Standard Guide for
Use of Direct Rotary Wireline Casing Advancement Drilling Methods for Geoenvironmental Exploration and Installation of Subsurface Water-Quality Monitoring Devices[1]

This standard is issued under the fixed designation D 5876; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This guide covers how direct (straight) wireline rotary casing advancement drilling and sampling procedures may be used for geoenvironmental exploration and installation of subsurface water-quality monitoring devices.

NOTE 1—The term "direct" with respect to the rotary drilling method of this guide indicates that a water-based drilling fluid or air is injected through a drill-rod column to rotating bit(s) or coring bit. The fluid or air cools the bit(s) and transports cuttings to the surface in the annulus between the drill rod column and the borehole wall.

NOTE 2—This guide does not include all of the procedures for fluid rotary systems which are addressed in a separate guide, Guide D 5783.

1.2 The term "casing advancement" is sometimes used to describe rotary wireline drilling because at any time, the center pilot bit or core barrel assemblies may be removed and the large inside diameter drill rods can act as a temporary casing for testing or installation of monitoring devices. This guide addresses casing-advancement equipment in which the drill rod (casing) is advanced by rotary force applied to the bit with application of static downforce to aid in the cutting process.

1.3 This guide includes several forms of rotary wireline drilling configurations. General borehole advancement may be performed without sampling by using a pilot roller cone or drag bit until the desired depth is reached. Alternately, the material may be continuously or incrementally sampled by replacing the pilot bit with a core-barrel assembly designed for coring either rock or soil. Rock coring should be performed in accordance with Practice D 2113.

1.4 The values stated in both inch-pound and SI units are to be regarded separately as the standard. The values given in parentheses are for information only.

1.5 Direct rotary wireline drilling methods for geoenvironmental exploration will often involve safety planning, administration, and documentation. This guide does not purport to specifically address exploration and site safety.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

1.7 *This guide offers an organized collection of information or a series of options and does not recommend a specific course of action. This document cannot replace education or experience and should be used in conjunction with professional judgment. Not all aspects of this guide may be applicable in all circumstances. This ASTM standard is not intended to represent or replace the standard of care by which the adequacy of a given professional service must be judged, nor should this document be applied without consideration of a project's many unique aspects. The word "Standard" in the title of this document means only that the document has been approved through the ASTM consensus process.*

2. Referenced Documents

2.1 *ASTM Standards:*

D 420 Guide to Site Characterization for Engineering, Design, and Construction Purposes[2]

D 653 Terminology Relating to Soil, Rock, and Contained Fluids[2]

D 1452 Practice for Soil Investigation and Sampling by Auger Borings[2]

D 1586 Test Method for Penetration Test and Split-Barrel Sampling of Soils[2]

D 1587 Practice for Thin-Walled Tube Geotechnical Sampling of Soils[2]

D 2113 Practice for Diamond Core Drilling for Site Investigation[2]

D 2488 Practice for Description and Identification of Soils (Visual-Manual Procedure)[2]

D 3550 Practice for Ring-Lined Barrel Sampling of Soils[2]

D 4220 Practice for Preserving and Transporting Soil Samples[2]

D 4428/D4428M Test Methods for Crosshole Seismic Testing[2]

D 4630 Test Method for Determining Transmissivity and Storage Coefficient of Low-Permeability Rocks by In Situ Measurements Using the Constant Head Injection Test[2]

D 4631 Test Method for Determining Transmissivity and

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[1] This guide is under the jurisdiction of ASTM Committee D18 on Soil and Rockand is the direct responsibility of Subcommittee D18.21 on Ground Water and Vadose Zone Investigations.

Current edition approved Dec. 10, 1995. Published February 1996.

[2] *Annual Book of ASTM Standards*, Vol 04.08.

Storativity of Low-Permeability Rocks by In Situ Measurements Using the Pressure Pulse Technique[2]

D 4700 Guide for Soil Sampling from the Vadose Zone[2]

D 4750 Test Method for Determining Subsurface Liquid Levels in a Borehole or Monitoring Well (Observation Well)[2]

D 5079 Practices for Preserving and Transporting Rock Core Samples[2]

D 5088 Practice for Decontamination of Field Equipment Used at NonRadioactive Waste Sites[2]

D 5092 Practice for Design and Installation of Ground Water Monitoring Wells in Aquifers[2]

D 5099 Practice for Development of Ground Water Monitoring Wells in Aquifers[2]

D 5254 Practice for Minimum Set of Data Elements to Identify a Ground-Water Site[2]

D 5434 Guide for Field Logging of Subsurface Explorations of Soil and Rock[3]

D 5730 Guide to Site Characterization for Environmental Purposes with Emphasis on Soil, Rock, the Vadose Zone, and Ground Water[2]

D 5781 Guide for Use of Dual-Wall Reverse-Circulation Drilling for Geoenvironmental Exploration and Installation of Subsurface Water-Quality Monitoring Devices[3]

D 5782 Guide for Use of Direct Air-Rotary Drilling for Geoenvironmental Exploration and Installation of Subsurface Water-Quality Monitoring Devices[3]

D 5783 Guide for Use of Direct Rotary Drilling with Water-Based Drilling Fluid for Geoenvironmental Exploration and Installation of Subsurface Water-Quality Monitoring Devices[3]

D 5784 Guide for Use of Hollow-Stem Augers for Geoenvironmental Exploration and Installation of Subsurface Water-Quality Monitoring Devices[3]

D 5876 Guide for the Use of Direct Rotary Wireline Casing Advancement Drilling Methods for Geoenvironmental Exploration and the Installation of Subsurface Water-Quality Monitoring Devices[3]

3. Terminology

3.1 *Definitions*—Terminology used within this guide is in accordance with Terminology D 653 with the addition of the following:

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *bentonite*—the common name for drilling fluid additives and well-construction products consisting mostly of naturally occurring montmorillonite. Some bentonite products have chemical additives that may affect water-quality analyses.

3.2.2 *bentonite pellets*—roughly spherical- or disk-shaped units of compressed bentonite powder (some pellet manufacturers coat the bentonite with chemicals that may affect the water-quality analysis).

3.2.3 *cleanout depth*—the depth to which the end of the drill string (bit or core barrel cutting end) has reached after an interval of cutting. The cleanout depth (or drilled depth as it is referred to after cleaning out of any sloughed material in the bottom of the borehole) is usually recorded to the nearest 0.1 ft (0.03 m).

3.2.4 *coefficient of uniformity*— $C_u(D)$, the ratio D_{60}/D_{10}, where D_{60} is the particle diameter corresponding to 60 % finer on the cumulative particle-size distribution curve, and D_{10} is the particle diameter corresponding to 10 % finer on the cumulative particle-size distribution curve.

3.2.5 *drill hole*—a cylindrical hole advanced into the subsurface by mechanical means. Also known as a borehole or boring.

