STANDARD OPERATING PROCEDURE

NINE

DRILLING METHODS

Modified from

U.S. Environmental Protection Agency Environmental Response Team

Response Engineering and Analytical Contract

Standard Operating Procedures

Drilling and Monitoring Well Installation

at Hazardous Waste Sites in South Dakota

SOP 2150

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1.0 SCOPE AND APPLICATION

The purpose of soil borings is to provide access to subsurface soils at specified locations and depths. Soil borings also allow for installation of ground water monitoring wells and in-situ remediation systems.

2.0 METHODS

The planning, selection, and implementation of any soil boring program should include the following:

- Review of existing data on site geology and hydrogeology including South Dakota Geological Survey (SDGS) and U.S. Geological Survey (USGS) publications and unpublished databases (available at SDGS, Vermillion, South Dakota, and USGS, Rapid City and Huron, South Dakota), county soils surveys (available from the county Soil Conservation Service [SCS] offices), air photos (available from county SCS offices and Earth Resources Observation Systems [EROS] Data Center, Baltic, South Dakota), water- quality data (available at SDGS and the South Dakota Department of Environment and Natural Resources [DENR], Division of Water Rights), and existing maps available from local, state, or federal agencies. Maps and photos showing historical land uses from local city or county planning agencies and historical societies or groups may also be significant. Every effort should be made to collect and review all applicable field and laboratory data from previous investigations of the project area.

- A visit to the site to observe field geology and potential access problems for a drilling rig, to secure a water supply for drilling (if needed), and to check for hazards to personnel and equipment (such as utilities on and near the site).

- Preparation of site safety plan in compliance with applicable U.S. Environmental Protection Agency (U.S. EPA) and Occupational Safety and Health Administration (OSHA) guidelines.

- Definition of project objectives and selection of drilling methods.

- Determine need for containing and disposing of potentially contaminated soil generated by the drilling process.

- Preparation of written work plan including site safety plan, definition of objectives and work methods, listing of material and equipment specifications, and plan for disposal/treatment of contaminated materials.

- Preparation and execution of the drilling contract.

- Field implementation of the drilling program.

- Final report preparation including background data, project objective, field procedure, and well-construction data, including well logs and well construction information.

A contractor licensed by the Division of Water Rights, DENR, must perform all drilling activities (Phone: 605-773-3352). Well construction standards ARSD 74:02:04 which govern test-hole drilling, monitoring well drilling, and other drilling related to water resources are available from the Division of Water Rights. The driller must apply for a variance if the planned monitoring wells will not meet the well construction standards. All drilling and well installation programs must be planned and supervised by a qualified geologist or hydrologist.

2.1 Drilling Methods

The most commonly used drilling methods are:

- Hollow-stem auger
- Solid-stem auger
- Bucket auger
- Direct-mud rotary
- Reverse-air rotary
- Cable tool

The type of equipment used depends upon the site geology, hydrology, equipment available, and monitoring design. Control of cuttings and other potentially contaminated materials at the drill site may influence drilling method selection. Depending upon equipment availability and site geology, more than one method may be combined to complete a particular monitoring well installation.

2.1.1 Hollow-Stem auger

Hollow-stem auger drilling uses large diameter (up to 14-inch outside diameter [OD]) continuous-flight augers which mechanically excavate drilled materials from the hole. These augers are built with a large (up to 10.25-inch inside diameter [ID]) axial opening to allow access to the bottom of the hole without withdrawing the auger string. The augers act as temporary casing during and at the completion of drilling to facilitate the sampling of sediment and water and the installation of monitoring wells.

Some advantages of hollow-stem auger drilling often make it the preferred method of installing monitoring wells. Hollow-stem auger drilling is relatively rapid, especially in shallow applications in poorly lithified to unlithified sediments. Little or no outside fluid is required in the drilling process. Though a relatively large volume of cuttings are generated, they are normally easily contained. The volume of effluent, resulting from well-development efforts and requiring disposal, is normally lower than with some methods, notably mud rotary. Hollow-stem auger drilling readily supports thin-wall and split-tube sampling in poorly lithified sediments. Most hollow-stem rigs operating in the state also support other drilling methods such as mud rotary, solid-stem auger, and coring. Hollow-stem rigs are relatively simple, with few lubricated parts at positions likely to contaminate the test hole or monitoring well. Rigs capable of supporting hollow-stem drilling are available statewide.

