Penetration rates with the X-810 system ranged from 12.5 to 24 feet (3.8 to 7.3 meters) per hour. The pipe handling time amounted to approximately 10% of the total drilling time. Water was pumped while drilling at a rate ranging from 1.6 to 10 gallons (6 to 37.9 liters) per minute.

3.2.2 P-80 System

The P-80 system was able to penetrate the Hanford formation at a rate of 120 feet (36.6 meters) per hour. The pipe handling time for the P-80 system averaged approximately 50% of the drilling time. No water addition was required.

3.3 DOWNTIME FOR EQUIPMENT REPAIR

Neither the X-810 nor the P-80 systems experienced any downtime resulting from equipment malfunctions. Both machines are durable and reliable. The walkover tracking was reliable to a depth of about 10 feet (3 meters) below ground level; beyond this depth, the accuracy of the tool became uncertain. The steering tool provided accurate readings of the borehole trajectory; within its limits.

3.4 BOREHOLE STABILITY

As discussed in Section 2.1.1, the stability of the hole drilled by the X-810 was marginal. Each time the drill bit was withdrawn from the formation, approximately 40 to 50% of the borehole would collapse. In order to horizontal drill successfully, the borehole walls may require casing support.

The instability of the borehole walls was less detrimental to the operations of the P-80 system. Each time the drill bit or sampler was withdrawn, the borehole walls would collapse; however, because the P-80 uses small diameter drill rods, the borehole was easily re-entered each time.

3.5 CONTROL OF CHEMICAL AND RADIOLOGICAL CONTAMINATION

The DBS was not used in areas of chemical or radiological contamination. However, because the system requires no circulation of fluid (air or water), it would be well suited for drilling in contaminated conditions. The X-810 has been used in chemically contaminated sites at the SRS and SNL with no return of contamination to the surface. The water used to cool the drill bit and steering tools at a rate of 1 gallon (3.8 liter) per minute does not come to the surface and thus does not pose a contamination problem. However, adding water to a contaminated condition can create additional problems and must be evaluated on a case by case basis.

3.6 WASTE MINIMIZATION

Because the DBS drills by soil displacement, no cuttings are returned to the surface; therefore, waste minimization is excellent.

3.7 PROTECTION OF HUMAN HEALTH AND THE ENVIRONMENT

The DBS was successfully deployed at the Hanford Site with no measurable adverse effects to human health or the environment. The system uses no air and minimal water during drilling, unlike other drilling systems. The containment demonstrated with the DBS is similar to that available with a cable-tool rig used for vertical drilling. In addition, the DBS does not generate any waste, which eliminates worker exposure to contaminated soils. Based on these attributes, the DBS could be used at mixed-waste (radioactive and chemical) sites without endangering the workers or the public.

The DBS also limits industrial exposure to the workers to a minimum. All drill pipe is handled by a hydraulic arm that is operated remotely. The system uses hydraulically actuated cylinders to tighten drilling tools and the connections between joints of drill pipe. There were no reportable injuries during the testing period.

3.8 COMPLIANCE WITH WAC GUIDELINES

A variance to the WAC was approved to allow testing of the DBS. All boreholes were completed and/or abandoned in compliance with the variance.

3.9 VALUE EVALUATION/LESSONS LEARNED

Overall, the DBS field test operation was successful. Support from CMW, Kaiser Engineers Hanford, SNL, and Westinghouse Hanford Company personnel was timely and efficient. The drilling test site was representative of drilling conditions found elsewhere at the Hanford Site and will be used in the future for other drilling technology tests. Although several objectives were not met, the test was completed without significant complications.

4.0 CONCLUSIONS

The Ditch Witch X-810 system has applications at waste sites with less aggressive soils (fewer boulders and cobbles) than the Hanford Site. The system has been used successfully at the SNL Site in Albuquerque, New Mexico and the SRS near Aiken, South Carolina.

The Ditch Witch P-80 system may be useful for initial site characterization using small diameter samplers. Sensors currently used for the cone penetrometer technology (Cassem 1992) will not work with the P-80 because the rods are solid. If hollow rods would provide enough strength, sensors could be pushed into place horizontally.