3.2.6 *drill string*—the complete rotary drilling assembly under rotation including bit, sampler/core barrel, drill rods, and connector assemblies (subs). The total length of this assembly is used to determine drilling depth by referencing the position of the top of the string to a datum near the ground surface.

3.2.7 *filter pack*—also known as a gravel pack or primary filter pack in the practice of monitoring-well installations. The gravel pack is usually granular material, having selected grain-size characteristics, that is placed between a monitoring device and the borehole wall. The basic purpose of the filter pack or gravel envelope is to act as: a nonclogging filter when the aquifer is not suited to natural development or, as a formation stabilizer when the aquifer is suitable for natural development.

3.2.7.1 *Discussion*—Under most circumstances, a clean, quartz sand or gravel should be used. In some cases, a prepacked screen may be used.

3.2.8 *head space*—on a double- or triple-tube wireline core barrel it is the spacing adjustment made between the pilot-shoe leading edge and the inner kerf of the outer-tube cutting bit. Spacing should be about 1⁄16 in. or roughly, the thickness of a matchbook. (The head-space adjustment is made by removing the inner-barrel assembly, loosening the lock nut on the hanger-bearing shaft and either tightening or loosening the threaded shaft until the inner barrel is moved the necessary distance, up or down, to obtain the correct setting. Reassemble the inner- and outer-barrel assemblies, attach the barrel to the drill rod or a wireline and suspend vertically allowing the inner-barrel assembly to hang freely inside the outer barrel on the inner hanger-bearing assembly. Check the head space. It is imperative that the adjustment is correct to ensure that the inner barrel is free to rotate without contacting the outer barrel. If incorrectly adjusted, the inner barrel will ′′hang up” and rotate with the outer barrel as the core is being cut. This will cause the core to break and block entry of core into the inner barrel.)

3.2.9 *grout shoe*—a drillable ′′plug” containing a check valve that is positioned within the lowermost section of a casing column. Grout is injected through the check valve to fill the annular space between the casing and the borehole wall or another casing.

3.2.9.1 *Discussion*—The composition of the drillable ′′plug” should be known and documented.

3.2.10 *grout packer*—an inflatable or expandable annular plug that is attached to a tremie pipe, usually positioned immediately above the discharge end of the pipe.

3.2.11 *intermittent sampling devices*—usually barrel-type samplers that are driven or pushed below the bottom of a borehole with drill rods or with a wireline system to lower,

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[3] *Annual Book of ASTM Standards*, Vol 04.09.

drive, and retrieve the sampler following completion of an increment of drilling. The user is referred to the following standards relating to suggested sampling methods and procedures: Practice D 1452, Test Method D 1586, Practice D 3550, and Practice D 1587.

3.2.12 *in-situ testing devices*—sensors or probes, used for obtaining mechanical- or chemical-test data, that are typically pushed, rotated, or driven below the bottom of a borehole following completion of an increment of drilling. However, some in-situ testing devices (such as electronic pressure transducers, gas-lift samplers, tensiometers, and so forth) may require lowering and setting of the device(s) in preexisting boreholes by means of a suspension line or a string of lowering rods or pipes. Centralizers may be required to correctly position the device(s) in the borehole.

3.2.13 *lead distance*—the mechanically adjusted length or distance that the inner-barrel cutting shoe is set to extend beyond the outer core-barrel cutting bit in order to minimize possible core-erosion damage that can be caused by the circulating drilling-fluid media. Lead distance is checked by vertically suspending the entire core-barrel assembly from a wireline or from a section of drill rod so that the inner-barrel can hang freely from the upper inner-barrel swivel assembly. The cutting shoe extension below the outer core-barrel cutting bit can then be checked. The ′′stiffer” or more competent the formation to be cored, the less the extension of the inner-barrel cutting shoe is necessary to avoid core erosion.

3.2.14 *overshot*—a latching mechanism located at the end of the hoisting line. It is specially designed to latch onto or release pilot bit or core-barrel assemblies.

3.2.15 *pilot bit assembly*—design to lock into the end section of drill rod for drilling without sampling. The pilot bit can be either drag, roller cone, or diamond plug types. The bit can be set to protrude from the rod coring bit depending on formation conditions.

3.2.16 *sub*—a substitute or adaptor used to connect from one size or type of threaded drill rod or tool connection to another.

3.2.17 *subsurface water-quality monitoring device*— an instrument placed below ground surface to obtain a sample for analyses of the chemical, biological, or radiological characteristics of subsurface pore water or to make in-situ measurements.

3.2.18 *wireline drilling*—a rotary drilling process which uses special enlarged inside diameter drilling rods with special latching pilot bits or core barrels which are raised or lowered inside the rods with a wireline and overshot latching mechanism.

4. Summary of Practice

4.1 Wireline drilling is a rotary drilling process that uses special enlarged inside diameter drilling rods with special latching pilot bits or core barrels which are raised or lowered inside the rods with a wireline and overshot latching mechanism. The bottom section of rod has either a diamond or carbide coring bit at the end and is specially machined to accommodate latching of either pilot bits or core barrels. The overshot mechanism is designed to latch and unlatch bit or barrel assemblies. Bit cutting is accomplished by application of the combination rotary and static down forces to the bit. General drill-hole advancement may be performed without sampling by using either a pilot roller cone or drag bit until the desired depth is reached. Alternately, the material may be continuously or incrementally sampled by replacing the pilot bit with a core-barrel assembly designed for coring either rock or soil.

4.2 The pilot bit or core barrel can be inserted or removed at any time during the drilling process and the large inside diameter rods can act as a temporary casing for testing or installation of monitoring devices.

5. Significance and Use

5.1 Wireline casing advancement may be used in support of geoenvironmental exploration and for installation of subsurface monitoring devices in both unconsolidated and consolidated materials. Use of direct-rotary wireline casing-advancement drilling methods with fluids are applicable to a wide variety of consolidated or unconsolidated materials as long as fluid circulation can be maintained. Wireline casing-advancement drilling offers the advantages of high drilling-penetration rates in a wide variety of materials with the added benefit of the large-diameter drilling rod serving as protective casing. Wireline coring does not require tripping in and out of the hole each time a core is obtained. The drill rods need only be removed when the coring bit is worn or damaged or if the inner core barrel becomes stuck in the outer barrel.