There are some disadvantages and limitations to the use of the hollow-stem auger method in the construction of monitoring wells. It is limited to drilling in poorly lithified to unlithified sediments and to a maximum depth of about 150 feet. Shallow bedrock or other hard-to-drill materials may reduce this depth significantly. Hollow-stem augers are prone to cross contamination of fluids within the bore hole along the large annular space around the auger tubing. High hydrostatic pressures in the bore hole can cause problems with sand heaving up into the augers during sampling and well-installation procedures. Wide variations in bore-hole size, common to auger drilling in poorly cohesive sediments, may complicate effective sealing of the annular space during monitoring-well installation. The design of hollow-stem augers produce an approximately 1-inch thick rind of smeared cuttings which may effectively seal the bore-hole walls in clayey sediments. This rind may interfere with the flow of fluids to the monitoring well.

U.S. Environmental Protection Agency guidelines (U.S. Environmental Protection Agency, 1986, 1987) recommend that hollow-stem auger inside diameters be 3 to 5 inches greater than the outer diameter of well casings to allow effective placement of filter and sealing materials. Ideally, 2-inch diameter monitoring wells should therefore be installed within 5.5 inch ID or larger hollow-stem augers.

Hollow-stem auger drilling is usually appropriate in the more poorly lithified sediments of South Dakota. The method is well suited to drilling in glacial drift that make up most of the land-surface deposits east of the Missouri River. These sediments, however, are composed primarily of sticky bentonitic clays that require a rig which can supply high drill head torque to complete deeper holes. Cretaceous shale, chalk, and sandstone underlying much of the area west of the Missouri River provide for difficult hollow-stem auger drilling but may often be penetrated with larger, more powerful rigs equipped with heavy-duty augers. Sediments containing abundant large boulders (like those along the high-gradient stream valleys of the Black Hills) may be penetrated only with great difficulty by hollow-stem methods. Other well lithified bedrock units such as well-cemented sediments, igneous and metamorphic rocks in the Black Hills, the Sioux Quartzite, and the Milbank Granite preclude hollow-stem drilling.

2.1.2 Solid-Stem auger

Solid-stem auger drilling uses continuous-flight augers which mechanically cut and continuously transport cuttings to the land surface. Augers are available in diameters of 3 to 14 inches. Augers used for monitoring-well construction must be of sufficient diameter (about 3 to 5 inches larger in diameter than the monitoring well OD) to allow effective placement of well filter and sealing materials.

Solid-stem augering has a number of advantages. It produces a moderate amount of easily contained cuttings; little or no fluid is required in the drilling process. The entire surface area of the augers is easily accessible, facilitating complete and simplified decontamination. Thin wall and split barrel soil sampling operations are supported. Smaller rigs than used in hollow-stem auger drilling may be used, simplifying decontamination, site maneuvering and often incurring lower costs. These rigs drill relatively rapidly, especially in shallow applications. Solid-stem rigs are relatively simple, with few lubricated parts at positions likely to contaminate the test hole or monitoring well. Rigs capable of supporting this method are available statewide.

Solid-stem auger drilling has some disadvantages. It is prone to cross contamination of fluids in the bore hole along the large annular space around the auger. Like hollow-stem augers, the design of these augers produce an approximately 1-inch thick rind of smeared cuttings which may effectively seal the bore-hole walls in clayey sediments. This rind may interfere with the flow of fluids to the monitoring well. Solid-stem augers must be removed from the hole before any soil sampling or well installation can commence. The method is, therefore, generally limited to stable earth materials which will not collapse when the augers are removed from the hole. Saturated silts, sands and gravels, and materials below those sediment types are not suited to monitoring-well construction by this drilling method. Soil sampling during solid-stem auger drilling is labor intensive, especially in deeper holes because the augers must be removed from the hole during each sampling procedure. Workers are also more likely to contact contaminated materials and equipment during this repeated large scale handling of down-hole equipment.