5.0 RECOMMENDATIONS

At this time, it is recommended that no further tests of the X-810 system be conducted at the Hanford Site. If tools can be developed that will allow drilling and steering of the system in the unconsolidated Hanford sands and gravels, further testing may be warranted.

The P-80 system is an efficient tool for placing utility lines under roadways and for other shallow subsurface activities. It is recommended that any environmental uses remain shallow (less than 25 feet [7.6 meters] below ground level) to allow use of the tracking system. No further testing of the P-80 at the Hanford Site is recommended.

6.0 QUALITY ASSURANCE

To ensure the objectives of this test were met, work was performed in compliance with the *Integrated Test Plan for Directional Boring* (Volk 1993).

7.0 RECORDS

The documentation for this test was recorded in Controlled Notebook #EFL-1075, "Directional Boring Test," in accordance with EII 1.5, "Field Logbooks".

8.0 REFERENCES

WHC-CM-7-7, *Environmental Investigations and Site Characterization Manual*, Westinghouse Hanford Company, Richland, Washington.

Cassem, B. R., 1992, *Demonstration of Heavyweight Penetrometer Technology at the Hanford Site*, WHC-SD-EN-TRP-003, Revision 0, Prepared by Applied Research Associates for Westinghouse Hanford Company, Richland, Washington.

McLellan, G. W., 1990, *Results of Testing the Dual Wall Percussion Hammer Method and Drill Cuttings Containment System at the Hanford Site*, WHC-SD-WM-TRP-042, Westinghouse Hanford Company, Richland, Washington.

Volk, B. W., 1993, *Integrated Test Plan for Directional Boring*, WHC-SD-EN-TP-020, Revision 0, Westinghouse Hanford Company, Richland, Washington.

WAC 173-160, "Minimum Standards for Construction and Maintenance of Wells," *Washington Administrative Code* 173-160, as amended.

Wemple, R. P., 1993, *SNL-NM Environmental Drilling Project*, Department 6111, Sandia National Laboratories, Albuquerque, New Mexico.

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WHC-CM-4-2, *Quality Assurance Manual*, Westinghouse Hanford Company, Richland, Washington.

WHC, 1990, *Environmental Engineering, Technology, and Permitting Function Quality Assurance Program Plan*, WHC-EP-0383, Westinghouse Hanford Company, Richland, Washington.

APPENDIX A

DETAILED DESCRIPTION OF DRILLING ACTIVITIES

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HANFORD WASHINGTON DRILLING TESTS 3/1/93 thru 3/6/93 **5/13/93 RDM**

Feasibility tests using the X-810, P-80 and the Pierce Arrow

During 1992 it was decided to try using the X-810 and the P-80 boring systems at the Hanford, VOC-Arrid I.D. site in Washington State to complement the testing already done at Perry, Ok., Albuquerque, N.M. and Savannah River Site, S.C. Test and logistics plans were formulated for testing to be done in March 1993.

The test areas selected were between 200 East and 200 West. The location for the X-810 test was about 1000 ft. N. W. of the 200 Area Fire Station and the P-80 tests were done at the gravel pit about a 1/2 mile due East of that. The original plan called for two bores, S1-1 and S1-2 with the X-810; and sampling experiments and bore attempts, S1-3, to be done at the gravel pit. In addition two Pierce Arrow machines, a 4 in and a 6 in. were available to try should time permit. For a description of the operation of the X-810 and the P-80 see Test Plan WHC-SD-EN-TP -020, Ben Volk Environmental Field Services, WHC. The Pierce Arrow is a cylindrical air powered in-hole hammer system which produces a hole by compaction. Air is supplied thru a connecting hose. The direction (forward or reverse) can be changed while in the hole by turning the hose about 10 turns CCW (to reverse); the system is, however, not steerable.