5.1.1 Wireline casing advancers may be adapted for use with circulating air under pressure for sampling water-sensitive materials where fluid exposure may alter the core or in cavernous materials or lost circulation occurs **(1, 2)**.[4] Several advantages of using the air-rotary drilling method over other methods may include the ability to drill rather rapidly through consolidated materials and, in many instances, not require the introduction of drilling fluids to the borehole. Air-rotary drilling techniques are usually employed to advance the borehole when water-sensitive materials (that is, friable sandstones or collapsible soils) may preclude use of water-based rotary-drilling methods. Some disadvantages to air-rotary drilling may include poor borehole integrity in unconsolidated materials when casing is not used and the possible volatilization of contaminants and air-borne dust. Air drilling may not be satisfactory in unconsolidated or cohesionless soils, or both, when drilling below the ground-water table. In some instances, water or foam additives, or both, may be injected into the air stream to improve cuttings-lifting capacity and cuttings return. Use of water or other additives, or both, should be documented. The use of air under high pressures may cause fracturing of the formation materials or extreme erosion of the borehole if drilling pressures and techniques are not carefully maintained and monitored. If borehole damage becomes apparent, other drilling method(s) should be considered.

5.1.2 When air is used as the circulating fluid, the user should consult Refs **(1, 2)** and Guide D 5782.

5.2 The application of wireline casing advancement to geoenvironmental exploration may involve sampling of ground

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[4] The boldface numbers given in parentheses refer to a list of references at the end of the text.

water, soil, or rock; or in-situ or pore-fluid testing; or installation of other casings for subsequent drilling activities in unconsolidated or consolidated materials.

5.3 The wireline drill rod can act as a temporary casing and may be used to facilitate the installation of a monitoring device. The monitoring device may be installed as the drill rod is removed from the drill hole.

NOTE 3—The user may install a monitoring device within the same drill hole wherein sampling or in-situ testing was performed.

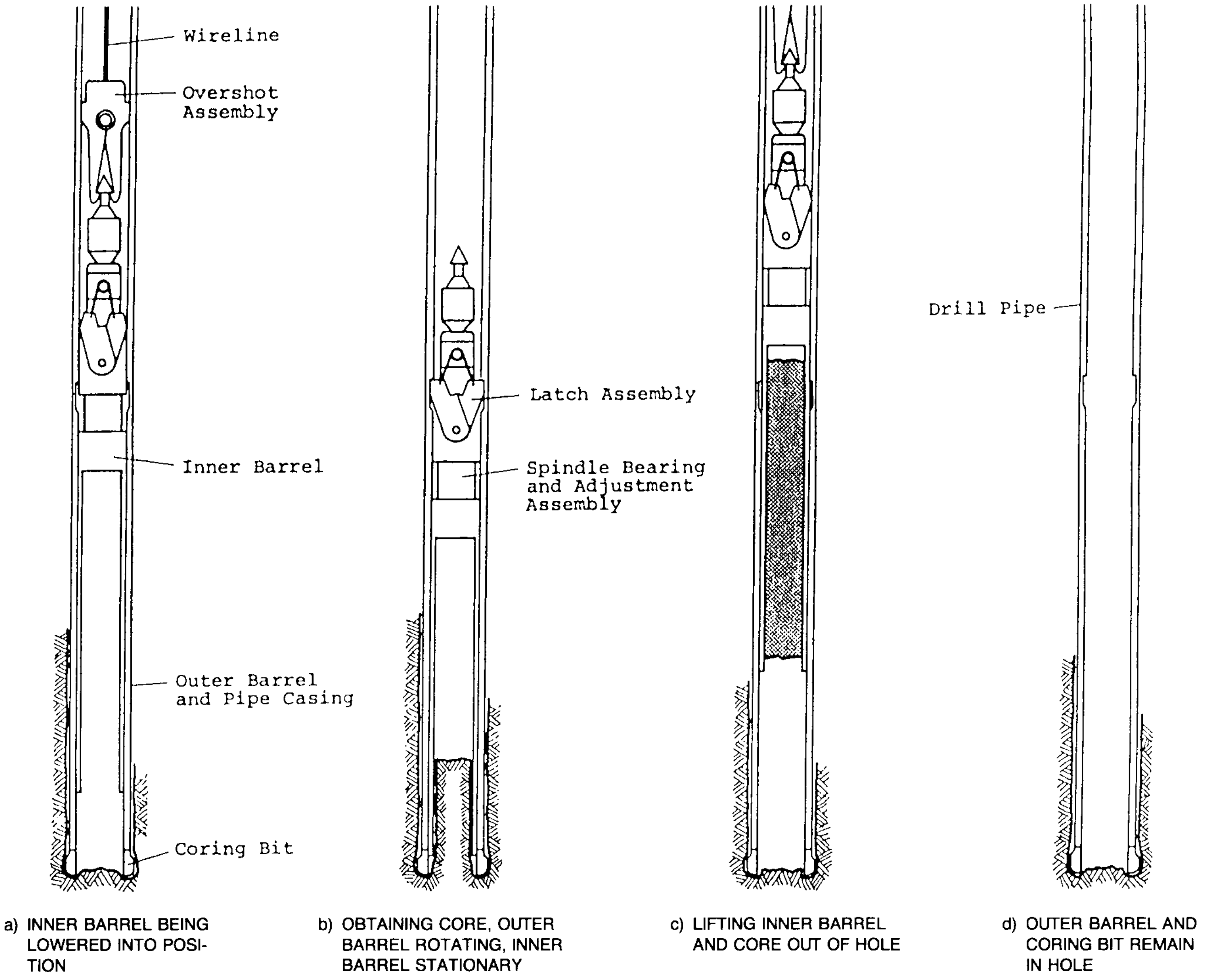
5.4 Wireline casing-advancement rotary-drilling methods use fluid or air circulation to lubricate cutting bits and for removal of drill cuttings. In many cases, additives are added to improve circulation, cuttings return, borehole wall stabilization, and sealing of the borehole wall from fluid loss. The use of fluid or air under high pressures may allow for damage to formation materials by fracturing or excessive erosion if drilling conditions are not carefully maintained and monitored. If undesirable formation damage is occurring or evident, other drilling method(s) should be considered.

6. Apparatus

6.1 *General*—Direct rotary wireline casing advancement systems and procedures used for geoenvironmental exploration and subsurface water-quality monitoring device installations include direct air or mud-rotary drilling using wireline drill rods. The wireline drill rod has a large inside diameter and is equipped with either a wireline-retrievable center pilot bit for general hole advancement, or a rock- or soil-core barrel for sampling the borehole as it is advanced. Fig. 1(*a* through *d*) shows basic schematics of the components of a wireline-drilling assembly using a rock core-barrel assembly to sample formations as drilling progresses.

6.2 The basic mechanical components of wireline casing-advancement drilling systems include the drill rig with either hollow spindle or top-head drive, drill rods, coring or casing bits, overshot assembly, pilot bit, or core barrel. Water-based fluid circulation systems require drill fluid, mud pit, suction hose, drill fluid circulation pump, pressure hose, and swivel. Air circulation systems require an air compressor, dust collector, air cleaning device, pressure hose, and swivel.