Solid-stem auger drilling is generally restricted to the more cohesive, yet poorly lithified sediments of South Dakota. The method is well suited to drilling in glacial tills that make up most of the land-surface deposits east of the Missouri River. These sediments are composed primarily of sticky-bentonitic clays that require high rotary head torque to cut and transport cuttings from deeper holes. Cretaceous shale, chalk, and sandstone underlying much of the area west of the Missouri River provide for difficult auger drilling but may often be penetrated with larger, more powerful auger rigs and heavy-duty augers. Sediments containing abundant large boulders (like those along the high-gradient stream valleys of the Black Hills) may be penetrated only with great difficulty by solid-stem auger methods. Other well lithified bedrock units such as well-cemented sediments, igneous and metamorphic rocks in the Black Hills, the Sioux Quartzite, and the Milbank Granite preclude solid-stem auger drilling.

2.1.3 Bucket auger

Bucket auger drilling uses a rotating cylindrical bucket with cutting blades mounted on a hinged bottom to repeatedly cut and lift sediments from the hole, much like the operation of a common post hole auger. Bucket-auger rigs may be equipped to drill holes from 10 to 60 inches in diameter. Bore holes for monitoring wells drilled in the state by this method are commonly 12 inches in diameter. Bucket-auger rigs are capable of drilling to about 100 feet in depth.

Bucket augering requires little or no fluid in the drilling process. The entire surface of the drilling tools is easily accessible, allowing complete and simplified decontamination. Though normal soil sampling tools are not usually supported, samples from the drilling process are adequate for most purposes and easily located as to position within stratigraphy of the hole. A variation of bucket-auger drilling available in the state, fashioned after the California Stovepipe method, advances casing during the drilling process. This variation greatly limits the potential for cross contamination of fluids within the bore hole. Bucket-auger rigs are relatively simple, with few lubricated parts at positions likely to contaminate the test hole or monitoring well. They are capable of quite rapid drilling rates. Bucket-auger rigs are available at several locations statewide.

Disadvantages of bucket augering include the production of a large volume of cuttings and fluids (when operating within the saturated zone). When water-tight casing is not advanced concurrent with drilling, cross contamination of fluid-bearing intervals is likely. Bucket augering is generally limited to poorly lithified but cohesive sediments, but may continue even into sand and gravel if the hole is cased concurrent with the drilling process, or the hole is kept full of water. Even moderately lithified sediments usually are too resistant for bucket-auger rigs to penetrate.

Bucket augering is generally restricted to the more cohesive, yet unlithified sediments of the state. The method is well suited to drilling in glacial tills that make up most of the surficial deposits east of the Missouri River. Cretaceous shale, chalk, and sandstone underlying much of the area west of the Missouri River are difficult to impossible to drill using the bucket-auger method. Sediments containing abundant large boulders (like those along the high-gradient streams of the Black Hills), well lithified sediments, igneous and metamorphic rocks in the Black Hills, the Sioux Quartzite, and the Milbank Granite preclude bucket-auger drilling.

2.1.4 Direct-Mud rotary

In the direct-mud rotary method, the bore hole is advanced by rapid rotation of a drill bit mounted upon the end of drill rods. The bit cuts and breaks the material at the bottom of the hole into small pieces (cuttings). The cuttings are removed by pumping drilling fluid (water, or water mixed with bentonite or other fluid enhancers) down through the drill rods and bit and up the annulus between the bore hole and the drill rods. The drilling fluid also serves to cool the drill bit and stabilize the bore-hole walls, to prevent the flow of fluids between the bore hole and surrounding earth materials, and to reduce cross contamination between aquifers.