The preliminary plan (Nov. 1992) for drilling S1-1 was to use an entry angle of 10°, target depth of 12 ft. and a length of 200 ft. with a level section 45 ft. long. Bore S1-2 was planned to start at 15°, boring straight for 45 ft. then at a constant radius of 250 ft. until Rl=195 (rod length)and inclination of 20° then straight to the exit at 200 ft. horizontal distance. Each of these holes were to be cased with 4 in. CEN-800 fiberglass cassing. The first portion of the bore establishes a section to allow the drill string to work against to turn or steer from, the exit angle of 20° or so is the preferred angle for casing installation. The above drilling plans were modified in the field to account for the actual entry angle of the drill as measured in the launch pit.

WHC provided a set of engineered reaction plates for the front and back of the drill frame to distribute the load along the launch pit walls and reduce the damage done to those walls during the drilling and casing pull back. Also provided was a buried anchor which consisted of 10 ft. long steel rods attached to a piece of 8 in. casing and set to a depth which allowed an eye on the rod to be just above the pit floor. Both of these system were major improvements over previous methods and will be incorporated in future drilling where possible.

The site chosen to test the X-810 was the same as had previously been used for the Dual Wall Percussion Hammer and the Cone Penetrometer Tests. The location is flat and the top soil is about 2 ft. of sandy soil over gravel. The gravel is unconsolidated mixed oval stones of all sizes mainly 1 in. to 4 in. some as large as 12 in and occasionally larger. The remainder is made up of both fine and coarse loose sand. This area is said to be typical of most of the Hanford site, neither the toughest or the easiest to drill.

The following is a description of the drilling activities for each of the machines.

Monday 3/1/93

Part of the day was spent clearing security, along with a small amount of site-required training. The truck carrying the shipment arrived on schedule and the X-810, P-80 and support equipment was unloaded by crane using site personnel. The X-810 drill, power pack, drill rods, and equipment boxes were spotted, hook up of the hydraulics and drill system check out completed without problems. The drill frame was coupled to the anchor system and the drill set to the 10° stop. Actual angle was 12.4^o due to a ~-2.5^o slope of the pit floor. The bore line was surveyed in use a measuring tape and Brunton compass, the bore azimuth 102.5^o mag. The steering tool was checked out and found to be operating satisfactorily.

Tuesday 3/2/93

0900 Preparing to drill S1-1, air temperature ~20°F, the Drillscout will not respond in azimuth and it is probably too cold, it will may be OK by the time we get it all assembled.

Bottom Hole Assembly (BHA)

Subsite and housing

Drillscout and housing

P-80 style bit

The flex sub, Drillscout housing and P-80 style bit are ~5 ft long. It should be noted that the steering tool, a Drillscout, mounts to the back side of the bit and thus provides excellent data on bit reaction, azimuth, inclination and tool face (rotation) can be taken at any time during drilling, except while rotating. The BHA is followed by four 5 ft. long non-magnetic drill rod sections.

1120 Inclinometer angle reading 12.4°, starting to drill. The Drillscout is responding to both Az and inclination although the 180° inclination reading is very noisy.

1124 Lost ~2° angle during the first 5 ft.

1136 Rl=10 ft. held ~10° for this rod, attempting to steer down. (Rl=total rod length including BHA)

1202 Rl= 20 ft., inc. now ~9.7°. (inc.=inclination)

1208 Redrill (push only) this rod steering down; angle now -11.6°, Az 101°; very rocky, the drill string bucks and jumps as torque is applied, very difficult to maintain down angle even with no rotation. Angle now -11.4°. Water flow rate 1.6 gpm.

1320 Rl=25 ft. inc. -4°, Az 95°; the bit deviated up and to the right.

Swabbed this rod with tool face down, inc. now -4.8°.

1329 Rl=30 ft. inc. now -5.6°. The Subsite tracking also indicates that the bit is leveling off.

1347 Rl=35 ft. inc. now -0.6°. Decided to pull back 4 rods and read inclination.

Rl=15 ft. inc. -7.7°/-6.3°(0° and 180°).

Rl=10 ft. inc. -8.6°/-7.5°.

Pulled all the way back, there is now a discrepancy between the tool face reading of the Drillscout and the Subsite, also the flex sub is bent ~2°(eye ball).

1515 Making up the BHA without the flex sub. It will be taken to town to a machine shop to be straightened. Realigned the Drillscout and Subsite to give proper tool face and will drill with a stiff assembly.