6.2.1 *Drill Rig*—Most top-head drive or hollow-spindle drills are suitable for performing rotary wireline drilling. Rock-coring drills with smooth hydraulic operation and high



a) INNER BARREL BEING LOWERED INTO POSITION
b) OBTAINING CORE, OUTER BARREL ROTATING, INNER BARREL STATIONARY
c) LIFTING INNER BARREL AND CORE OUT OF HOLE
d) OUTER BARREL AND CORING BIT REMAIN IN HOLE

FIG. 1 Schematics of Wire-Line Drilling Assembly

RPM capability are desirable for rock-coring operations. Rotary table and kelly drills generally are not acceptable for wireline-drilling use due to difficulty or inability to raise and lower wireline assemblies. The drill unit should have the ability to rotate a drill-rod column and apply a controllable axial force on the drill bit appropriate to the drilling and sampling requirements and the geologic conditions.

6.2.2 *Drill Rods*, transfer force and rotation from the drill rig to the bit or core barrel. When rotary drilling is stopped, the large inside diameter wireline drill rod acts can as casing, that is, by preventing against hole collapse—to allow for testing or installation of monitoring devices for hole protection. Drill rods conduct drilling fluid to the bit or core barrel. Individual drill rods (that is, drill stem, drill string, drill pipe) should be straight so they do not contribute to excessive vibrations or "whipping" of the drill-rod column. All threaded connections should be in good repair and not leak significantly at the internal fluid pressure required for drilling. Drill rods should be made up securely by wrench tightening at the threaded joint(s) at all times to prevent rod damage.

6.2.2.1 Wireline drill rod dimensions are not fully standardized. The available sizes depend on the manufacturing sources **(3)**. General hole diameter available from most manufacturers follows the Diamond Core Drill Manufacturers Association (DCDMA) size conventions of A (48-mm), B (59.9-mm), N (75.7-mm), H (96.3-mm), and P (122.6-mm) sizes **(4)**. Inside diameter varies depending on the manufacturer.

NOTE 4—Sizes of casings, casing bits, drill rods, and core barrels are standardized by the DCDMA and the American Petroleum Institute (API). Refer to Ref **(4)** for available sizes and capacities of common use drilling equipments for soil and rock exploration.

6.2.2.2 The wireline lead rod contains shoulders for latching of pilot bits or core barrels. All wireline lead-rod sections are equipped with coring or casing bits. There are many configurations of wireline drilling equipment possible depending on the manufacturer. With rock-coring systems, the wireline lead rod is equipped with a reaming shell to ensure circulation and act as a stabilizer. Some multipurpose systems allow for latching of pilot bit, rock-core barrel, or soil-core barrel to the lead wireline rod section. In most coring operations the lead wireline rod is considered to be the outer barrel in a double- or triple-tube core barrel design (see Practice D 2113). The bit is referred to as a core bit.

6.2.2.3 The wireline rod size is usually selected to provide a drill hole of sufficient diameter for the required sampling, testing, or insertion of instrumentation-device components, such as, the screened intake and filter pack and installation devices such as a tremie pipe. The inside diameter of the wireline rod should permit easy insertion and retraction of a sampler or a pipe with a sufficiently large inside diameter to accommodate the placement of completion materials adjacent to the screened intake and riser of an instrumentation device. Coring bits are selected to provide adequate required hole or core diameter, or both. Selection of protective casings, bits, and core barrels is made by considering size requirements listed above combined with: annulus circulation capabilities of drill rod used, and the need for tapering from larger to smaller diameters casings ("nesting" of casing) if difficult drilling conditions occur (lost circulation, zones of contamination, and so forth) requiring these problem zones in the borehole to be cased off.

NOTE 5—Drill rods usually require lubricants on the threads to allow easy threading and unthreading of the drill-rod tool joints. Some lubricants have organic or metallic constituents, or both, that could be interpreted as contaminants if detected in a sample. Various lubricants are available that have components of known chemistry. The effect of drill-rod lubricants on chemical analyses of samples should be considered and documented when using direct-rotary drilling. The same consideration and documentation should be given to lubricants used with water swivels, hoisting swivels, or other devices used near the drilling axis.

6.2.3 The casing bit or core bit provides the material cutting capability. In coring operations, the bit is referred to as a core bit. Rock coring should be performed in accordance with Practice D 2113. Soil sampling or coring methods, some of which are listed in 2.2, can also be used to obtain samples. When drilling in a casing-advancement mode using a pilot bit, without sampling, the bit is referred to as a casing bit.

6.2.3.1 Numerous coring or casing bits can be selected depending on the properties of the formation to be drilled or cored. Since it is undesirable to remove the outer bit, design of this bit is extremely important. When coring, particularly in unconsolidated materials, it is important that the bit cuts the material and not merely tears it and pushes it aside. Some bit types successfully used include either carbide inserts coring bits or diamond core bits. In rock-coring operations the kerf design inner gage of bit, matrix cutting capacity, and location of drilling-fluid circulation ports are important. The inner gage of the bit can be selected so that the core is slightly undercut, thereby allowing it to move freely up the inner tube and not cause core blockage. If the core is over cut and air is present in the barrel, consideration should be given to possible alteration of the core that may occur during subsequent sealing and storage of the core obtained. It is beyond the scope of this guide to recommend bit styles. Bit selection can be aided by review of literature **(1, 2, 3, 5, 6)** and consultation with manufacturers.

6.2.3.2 The dimensions of the coring or casing bits often control the maximum diameter of testing or sampling device that can be inserted through the wireline drill rods. As mentioned previously, the bit size is usually selected to provide a drill hole of sufficient diameter for required borehole sampling or testing to be accomplished or for insertion of instrumentation device components such as the screened intake, riser pipe, filter pack, and well-completion installation devices such as a tremie pipe in the borehole.

6.2.4 *Wireline Retrievable Pilot-Bit Assembly*, used when no borehole coring/sampling is desired. The assembly is equipped with a receiver for pickup by the overshot latching assembly. Several pilot-bit styles are available including roller cone and drag bit configurations. Bit selection can be aided by review of literature **(1, 2, 3, 5, 6)** and consultation with manufacturers.

NOTE 6—Bottom-discharge bits are those having drill-fluid circulation discharge ports in direct contact with the base of the hole. If these bits are used to drill loose cohesionless materials, jetting or excessive erosion of the test intervals could occur.

6.2.5 *Overshot*, a latching retrieval assembly that is lowered into the hole with a wireline hoist cable to either retrieve or lower core-barrel inner assemblies or bits equipped with an upper retrieval spear and downhole latching assemblies.

NOTE 7—When lowering a latching bit assembly or retrievable inner-core barrel assembly into a dry hole, a retrievable dry-hole lowering tool should be employed to prevent damaging the outer bit kerf, matrix, or latching assemblies, or combination thereof. Inner tools should not be allowed to free-fall down the drill rod in a dry hole.