Direct-mud rotary drilling offers a number of advantages. It is a very fast and efficient means of drilling. Efficient rigs can produce several hundred feet of hole per day. The direct-mud rotary method can reach to several thousand feet in depth and create hole diameters to greater than 48 inches. The method is adaptable to a wide range of geologic conditions. Only exceptionally large, poorly stabilized boulders, or karst (cavernous) conditions are unsuited for direct-mud rotary drilling. Direct-mud rotary rigs are widely available throughout the state. Sediment sampling is broadly supported in direct-mud rotary drilling: standard split-barrel and thin-wall sampling are available in poorly lithified materials while a broad range of coring apparatus are supported for consolidated rock. Hydrologic conditions have little effect upon direct-mud rotary drilling; operations are usually unhindered by the presence of ground water. Direct-mud rotary drilling readily supports the telescoping of casings to successively smaller sizes to isolate drilled intervals and to protect lower geologic units from contamination by previously drilled, contaminated upper sediments.

Direct-mud rotary drilling has some inherent disadvantages for monitoring-well installation. If the drilling mud is not carefully engineered, drill fluids may invade permeable zones, compromising the validity of subsequent monitoring well samples from those intervals. The mud cake necessary for hole stability will usually interfere to some unknown extent by ionic exchange with the analysis of monitoring well water samples (U.S. Environmental Protection Agency, 1991). Organic compounds that are commonly added to drilling fluids may also interfere with chemical and physical tests on sediment samples. Poorly engineered drill fluids may produce difficult-to-remove mud cakes that inhibit the flow of fluids to the well. Relatively large volumes of cuttings and drilling fluids may provide containment problems and must be disposed of properly. At sites being monitored for hydrocarbons, inherently complex rotary rigs may introduce grease and oil to the monitoring system. Mud pumps, water swivels, rotary drives, rod connections, and drill-fluid components all may contribute hydrocarbons inadvertently to the system, despite the best decontamination/degreasing efforts. When water or other materials are introduced to the drill hole, those materials must be sampled and analyzed as control samples.

Despite these problems, direct-mud rotary drilling may sometimes be the best available alternative, especially for deep wells or wells completed into well lithified rocks. When direct-mud rotary methods are used, hole diameters should be 3 to 5 inches larger than the outer diameter of the well casings to allow effective placement of filter and sealing materials. Two-inch diameter monitoring wells should therefore be installed within 5.5-inch diameter or larger holes.

Direct-mud rotary drilling is well suited to most geologic conditions found in South Dakota. Only areas prone to lost circulation such as the karstic limestones of the Black Hills and bouldery formations such as found along high-gradient stream valleys in the Black Hills are beyond the capabilities of direct-mud rotary drilling.

2.1.5 Reverse-Air rotary

The reverse-air rotary method operates by the same general principles as direct-mud rotary except that compressed air is pumped down the drill rods and returns with the drill cuttings up through the annulus. The reverse-air rotary method is best suited to drilling in relatively stable to consolidated formations. Casing is sometimes used to prevent caving in poorly consolidated formations.

Reverse-air rotary drilling is a very fast and efficient means of drilling. Rigs that are properly equipped and staffed can drill several hundred feet of hole per day. The reverse-air rotary method can reach to several thousand feet in depth and create hole diameters up to approximately 17 inches. Reverse-air rotary rigs are unrestrained by karst (cavernous) terrain. Sediment sampling is supported both in poorly lithified materials (by split-barrel samplers) and in consolidated rock (by coring). Reverse-air rotary drilling supports the telescoping of casings to successively smaller sizes to isolate drilled intervals and protect lower geologic units from contamination by previously drilled contaminated upper sediments. Reverse-air rotary rigs are sometimes fitted with a casing driver to overcome bore hole instability problems in unconsolidated sediments. When so equipped, reverse-air rotary rigs minimize the potential for interaquifer contamination. Reverse-air rotary rigs are available at several locations in the state.