Attempt#2 S1-1

1610 Ready to drill, BHA is the Subsite housing, Drillscout housing and bit. Surface inc. -12.2°/-12.2°. Drilled fairly smoothly to Rl=20ft. The angle held much better than before.

1639 Rl=20 ft. inc. -12.5°/-11.6°. Slight turn to the right to ~95°.

At 22 ft. we apparently hit a large rock, started to rotate and drilled the rest of the rod.

1648 Rl=25 ft. Hard thrust, tool face down with some rotation, inc. -12.4°/-11.2°, water flow rate ~3gpm.

1656 During the drilling of this rod (#6) an attempt was made to swab and steer down as the bit apparently rode up and over a rock to an angle of -6°. The hole was then worked until 1705 trying to build down angle.

1705 Rl=30 ft. inc. -10.3°/-8.2°, Az 92°/ 93°. Added one more rod which encountered big rocks and required lots of force.

1712 Rl=35 ft. inc. -8.4°/-7.5°, Az 90°/92°. Difficult down push.

1750 Rl=40 ft. inc. -4.5°/-4.9°, Az 90°/90°.

EOD (end of day) 3/2/92

3/3/93

0845 Removed one rod, inc. -8.4°/-7.5° @Rl=35 ft.

0900 Drilled rod #8 back in, inc. -2.3°/-2.0°, Az 85°/87° @ Rl=40 ft.

0915 Rl=45 ft. inc. +1.3°/+1.9°, Az 86°/85°. The bit is turning right with a hard up.

0930 Rl=49 ft. inc. +3.9°, Az 84° tool face 0°. Cannot steer, the bit jet is now plugged, tripping out!

Attempt #3

The drill frame was raised to the 20° stop in preparation for starting a new hole under the old one. In addition the Subsite and housing have been removed, the BHA now consists of just the bit, Drillscout and housing. The drill bit water jet has been replaced.

1100 Starting to drill with inclination -22.0°.

1111 Rl=5 ft. push down, inc. -22.7°/-22.1°, Az 41°/41°. Note that the Azimuth readings are affected by the drill frame

1119 Rl=10 ft. push down and rotate, inc.-25.8°/24.9°, Az109°/106°.

1129 Rl=15 ft. push down and rotate, inc. -22.1°/-21.0°, Az 106°/103°.

1141 Rl=20 ft. push down and rotate, very hard drilling of this rod from 17 ft. to 20 ft. inc. -12.2°/-11.2°, Az 100°/99°. Obviously the bit rode over the top of a large rock.

1256 Rl=25 inc. -2.0°/-1.5°, Az 93°/95°, Cannot hold water pressure with flow rate at 10 gpm, looks as if the drill string has twisted off, tripping out of the hole.

Retrieved 3 rods from the hole leaving one non-mag section and the BHA for the backhoe to dig up. The two bottom non-mag rods both had belled box sections and were no longer usable. Upon retrieval of the remaining rod and BHA the box on this rod was also damaged and unusable. The drill bit was still in relatively good condition although did show some wear. This ended the effort to drill with the X-810.

The remainder of this day was spent preparing the X-810 for shipping, cleaning up the drilling area and conducting a test of the Pierce Arrow. At the gravel pit the P-80 trench box was placed in the pit for the sampling and boring test to follow.

Conclusions X-810 Boring System Performance

This machine is designed and intended to be used where conditions permit compaction by displacement of the soil along the bore path. The choice of the P-80 style bit which has no provisions for cutting was felt to give the best chance of accomplishing the compaction process. This bit it was felt would move material to the side and compress it enough to stabilize the bore walls. An aggressive cutting bit by contrast would create more fine material and dislodge rock and sand in an already unconsolidated media thus reducing wall stability. It appeared during the drilling that as the bore was swabbed that fine material would build up under the nearly horizontal drill string causing it ride on top and lose angle. Since the string turns clockwise looking down hole that the deviations to the right may have been caused by the same effect, that is fine material building both under and the left side of the string. It was also apparent that some rather severe deflections occurred as a result of some of the larger rocks in the formation. This eventually caused failure due to bending the drill rod on too short a radius. There may be a bit design in the middle that would cut the larger stone, a more aggressive steering surface while still providing substantial compaction capability. Bit design and testing would involve a rather extensive development program.