6.2.6 *Wireline Core Barrels*, available for obtaining continuous samples of soil or rock. The barrels for use in coring rock vary in design and manufacture from those barrels used for coring unconsolidated materials. The best core recovery in rock usually requires a double- or triple-tube, swivel-type design. The inner tube of the rock core barrel consists of a core-lifter case and core lifter that threads onto the lower end of the inner tube. On the upper end of the inner tube is a removable threaded inner-tube head swivel-bearing assembly with an inner-tube latching device and release mechanism. The inner-tube latching device locks into a complementary recess in the wall of the lead outer drill rod such that the drill rod may be rotated while the inner tube remains stationary. The use of split inner tubes or split inner-tube liners inside a solid inner-tube barrel facilitates easier handling, inspection, and removal of the core from the core barrel.

6.2.6.1 Several types of soil core barrels are also available. Most barrels have a cutting shoe that is either flush with the outer tube cutting bit or, it is made to extend past the outer tube core bit. Sample barrels may be of either the solid- or split-tube configuration. Some barrels may also be equipped with either a split tube or solid tube inner liner to minimize exposure of the core to fluids or other materials. Important considerations for optimum sampling results and maximum core recovery are: use of the "correct" lead distance of the inner barrel cutting shoe, using the "optimum" clearance ratio or head space of the cutting shoe, and prevention of inner-barrel rotation. (For optimum core recovery and minimum core damage the user is referred to 3.2.7 and 3.2.13 for making proper lead-distance or head-space adjustments of the inner-barrel cutting shoe.) The lead distance of the cutting shoe ahead of the cutting bit depends on the stiffness of the formations to be sampled. Stiffer materials require less lead distance.

6.2.6.2 The clearance ratio or head space of the cutting shoe with respect to inner barrel should be selected to result in core that fills the barrel without excessive compression of the core due to friction. If the clearance ratio is too great and the core is over cut, core-erosion damage may occur. If core is over cut and air is present in the barrel, alteration of the soil may occur during subsequent packaging, sealing, and storage of the core(s). Use of single-tube split barrels below the water table may expose soil cores to fluids present in the drill rod.

6.2.7 *Pressure Hose*, conducting the drilling fluid from the circulation pump to the swivel.

6.2.8 *Swivel*, directing the drilling fluid to the rotating kelly or drill-rod column.

6.3 *Rotary Wireline Drilling*, with water-based drilling fluids.

6.3.1 *Mud Pit*, a reservoir for the drilling fluid and, if properly designed and utilized, provides sufficient flow velocity reduction to allow separation of drill cuttings from the fluid before recirculation. The mud pit is usually a shallow, open metal tank with baffles; however, for some circumstances, an excavated pit with some type of liner, designed to prevent loss of drilling fluid and to contain potential contaminants that may be present in the cuttings, may be used. The mud pit can be used as a mixing reservoir for the initial quantity of drilling fluid and, in some circumstances, for adding water and additives to the drilling fluid as drilling progresses.

NOTE 8—Some drilling-fluid components must be added to the composite mixture before other components; consequently, an auxiliary mixing reservoir may be required to premix these components with water before adding to the mud pit. All quantities and types of drilling-fluid components and additives used in the composite drilling-fluid mixture should be documented.

6.3.2 *Suction Hose*, sometimes equipped with a foot valve or strainer, or both, conducts the drilling fluid from the mud pit to the drilling-fluid circulation pump.

6.3.3 *Drilling-Fluid Circulation Pump*, having the capability to lift the drilling fluid from the mud pit and move it through the system against variable pumping heads at a flow rate to provide an annular velocity that is adequate to transport drill cuttings out of the drill hole.

6.3.3.1 Fluid pressures at the bit should be as low as necessary to maintain circulation in order to minimize hydraulic fracturing or excessive erosion of the surrounding materials. Fluid pressures should be monitored during drilling. Normally, injection fluid pressures are readily monitored. Changes in fluid return and circulation pressures may indicate occurrence of excessive erosion, formation fluid loss, or formation fracturing. Any abrupt changes or anomalies in the fluid pressures should be duly noted and documented including the depth(s) of occurrence(s).

6.3.4 *Drilling Fluid*, usually consisting of a water-based circulation media and one or more additives that increase viscosity or provide other desirable physical or chemical properties. Principal functions of drilling fluid include: sealing the drill hole wall to minimize loss of drilling fluid, providing a hydraulic pressure against the drill-hole wall to support the open drill hole, removing cuttings generated at the bit, and lubricating and cooling of the bit. Drilling-fluid management requires considerable experience for successful use. Drilling-fluid program design can be aided by review of literature **(1, 3, 4, 5, 6)** and consultation with manufacturers. If changes to the circulating medium are made, the depth(s) or interval(s) of these changes should be documented. Samples of cuttings can be collected for analysis of materials being penetrated. If samples are taken, the depth(s) and interval(s) should be documented.

NOTE 9—Particular attention should be given to the drilling-fluid makeup-water source and the means used to transport the makeup water to the drilling site as potential sources of contamination in the drilling fluid. If the chemical makeup of the water is determined the test results should be documented.

6.3.4.1 Some commonly used additives for water-based drilling fluids are listed in 6.3.4.2-6.3.4.10.

6.3.4.2 Beneficiated bentonite, a primary viscosifier and borehole sealer, consists of montmorillonite with other naturally occurring minerals and various additives such as sodium carbonate or polyacrylates, or both.

6.3.4.3 Unbeneficiated bentonite, a primary viscosifier and drill hole sealer, consists of montmorillonite with other naturally occurring minerals but without additives such as sodium carbonate or polyacrylates.

6.3.4.4 Sodium carbonate powder (soda ash) is used to precipitate calcium carbonate hardness from the drilling fluid water-base before adding other components. An increase in pH will occur with the addition of sodium carbonate. Sodium hydroxide (caustic soda) generally should not be used in this application.

6.3.4.5 Carboxylmethylcellulose powder (CMC) is sometimes used in a water-based fluid as a viscosifier and as an inhibitor to clay hydration.

NOTE 10—Some additives to water-based drilling-fluid systems retard clay hydration, thus inhibiting swelling of clays on the drill-hole wall and inhibiting “balling” or “smearing” of the bit.

6.3.4.6 Potassium chloride (muriated potash) or diammonium phosphate can be used as an inhibitor to clay hydration.

6.3.4.7 Polyacrylamide, a primary viscosifier and clay-hydration inhibitor, is a polymer that is mixed with water to create a drilling fluid.

6.3.4.8 Barium sulfate increases the density of water-based drilling fluids. It is a naturally occurring high specific gravity mineral processed to a powder for rotary drilling-fluid applications.

6.3.4.9 Lost-circulation materials are used to seal the borehole wall when fluids are being lost through large pores, cracks, or joints. These additives usually consist of various coarse-textured materials such as shredded paper or plastic, bentonite chips, wood fibers, or mica.