Reverse-air rotary drilling presents some disadvantages. In contaminated formations, the use of high-pressure air may pose a significant hazard to the drill crew due to rapid transport of contaminated material up the bore hole during drilling. Large volumes of hazardous gases may be discharged at the surface, posing an immediate hazard to the drill crew and others in the vicinity. Introduction of air to ground water could interfere with chemical analyses primarily by oxidation and by vigorous agitation and mixing. Concentrations of volatile contaminants are very likely to be reduced in ground water adjacent to holes drilled using the reverse-air rotary method. The air discharged from air compressors normally contain finely atomized lubricating oil. To help prevent this oil from contaminating monitoring well drill holes, compressor discharge filters must be installed (and maintained during regular intervals) on rigs used to drill monitoring wells. Air-discharge samples should be collected as reference samples for future comparison where hydrocarbon contamination is being studied. These samples are a necessity in applications where lubrication of down-the-hole hammers or other tools is essential. The use of foam additives to aid cuttings removal can also introduce organic contaminants into the monitoring system. These should be avoided, but where necessary, samples of the foaming agent must be taken as reference samples.

Cuttings above the water table are usually very fine and hard to interpret. Also, the drying effect of the air in the annulus may reduce or eliminate any natural moisture in the cuttings, thereby masking low yield water producing zones. Conversely, when high-yield aquifers are encountered, large volumes of water may be produced during drilling, a definite disadvantage if the water is contaminated and requires special handling and disposal.

When reverse-air rotary methods are used, hole diameters should be 3 to 5 inches larger than the outer diameter of the well casings to allow effective placement of filter and sealing materials. Two-inch diameter monitoring wells should therefore be installed within 5.5-inch diameter or larger holes.

2.1.6 Cable tool

Cable-tool drilling involves chipping and cutting earth materials by lifting and dropping a heavy, solid chisel-shaped bit, suspended on a steel cable from a truck-mounted rig. Steel casing is often used to keep the hole open during drilling in unstable materials. Casing is also used to isolate potentially contaminated strata.

In the context of monitoring-well drilling, the cable-tool method is unrestricted as to depth, diameters, and ability to penetrate geologic materials. The method is well suited to drilling both below and above the water table. Small volumes of easily contained cuttings are produced. Little or no outside drilling fluids are normally needed, and fluids which are used are primarily to facilitate cuttings removal by a bailer or sand pump. Detection and isolation of thin fluid bearing intervals and ease of well development is unsurpassed by any other drilling technique. Excellent sediment samples are obtainable. Successively smaller casing may be easily telescoped within previously installed casing to avoid carrying shallow contaminated materials into lower stratigraphic units. Sampling of soil and water during drilling and the installation of monitoring equipment is easily accomplished during cable-tool drilling. Cable-tool rigs are extremely simple with few lubricated parts at positions likely to contaminate the test hole or monitoring well. Some cable-tool rigs are dual purpose, also supporting rotary-drilling techniques.

The primary disadvantage of cable-tool drilling is its relatively slow rate of penetration. Cable tool drilling rates in South Dakota range from as low as 10 feet per day in Sioux Quartzite to rarely over 100 feet per day in glacial drift. Cable-tool rigs are becoming relatively rare. Only a few are now based in the state.

Sufficient annular space should be maintained between drilling casing and monitoring-well casing to allow effective placement of filter and sealing materials. Test holes or steel casing around the well casings should be 3 to 5 inches greater in diameter than the monitoring-well casings. Two-inch diameter monitoring wells should therefore be installed within a 5.5-inch diameter or larger test hole or drilling casing.

Cable-tool drilling is applicable throughout the state in all geologic and hydrologic conditions.

3.0 ADVANTAGES, DISADVANTAGES, AND INTERFERENCES OF THE DRILLING METHODS

3.1 Auger (hollow-stem, solid-stem, and bucket)

3.1.1 Advantages

- Allows accurate and useful soil sampling from different strata during drilling, especially from hollow-stem and solid-stem methods.

- Easy and relatively accurate water level detection during drilling.

- Relatively quick and efficient.

- For hollow-stem method: moderate amount of easily contained cuttings and well-development fluids generated; versatile; usually supports solid-stem, rotary, and coring techniques.

- For solid-stem method: small amount of easily contained cuttings and well-development fluids generated; versatile; often supports hollow-stem, rotary, and coring techniques.

- Available at several locations in the state.

- Relatively simple; few lubricated parts at positions likely to contaminate the test hole or monitoring well.

- Less well development is generally needed because little or no fluids are added during the drilling process that must be removed during the development process.