There may be some locations at the Hanford site where the existing system could be used effectively.

The rest of the systems performed very well, in particular the method of anchoring the drill to the ground.

Pierce Arrow™ Tests 3/3/93; R.P.Wemple,SNL Org. 6111

The purpose of this experiment was to qualitatively test the effectiveness of percussion hammer type tools in the Hanford geology. The device used was a standard 4 in. diameter Pierce Arrow using threaded anvil nose piece and a tapered tailpiece. The X-810 and other Ditch Witch equipment is adaptable to similar hammer devices which are steerable when coupled to a bent sub. Also the Pierce Arrow has been used in the Southeastern Washington area by utilities contractors with some success.

This experiment was performed after the completion of the X-810 tests and used the east pit wall about 5 ft. south of that location. The Pierce Arrow was launched horizontally about 4 ft. below grade in an intermediate zone of sand and small gravel (up to 3/4 in. dia.) that was confined above and below by cobble zones with material up to 2 in. dia. The tool was supported on timbers for the launch. The air hose attached to the rear of the tool was marked at 1 ft. intervals to monitor rate and distance.

Initial penetration was surprisingly easy (~1ft./min. for 30 min.) but forward progress gradually slowed as drag on the air supply hose increased. The drag was caused by partial collapse of the borehole on the hose. Penetration rate also varied due to the type of rocks and cobbles encountered along it path.

After approximately 90 min. forward progress had ceased. The tool was allowed to hammer the impediment for an additional 90 min. to see if it could break through, it was then shut down and retrieved with a backhoe. It was found at depth of 8 ft. in a zone of rather large cobble and had traveled about 52 ft. The supply hose was disconnected from the tool and pulled out from the entry end with some difficulty, indicating that progress had been stopped by the hole collapsing on the hose.

Conclusions From The Pierce Arrow Test

This test demonstrated that small hammer tools may be applicable in the Hanford geology. The particular type of free-launched, non-steerable tool used in this test would not be recommended for emplacing very long boreholes. It may be necessary to advance casing while drilling because of the poor borehole stability as the formation may be too loose to rely on compaction to maintain stability. A similar hammer tool is being considered for use with the X-810 prototype machine at Hanford during Fy 94.

P-80 Sampling and Boring

Friday 3/5/93

The launch pit for P-80 Trench Box was located About 100 ft. West of the gravel pit and up near the original grade level. The top soil here is mainly fine sand about 1.5 ft. thick overlaying beds of small gravel most of which was less than 2 in. The gravel pit wall is about 30 ft. tall and displays numerous beds of gravel and large rocks at various depths. The launch pit was about 9 ft. x 9 ft. x 4 ft. deep, the walls below the top soil somewhat unstable and some minor sluffing of the gravel layer had occurred. The launch direction was to the North under a slight rise in the grade. The trench box was placed in the pit and the two ends shored in with timbers.

Set up to pre-bore for the sampler using the 1 3/4 in. conical non-steerable point. The first sample attempt was to be at 10 ft. so the bore was made to 8 ft. without difficulty, the rods tripped out and the sampler with transmitter housing attached. The tracking system was used at the end of each rod to set a flag and obtain a depth reading. The sampler was then pushed to 10 ft. cocked (withdrawn) with 1/2 rod then driven in 1 full rod (4 ft.). It appeared from the tracking data that the bore path was at an upward angle, possibly due to the sluffing of the gravel at the entry point causing the rod to deflect upward at entry. Also there was considerable difficulty with the P-80 cylinder dragging on the rod during both forward and reverse cylinder travel. The gravel seems to have a very loose grip on the rods. The sampler was recovered but did not contain a sample. The entry to sampler was packed with a clay like material with a small hole in the center and a internal shape conforming to the cone rod point. Apparently the cone rod had retracted but not far enough to latch up until withdrawal. The second attempt was at 20 ft., the bore was made to 18 ft. with the conical point as before. This time the rods were withdrawn 3 ft. for cocking and then inserted 6 ft. to obtain the sample. The sampler again came out without a sample. For the third attempt the hole was pre-drilled for 7 rods (28 ft.), the sampler installed for an attempt at 30 ft. For this attempt a full rod was used to set the sampler latch and this rod plus an additional rod to take the sample. During the second rod a loud pop was heard. This was not unusual as similar sounds are made frequently during the pre bore with the cone point. However in this case the sampler had broken off at the cone rod thread where it screws into the rod adapter. The surface was flagged over the point where the sampler had broken off to enable it to be recovered using a back hoe.