6.3.4.10 Attapulgite, a primary viscosifier for rotary drilling in high-salinity environments, is a clay mineral drilling-fluid additive.

NOTE 11—The listing and discussion of the above drilling-fluid additives does not imply general acceptance for geoenvironmental exploration. Some of the additives listed above may impact water-quality analyses. Some readily available, but not as common, drilling-fluid additives, not listed above, could cause significant contamination in a borehole or hydrologic unit. Each additive should be evaluated for each specific application. The types, amounts, and chemical compositions of all additives used should be documented. In addition, a hole log should document the depths where any new additives were introduced. Methods to break revertible fluids should be documented.

If drilling-fluid additives, such as any of those previously mentioned, cannot be tolerated it is recommended that other drilling method(s) be considered by the user.

6.4 *Rotary Wireline Drilling*, using air as the circulation medium:

6.4.1 *Air Compressor*, providing an adequate volume of air, without significant contamination, for removal of cuttings. Air requirements will depend upon the drill rod and bit configuration, the character of the material penetrated, the depth of drilling below ground water level, and the total depth of drilling. The airflow rate requirements are usually based on an annulus upflow air velocity of about 1000 to 1300 m/min (about 3000 to 4000 ft/min) even though air-upflow rates of less than 1000 m/min are often adequate for cuttings transport. In order to maintain air circulation between the annulus of the hole wall and large-diameter drill rods, special reaming shells may be required **(2)**. For some geologic conditions, air-blast erosion may increase the borehole diameter in easily eroded materials such that 1000 m/min may not be appropriate for cuttings transport. Should air-blast erosion occur, the depth(s) of the occurrence(s) should be noted and documented so that subsequent monitoring equipment installation quality may be evaluated accordingly.

NOTE 12—The quality of compressed air entering the borehole and the quality of air discharged from the borehole and the cyclone separator must be considered. If not adequately filtered, the air produced by most oil-lubricated air compressors inherently introduces a significant quantity of oil into the circulation system. High-efficiency, in-line, air filters are usually required to prevent significant contamination of the borehole.

6.4.2 *Pressure Hose*, conducting the air from the air compressor to the swivel.

6.4.3 *Swivel*, directing the air to the rotating kelly or drill-rod column.

6.4.4 *Dust Collector*, conducting air and cuttings from the borehole annulus past the drill-rod column to an air cleaning device (cyclone separator).

6.4.5 *Air-Cleaning Device*, (cyclone separator) separates cuttings from the air returning from the borehole by means of the dust collector.

NOTE 13—A properly sized cyclone separator can remove practically all of the cuttings from the return air. A small quantity of fine particles, however, are usually discharged to the atmosphere with the “cleaned” air. Some air-cleaning devices consist of a cyclone separator alone; whereas, some utilize a cyclone separator combined with a power blower and sample-collection filters. It is virtually impossible to direct the return “dry” air past the drill rods without some leakage of air and return cuttings. Samples of drill cuttings can be collected for analysis of materials penetrated. If samples are obtained, the depth(s) and interval(s) should be documented.

NOTE 14—Zones of low air return also zones of no air return should be documented. Likewise, the depth(s) of sampled interval(s) and quality of samples obtained should be documented.

NOTE 15—Compressed air alone can often transport cuttings from the borehole and cool the bit. For some geologic conditions, injection of water into the air stream will help control dust or break down “mud rings” that tend to form on the drill rods. If water is injected the depth(s) of water injection should be documented. Under other circumstances, for example, if the borehole starts to produce water, the injection of a foaming agent may be required. The depth when a foaming agent is added should also be recorded. When foaming agents are used, a cyclone-type cuttings separator is not used and foam discharge accumulates near the top of the borehole. When contaminants are encountered during drilling and returning from the borehole at geoenvironmental-exploration sites, special measures should be taken to contain the foam and protect personnel and the environment. Therefore, added water and some available foaming agents could affect water-quality analyses. The need for chemical analysis of added water or foaming agents should be considered and documented.

7. Drilling Procedures

7.1 As a prelude to and throughout the drilling process, stabilize the drill rig and raise the drill-rig mast. Surface casings can be installed using a variety of drilling methods. The surface casing is normally backfilled, pressed, or sealed in place with bentonite or cement, or both. Establish and document a datum for measuring hole depth. This datum normally consists of a stake driven into the stable ground surface, the top of the surface casing, or the drilling deck. If there is a possibility for movement of the surface casing it should not be used as a datum. If the hole is to be later surveyed for elevation, record and report the height of the datum to the ground surface.

7.1.1 For water-based fluid drilling operation, position a mud pit to collect and filter fluid return flow. Mix an initial quantity of drilling fluid, usually using the mud pit as the primary mixing reservoir.

NOTE 16—The need for chemical analysis of samples of each drilling-fluid component and the final mixture should be documented.

7.1.2 For air-based circulation systems, position the dust collector or cyclone separator and "seal" to the ground surface. If air-monitoring operations are performed, consider the prevalent wind direction relative to the exhaust from the drill rig. Also, consider the location of the cyclone relative to the rig exhaust since air-quality monitoring will be performed at the cyclone separator discharge point.

NOTE 17—Deeper casing(s) or nested casing(s) may be required to facilitate adequate downhole fluid circulation and hole control. Records of casing(s) lengths and depth intervals installed should be maintained and documented if required. All casing used should be decontaminated according to Practice D 5088 prior to use.

NOTE 18—Check above the drilling rig for overhead obstructions or hazards, such as power lines prior to raising the mast. In most cases, it is required to perform a survey of underground and all other utilities prior to drilling to evaluate possible hazards.

7.2 Drilling usually progresses as follows:

7.2.1 Attach an initial assembly of lead drill rod and a bit or core barrel below the top-head drive unit with the bit or drill head placed within the top of the surface casing. Record hole depth by knowing the length of the rod-bit assemblies and comparing its position relative to the established surface datum.

NOTE 19—The drill rig, drilling, hoisting and sampling tools, the rotary gear or chain case, the spindle and all components of the rotary drive above the drilling axis should be cleaned and decontaminated according to Practice D 5088 prior to commencing drilling and sampling operations.

7.2.2 Activate the drilling-fluid circulation pump, causing drilling fluid to circulate through the system including the mud pit.

7.2.3 Initiate rotation of the bit and apply axial force to the bit.

7.2.4 Initiate drilling fluid or air circulation and apply rotation and axial force to the bit until drilling progresses to a depth where sampling or in-situ testing will be performed, the length of the drill-rod column limits further penetration, or (when core drilling) the core specimen has fully entered the core barrel or blockage is apparent. Monitor downfeed pressures, fluid/gas pressure, and circulations return during drilling. Observe the ease of drilling during drilling, and drill cuttings as they relate to the geologic strata being penetrated. Document occurrences of any significant abrupt changes and anomalies that occur during drilling.