3.1.2 Disadvantages

- Difficult to impossible to penetrate bouldery formations.

- Cannot drill hard-rock formations.

- Generally poor, or cessation of, performance deeper than 100 feet.

- Often severe operational problems in caving formations and when encountering high hydrostatic pressures in the bore hole, especially with bucket and solid-stem augers.

- Potential for disturbing large volume of subsurface materials around the bore hole and therefore affecting local permeabilities and decreasing chances of effective sealing of monitoring-well annulus in certain geologic settings.

- Prone to cross contamination by free exchange of fluids between aquifers during drilling.

- Hollow-stem and solid-stem augers are likely to produce smeared clay bore hole wall seal in and above thicker clayey sediment intervals interfering with the flow of fluids to the monitoring well.

3.2 Rotary (direct-mud and reverse-air)

3.2.1 Advantages

- Quite fast; several hundred feet of bore-hole advancement per day is possible.

- Capable of drilling to full range of depths and diameters necessary for monitoring-well installation. Direct-mud rotary is limited only by large poorly supported boulders and cavernous formations; reverse-air rotary requires casing in poorly cohesive materials.

- Direct-mud rotary effective in all hydrologic conditions.

- Rotary drilling easily supports the telescoping of casing to isolate drilled intervals and prevent cross contamination of strata encountered during drilling.

- Supports a broad range of sampling (disturbed and undisturbed) in all types of geologic materials.

- Geophysical logs such as self potential and resistivity (which must be run in an uncased bore hole) may be run before well installation.

3.2.2 Disadvantages

- Potential cross contamination of strata exposed to the fluid circulation during drilling.

- In direct-mud rotary drilling, difficulty in removing mud residues during well development.

- In direct-mud rotary drilling, the mud may alter the ground-water chemistry in vicinity of monitoring well intake fixtures.

- In direct-mud rotary drilling, the drilling mud may decrease local permeability of the formation.

- Rotary drilling, with either mud or air methods, produces relatively large volumes of cuttings, drilling fluids, and well-development residue. If contaminated, these materials may potentially cause a severe disposal problem.

- Complex equipment may introduce lubricants to the monitoring system.

- In reverse-air rotary drilling, a large volume of potentially contaminated air is discharged at the surface, a potential threat to drill operators and surrounding area.

- In reverse-air rotary drilling, introduction of air to ground water may change ground-water chemistry.

3.3 Cable Tool

3.3.1 Advantages

- Allows for easy and accurate water and soil sampling; easy detection of water levels during drilling; can detect very thin permeable zones.

- Driven casing seals off formation, minimizes threat of cross contamination in pollution investigation.

- Usually successful in drilling through boulders.

- Unrestricted as to hole depth, diameter, and geologic and hydrologic conditions.

- Produces minimal volumes of cuttings which are easily contained; minimal or no well development necessary.

- Little or no outside drilling fluids necessary.

3.3.2 Disadvantages

- Extremely slow rate of drilling.
- Normally necessary to install one or more strings of steel-drilling casing.

4.0 EQUIPMENT

Verify that the drilling contractor will arrive onsite with all proper and operational equipment for the drilling program outlined in the work plan and contract. The geologist should bring at a minimum:

- Soil boring log forms
- Ruler and other measuring apparatus for verifying borehole depths, water levels, and equipment dimensions.
- All required health and safety gear (i.e., a hard hat, steel-toed boots, hearing and eye protection); refer to applicable OSHA and U.S. EPA guidance documents.
- Contaminant-detection equipment appropriate with information derived during the program-planning stage and in the site-safety plan.
- Sample-collection containers, plastic Ziploc® bags (quart and gallon sizes), or other containers, as appropriate.
- Trowels, knives, hammers, chisels, as appropriate.
- Description aids (Munsell-color charts, grain-size charts, etc.) as appropriate.

5.0 REAGENTS

No chemical reagents are used in this procedure. Decontamination of drilling equipment should follow the Standard Operating Procedures on Sampling Equipment Decontamination (SOP # 8) and a site specific work plan.