The fourth try was done as before with the sample target at 39 feet. The sampler was set with 3 cylinder strokes (~30 in.) then two additional strokes used to get a sample. This time the sampler performed normally, the sample tube was packed with dry white sand. The sample tube was capped, dated and presented to WHC.

Conclusions From The Sampler Testing

The Hanford geology presents several problems to the punch/core type devices typically used with soil mechanics-type testing equipment for which the device used here was designed. The locations of interest usually contain high ratios of rock to sand. The rocks are of very little interest analytically so in order to have a viable sample you must recover the fine materials in which the contaminants are trapped. To accomplish this in a gravel bed the push distance with the sampler in the cocked position in necessarily longer than it would be for soil. This of course increases the risk to the cone rod which has been

recognized as vulnerable to breakage as it has happened before. However the system did work and it did get a sample. There is a need to increase both the strength and sample volume of this sampler and too also make an attempt to somehow prevent the opening from plugging off with stones. The other more serious problem of the cone rod breakage maybe a simple matter of increasing the diameter and or the heat treat of the rod. It is planned at this time (April 1993) to look into reducing the cone rod vulnerability and to design and build a prototype sampler of on the order of 2.25 in O.D. for the P-80 and possibly a 3 in. version for the X-810.

A later attempt to retrieve the broken sample was unsuccessful, the hole dug continued to fall in and they could not find it (Ben Volk, WHC).

Using The P-80 To Bore A Pit To Surface Hole

Saturday 3/6/93

With the trench box set up as for the sampling a 2 in. steering head and transmitter were installed to bore a pit to surface hole under the hill and to the surface in a flat area about 120 ft. away. The first attempt entered the same hole as that used for sampling. Seven rods (28 ft.) were pushed and it was determined the upward trajectory precluded doing an experiment to see if we could steer the hole. We then tripped out and started a new hole with a level trajectory. The tracking sonde used for this type of drilling transmits through the earth to a surface walkover receiver which indicates tool face and depth. Surface elevation change along the bore path were shot using a transit and level rod as the surface tracking data was taken. This data was entered into tracking software in a computer which then plots surface and bore elevations. The MSL values are arbitrary.

1003 to 1020 Steering down to maintain level path. Rl= 16 ft.
1020 to 1042 Steering down with some rotation. Rl=36 ft.
1042 to 1142 Rotating the rods in to steer straight. Rl=60 ft.
Lunch break
1247 to 1324 Rotating to steer straight. Rl= 82 ft.
1332 to 1344 Turning up for exit trajectory. Rl=94 ft.
1344 to 1410 Coming up at about .8 ft. per rod.
1410 Surface at Rl=114 ft.

The rods were then tripped out of the hole without an expander due to the poor condition of the pit wall in front of the trench box. The concern was that the trench box would slide forward under the large forces required with the use of an expander and up on the gravel that had sluffed in the bore entry area. This would put the rod in a bind and make removal very difficult. During the boring operation there was a fair amount of popping as the boring head was pushed forward and either broke or pushed rocks out of its way. This was energetic enough to be easily felt on the surface.

Conclusions From The P-80 Boring Tests

The P-80 can be used to make a bore in at least the zones of smaller gravel, the holes produced may stay open for short periods of time. At no time were the forces required either during the sampling or drilling near the capacity of the machine. It may be appropriate to do a more extensive set of tests with the P-80 to determine what the limits are in unconsolidated gravels for sampling, boring and casing installation.

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