7.2.4.1 During air drilling operations air-quality monitoring may be required. If air-quality monitoring is performed, document the sampled intervals and air-quality data.

NOTE 20—If circulation is lost and input fluid pressure is allowed to increase, the possibility of fracturing materials and excessive drill hole erosion exists.

NOTE 21—The time required to remove the cuttings from the drill hole will depend mainly upon the pumping rate, the cross-sectional area of the borehole annulus, the borehole depth, the viscosity of the drilling fluid, and the size of the cuttings.

7.2.5 Stop rotation, lift the bit slightly off the bottom of the hole to facilitate drill-cuttings removal, and continue circulation for a short time until the drill cuttings are removed from the borehole annulus. If sampling is to be done, stop circulation and rest the bit on the hole bottom to determine hole depth. Document the hole depth and amount of any caving that occurred.

7.2.6 Increase drilling depth by attaching an additional drill-rod section to the top of the previously advanced drill-rod column and resuming drilling operations according to 7.2.2-7.2.4.

NOTE 22—Drilling rates depend on many factors such as the density or stiffness of unconsolidated material and the existence of cobbles or boulders, the hardness or durability of the rock, or both, the swelling activity of clays or shales encountered in the borehole, and the erosiveness of the wall. Drilling rates can vary from a few mm/min (less than an in./min) to about a m/min (3 ft/min), depending on subsurface conditions. Other factors influencing drilling rates include the weight of the drill string, collar(s) weight and size of drill pipe, and the rig pulldown or holdback pressure. These data as well as any other drilling-rate information should be recorded.

7.2.7 In some cases it may be necessary to remove the pilot bit or core barrel during the drilling process. Remove core barrels when full or there is evidence of core blockage and loss of circulation. Remove pilot bits for sampling events, when worn, or when there is evidence of circulation blockage. When replacing the pilot bit or core barrel note the condition of the base of the boring and any difficulty latching the assembly. If heave is present it may be necessary to lift the drill rod to engage the locking mechanism. When drilling in unconsolidated materials it is recommended to use a vented hoisting plug when removing the inner bit or continued circulation to avoid "heaving," "piping," or "sanding in" problems.

7.2.8 In some cases it may be necessary to remove the drill-rod string to change the lead-rod bit. If the string is removed and replaced, check the depth to the base of the boring where the end of the string rests and compare to the cleanout depth to evaluate hole quality. If excessive hole cave or erosion is suspected, casing may be required to protect the borehole wall. As the drilling progresses, note and document drilling procedures such as circulation rates or losses, intervals where equipment is changed, intervals where casing is installed, or drilling method is changed.

7.2.9 *Continuous Sampling with Rock- or Soil-Core Barrels*—Continuous coring can be performed by using core barrels designed for rock or soil coring. Rock coring is performed in accordance with Practice D 2113. Soil coring follows similar procedures. When replacing the core barrel, note the elevation of the base of the boring. Record the sampling length and measure core recovery. If blockage of core and circulation loss is noted during the sampling process, the sample should be recovered.

7.2.10 Sampling or in-situ testing can be performed at any depth by interrupting the advance of the bit, stopping the fluid circulation (after cleaning the annulus of cuttings) and removing pilot bit from the drill-rod column. If there are apparent cuttings or evidence of caving, these should be noted as part of the sample taken. Drill-rod removal is not necessary when a sample can be obtained or an in-situ test can be performed through the hollow axis of the drill rods and bit.

7.2.10.1 Some sampling method may be performed through the drill-rod column (see Test Method D 1586, Practice D 1587, Practice D 2113, and Practice D 3550). Compare sampling depth to the cleanout depth. Verify the depth-comparison data by first resting the sampler on the bottom of the hole and comparing that measurement with the cleanout-depth measurement. This should be done before every sampling or in-situ testing is performed in the hole. If bottom-hole sloughing is apparent from a depth measurement made prior to sampling (determined by comparing the hole-cleanout depth with the sampling depth) it may be necessary to reclean the hole by rotary recirculation. Record the depth of in-situ testing or sampling as well as the depth below the sampler/bit for evaluation of data quality. Decontaminate sampling and testing devices according to Practice D 5088 prior to testing.

7.2.10.2 Perform in-situ testing at the base of the drill hole or at shallower depths if the hole is uncased. If in-situ testing is performed at the base of the borehole similar depth, perform checks to accurately document the location of the test.

7.2.10.3 Water testing is frequently performed in consolidated deposits by pulling back on the drill rods and passing inflatable packer(s) with pressure fittings for water injection through the drill rod to test the open borehole wall (see Test Methods D 4630 and D 4631). Record the depths or intervals of water tests performed.

7.2.10.4 Air drilling may not be satisfactory in unconsolidated or cohesionless soils, or both, under the ground water table. One problem is “heaving” or “sanding in” of sands during pilot-bit removal. Another problem with wet clays is bit plugging and formation of mud rings which may cause loss of circulation. If the purpose of the drilling is to perform in-situ tests or undisturbed sampling, and soil instability is evident from unbalanced hydrostatic pressure or pilot-bit disturbance, give consideration to using fluids or other casing-advancement methods where disturbance may be more readily controlled.

7.3 When drilling must progress through material suspected of being contaminated, installation of single or multiple (nested) casings may be required to isolate zones of suspected contamination. Isolation casings are usually installed in a predrilled borehole or by using a casing-advancement method. A grout seal is then installed, usually by applying the grout at the bottom of the annulus with the aid of a grout shoe or a grout packer and a tremie pipe. Allow the grout to set before drilling activities are continued. Document complete casing and grouting records, including location(s) of nested casings for the hole.

8. Installation of Monitoring Devices

8.1 Subsurface water-quality monitoring devices are generally installed in boreholes drilled by wireline casing-advancement methods using a three-step procedure. The three steps are: (*1*) drilling, with or without sampling, (*2*) removal of the pilot bit or core barrel and placement of the monitoring device, and (*3*) addition of other materials such as filter packs, seals, and grouts as the drill rods are removed. During placement of filter packs and seals the drill rods may be lifted in increments to be backfilled. Place tremie rods between riser and drill-rod wall to extend past the end of the drill rods for placement increments. The retraction increments depend on the anticipated borehole wall stability. Alternately, if borehole conditions are stable the complete drill-rod column may be removed prior to placement of the monitoring device.

NOTE 23—Document the volumes of emplaced filter packs and seals and compare the results to actual volumes of cuttings return based on hole diameter for evaluation of hole quality.

8.2 Assemble water-quality monitoring devices, with attached fluid conductors (risers), and insert into the borehole with the least possible addition of contaminants. The user is referred to Practice D 5092 for monitoring-well installation methods and Practice D 5088 for suggested methods of field equipment decontamination.