6.0 PROCEDURES

6.1 Drilling Equipment Cleaning and Decontamination

Prior to mobilization, the drill rig and all associated equipment should be thoroughly cleaned to remove all oil, grease, mud, etc. Any equipment that is not required at the site should be removed from the rig prior to entering the site. To the greatest extent possible, drilling should proceed from the least to most contaminated sections of the work site.

Before drilling each boring, all the down-the-hole drill equipment, the rig, and other equipment (as necessary) should be steam cleaned, or cleaned using high-pressure hot water, and rinsed with pressurized potable water to minimize cross contamination, if appropriate. Special attention should be given to the thread section of the casings and to the drill rods. Additional cleaning may be necessary during the drilling of individual holes to minimize the carrying of contaminated materials from shallow to deeper strata by contaminated equipment.

Equipment with porous surfaces, such as rope, cloth hoses, and wooden blocks or tool handles cannot be thoroughly decontaminated. These should be disposed of properly at appropriate intervals. These intervals may be the duration of drilling at the site, between individual wells, or between stages of drilling a single well, depending upon characteristics of the tools, site contamination, and other considerations.

Cleaned equipment should not be handled with soiled gloves. Surgical gloves, new clean cotton work gloves, or other appropriate gloves should be used and disposed of when even slightly soiled. The use of new painted drill bits and tools should be avoided since paint chips will likely be introduced to the monitoring system.

All drilling equipment should be steam cleaned or cleaned using high-pressure hot water, if appropriate, at completion of the project to ensure that no contamination is transported from the sampling site.

The Standard Operating Procedures on Sampling Equipment Decontamination (SOP # 8) should be consulted for further details.

6.2 Field Recording and Logging

Lithologic descriptions and all field measurements and comments should be recorded on the soil boring log form.

6.3 Test-Hole Abandonment

The South Dakota Well Construction Standards (ARSD 74:02:04:67) contain specific requirements for plugging and abandonment of test holes and wells. See the Standard Operating Procedure for Well and Test-Hole Abandonment (SOP #5) for details.

6.4 Handling of Drill Cuttings

See the Standard Operating Procedure for Well and Test-Hole Abandonment (SOP #5) and the Standard Operating Procedure for Investigation Derived Waste for information on the proper handling of drill cuttings.

7.0 CALCULATIONS

To maintain an open bore hole using sand or water rotary drilling, the drilling fluid must exert a pressure greater than the formation pore pressure.
The calculation for determining the hydrostatic pressure of the drilling fluid is:

Hydrostatic Pressure (psi) = Fluid Density (lb/gal) x Height of Fluid Column (ft) x 0.052

8.0 QUALITY ASSURANCE/QUALITY CONTROL

There are no specific quality assurance activities which apply to the implementation of these procedures. However, the following general quality assurance procedures apply:

- All data must be documented on standard soil boring log forms, field-data sheets of within field/site logbooks.

- All instrumentation and equipment must be operated in accordance with operating instructions as supplied by the manufacturer, unless otherwise specified in the work plan.

9.0 HEALTH AND SAFETY

The primary hazards associated with drilling operations are physical in nature. At a minimum, the following health and safety equipment should be used at all drilling operations to minimize hazards:

- Hard hat

- Work gloves

- Eye protection (when needed)

- Hearing protection (when needed)

Additional risks are incurred when drilling in a contaminated zone via exposure to the contaminants and/or increased physical hazard resulting from donning protective gear.

For further information on health and safety requirements, the reader is referred to EPA/REAC SOP #3012 REAC Health and Safety Guidelines for Activities at Hazardous Waste Sites wherein Subsection 4.9 outlines specific health and safety practices for drilling operations.

10.0 REFERENCES

U.S. Environmental Protection Agency, 1986, RCRA ground-water monitoring technical enforcement guidance document: Washington, D.C., Office of Waste Programs Enforcement, Office of Solid Waste and Emergency Response, OSWER-9950.1.

_____1991, Handbook of suggested practices for the design and installation of ground-water monitoring wells: Washington, D.C., Office of Research and Development EPA/600/4-89/034.