NOTE 24—If the integrity of the borehole wall will not be compromised by removing the filter cake from the borehole in the vicinity of the screened-intake device the drilling mud should be removed using a well-development procedure as suggested in Practice D 5099 prior to inserting a monitoring well or a water-quality monitoring device in the borehole.

8.2.1 Some materials, such as screens and risers, require cleaning or decontamination, or both, at the job site (see Practice D 5088).

8.2.2 Prior to installation, store all monitoring-device materials undercover and place upwind and well away from the drill rig and any other sources of contamination such as electrical generators, air compressors, or industrial machinery.

8.2.3 Clean and decontaminate hoisting tools, particularly wire rope and hoisting swivels, according to Practice D 5088 before using.

8.3 Select and install filter materials, bentonite pellets, granules and chips and grouts according to specific subsurface-monitoring requirements. Document this information.

NOTE 25—Filter packs for monitoring devices are usually installed in wireline casing-advancement drill holes using a tremie pipe inserted in the annulus formed between the drill rod or borehole wall (when drill rods are removed) and the monitoring device. The minimum annulus between riser pipe and drill rod or borehole wall should be about 1-in. (25.4 mm) completely around the riser pipe. The sizes of wireline drill rod are limited and the riser size may have to be reduced to accommodate placement clearances (see 6.2.2).

8.3.1 Monitoring devices installed in a saturated zone typically have sand-sized filter packs selected on the basis of the grain-size characteristics of the hydrologic unit adjacent to the screened intake. Filter-pack materials are usually selected with a coefficient of uniformity of less than 2.5. Filter packs for vadose-zone monitoring devices may be predominantly slit sized (however, soil-gas monitoring devices should not use silt-sized filter packs but typically use coarse sand or gravel filter packs). These filter materials are often mixed with water of known quality and then inserted through a tremie pipe and tamped into place around the device. The type(s) and volumes of filter materials used and the quality and quantities of mixing water should be documented. In most cases, a centralizer should be used to position the monitoring device in the borehole. The intake device and riser(s) should be suspended above the bottom of the borehole during installation of the filter pack(s), seal(s), and backfill to keep the riser(s) as straight as possible. Care should be taken when adding backfill or filter material(s), or both, so that the materials do not bridge. However, if bridging does occur during the installation procedure, tamping rods or other tamping devices may be used to dislodge the "bridge".

8.4 Place sealing materials, consisting of either bentonite pellets, chips, or granules, directly above the filter pack.

NOTE 26—It may be effective, when granular filter packs are used, to install a thin, fine sand, secondary filter either below the annular seal or both above and below the seal. These secondary filters protect both the monitoring-device filter and the seal from intrusion of grout installed above the seal.

8.5 The backfill that is placed above the annular seal is usually a bentonite or cement-base grout.

NOTE 27—Grouts should be designed and installed in consideration of the ambient hydrogeologic conditions. The constituents should be selected according to specific performance requirements and these data documented. Typical grout mixtures are given in Practice D 5092 and Test Method D 4428/D 4428M.

8.5.1 In most cases, the grout should be pumped into the annulus formed between the borehole wall and the monitoring device(s) riser(s) using a tremie pipe.

NOTE 28—Grouting equipment should be cleaned and decontaminated prior to use according to Practice D 5088. Also, the equipment used for grouting should be constructed from materials that do not "leach" significant amounts of contaminants to the grout.

8.5.2 The initial position of the tremie pipe and grouting pressures should be controlled to prevent materials from being jetted into underlying seal(s) and filter(s) (use of a tremie pipe having a plugged bottom and side-discharge ports should be considered to minimize bottom-jetting problems).

8.5.3 In most cases, the grout should be discharged at a depth of approximately 1.5 to 3 m (5 to 10 ft) below the grout surface within the annulus (after the placement of the initial 1.5 to 3 m (5 to 10 ft) of grout above the underlying filter or seal). Additional grout should be discharged at a depth of approximately 1.5 to 3 m (5 to 10 ft) below the grout surface within the annulus. The tremie pipe should be periodically raised as grout is discharged to maintain the appropriate depth below the grout surface.

NOTE 29—The need for chemical analysis of samples of each grout component and chemical analysis of the final mixture should be documented. Also, it should be noted that if cements are used for grouting, they generate hydroxides and thereby, can cause a localized increase in the alkalinity and pH of the surrounding ground water.

8.5.4 Install the grout from the bottom of the borehole to the top of the borehole so as to displace fluids in the borehole.

9. Development

9.1 Most monitoring-device installations should be developed to remove suspended solids from drilling fluids and disturbance of geologic materials during installation and to improve the hydraulic characteristics of the filter pack and the geologic unit adjacent to the monitoring-device intake. The method(s) selected and time expended to develop the installation and the changes in water quality discharged at the surface should be carefully observed and documented. For suggested well-development methods and techniques the user is referred to Practice D 5099.

NOTE 30—Under most circumstances, development should be initiated as soon as possible following completion, however, time should be allowed for setting of grout.

10. Field Report and Project Control

10.1 The field report should include all information identified as necessary and pertinent to the needs of the exploration program. Information normally required for the project include exploration type and execution, drilling equipment and methods used, and subsurface conditions encountered including: groundwater conditions, sampling events, and installations.

10.2 Additional information should be considered as follows:

10.2.1 *Drilling Methods*:

10.2.1.1 Description of the wireline casing-advancer system including type, sizes, pilot bits, core barrels, fluid pump, fluid circulation, and discharge systems. Note and document intervals of equipment change or drilling method changes and reasons for change.

10.2.1.2 Type, quantities, and locations in the borehole of use of additives such as water or foaming agent(s) added to the circulation media.

10.2.1.3 Descriptions of circulation rates and cuttings return, including quantities, over intervals used. Locations and probable cause of loss of circulation in the borehole.

10.2.1.4 Descriptions of drilling conditions related to drilling pressures, rotation rates, and general ease of drilling related to subsurface materials encountered.

10.2.2 *Sampling*—Document conditions of the bottom of the borehole at the base prior to sampling, and report any slough or cuttings present in the recovered sample.

10.2.2.1 Samples of fluid circulation cuttings can be collected for analysis of materials being penetrated. If samples are taken, the depth(s) and interval(s) should be documented.

10.2.3 *In-Situ Testing*:

10.2.3.1 For devices inserted below the bottom of the borehole, document the depths below the bottom of the hole and any unusual conditions during testing.

10.2.3.2 For devices testing or seating at the borehole wall, report any unusual conditions of the borehole wall such as inability to seat borehole packers.

10.2.4 *Installations*—A description of well-completion materials and placement methods, approximate volumes placed, depth-intervals of placement, methods of confirming placement, and areas of difficulty of material placement or unusual occurrences.

11. Keywords

11.1 drilling; geoenvironmental exploration; ground water; vadose zone; wireline drilling method

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