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Standard Guide for Use of Direct Air-Rotary Drilling for Geoenvironmental Exploration and the Installation of Subsurface Water-Quality Monitoring Devices[1]

This standard is issued under the fixed designation D 5782; 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) air-rotary drilling procedures may be used for geoenvironmental exploration and installation of subsurface water-quality monitoring devices.

NOTE 1—The term direct with respect to the air-rotary drilling method of this guide indicates that compressed air is injected through a drill-rod column to a rotating bit. The air cools the bit 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 considerations for geotechnical site characterizations that are addressed in a separate guide.

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

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

1.4 *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.*

1.5 *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 for Site Characterization for Engineering Design and Construction Purposes[2]
D 653 Terminology Relating to Soil, Rock, and Contained Fluids[2]
D 1586 Test Method for Penetration Test and Split-Barrel Sampling of Soils[2]
D 1587 Test Method for Thin-Walled Tube Sampling of Soils[2]
D 2113 Test Method for Diamond Core Drilling for Site Investigation[2]
D 3550 Practice for Ring-Lined Barrel Sampling of Soils[2]
D 4428/D 4428M Test Methods for Crosshole Seismic Testing[2]
D 5088 Practice for Decontamination of Field Equipment Used at Non-Radioactive Waste Sites[3]
D 5092 Practice for Design and Installation of Ground Water Monitoring Wells in Aquifers[3]
D 5099 Test Method for Rubber—Measurement of Processing Properties Using Capillary Rheometry[4]
D 5434 Guide for Field Logging of Subsurface Explorations of Soil and Rock[3]

3. Terminology

3.1 *Definitions*—Terminology used within this guide is in accordance with Terminology D 653. Definitions of additional terms may be found in Terminology D 653.

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 which may affect water-quality analyses.

3.2.2 *bentonite granules and chips*—irregularly shaped particles of bentonite (free from additives) that have been dried and separated into a specific size range.

3.2.3 *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).

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[2] *Annual Book of ASTM Standards*, Vol 04.08.
[3] *Annual Book of ASTM Standards*, Vol 04.09.
[4] *Annual Book of ASTM Standards*, Vol 09.01.

3.2.4 *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).

3.2.5 *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.

3.2.6 *drawworks*—a power-driven winch, or several winches, usually equipped with a clutch and brake system(s) for hoisting or lowering a drilling string.

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

3.2.8 *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.

3.2.9 *drill string*—the complete direct air-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.

3.2.10 *filter pack*—also known as a gravel pack or a primary filter pack in the practice of monitoring-well installations. The gravel pack is usually granular material, having specified 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: (*1*) a nonclogging filter when the aquifer is not suited to natural development or, (*2*) act as a formation stabilizer when the aquifer is suitable for natural development.

3.2.10.1 *Discussion*—Under most circumstances a clean, quartz sand or gravel should be used. In some cases a pre-packed screen may be used.

3.2.11 *grout packer*—an inflatable or expandable annular plug attached to a tremie pipe, usually just above the discharge end of the pipe.

3.2.12 *grout shoe*—a drillable plug containing a check valve 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.

3.2.12.1 *Discussion*—The composition of the drillable plug should be known and documented.

3.2.13 *hoisting line*—or drilling line, is wire rope used on the drawworks to hoist and lower the drill string.

3.2.14 *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 a preexisting borehole by means of a suspension line or a string of lowering rods or pipe. Centralizers may be required to correctly position the device(s) in the borehole.

3.2.15 *intermittent-sampling devices*—usually barrel-type samplers that are driven or pushed below the bottom of a borehole following completion of an increment of drilling. The user is referred to the following ASTM standards relating to suggested sampling methods and procedures: Practice D 1452, Test Method D 1586, Practice D 3550, and Practice D 1587.

3.2.16 *mast*—or derrick, on a drilling rig is used for supporting the crown block, top drive, pulldown chains, hoisting lines, and so forth. It must be constructed to safely carry the expected loads encountered in drilling and completion of wells of the diameter and depth for which the rig manufacturer specifies the equipment.

3.2.16.1 *Discussion*—To allow for contingencies, it is recommended that the rated capacity of the mast should be at least twice the anticipated weight load or normal pulling load.

3.2.17 *piezometer*—an instrument for measuring pressure head.

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

4. Significance and Use

4.1 The application of direct air-rotary drilling to geoenvironmental exploration may involve sampling, coring, in situ or pore-fluid testing, installation of casing for subsequent drilling activities in unconsolidated or consolidated materials, and for installation of subsurface water-quality monitoring devices in unconsolidated and consolidated materials. Several advantages of using the direct 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 drill hole 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 without using casing, and the possible volitization of contaminants and air-borne dust.

NOTE 3—Direct-air rotary drilling uses pressured air for circulation of drill cuttings. In some instances, water or foam additives, or both, may be injected into the air stream to improve cuttings-lifting capacity and cuttings return. 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, consideration to other drilling method(s) should be given.

NOTE 4—The user may install a monitoring device within the same borehole in which sampling, in situ or pore-fluid testing, or coring was performed.

4.2 The subsurface water-quality monitoring devices that are addressed in this guide consist generally of a screened or porous intake and riser pipe(s) that are usually installed with a filter pack to enhance the longevity of the intake unit, and with isolation seals and a low-permeability backfill to deter the movement of fluids or infiltration of surface water between hydrologic units penetrated by the borehole (see Practice D 5092). Inasmuch as a piezometer is primarily a device used for measuring subsurface hydraulic heads, the conversion of a piezometer to a water-quality monitoring device should be made only after consideration of the overall quality of the installation to include the quality of materials that will contact sampled water or gas.

NOTE 5—Both water-quality monitoring devices and piezometers should have adequate casing seals, annular isolation seals, and backfills to deter movement of contaminants between hydrologic units.

5. Apparatus

5.1 Direct air-rotary drilling systems consist of mechanical components and the drilling fluid.

5.1.1 The basic mechanical components of a direct air-rotary drilling system include the drill rig with rotary table and kelly or top-head drive unit, drawworks drill rods, bit or core barrel, casing (when required to support the hole and prevent wall collapse when drilling unconsolidated deposits), air compressor and filter(s), discharge hose, swivel, dust collector, and air-cleaning device (cyclone separator).

NOTE 6—In general, in North America, the sizes of casings, casing bits, drill rods, and core barrels are usually standardized by manufacturers according to size designations set forth by the American Petroleum Institute (API) and the Diamond Drill Core Manufacturers Association (DCDMA). Refer to the DCDMA technical manual and to published materials of API for available sizes and capacities of drilling tools equipment.

5.1.1.1 *Drill Rig*, with rotary table and kelly or top-head drive unit should have the capability 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.

5.1.1.2 *Kelly*, a formed or machined section of hollow drill steel that is joined to the swivel at the top and the drill rods below. Flat surfaces or splines of the kelly engage the rotary table so that its rotation is transmitted to the drill rods.

5.1.1.3 *Drill Rods*, (that is, drill stems, drill string, drill pipe) transfer force and rotation from the drill rig to the bit or core barrel. Drill rods conduct drilling fluid to the bit or core barrel. Individual drill rods 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 air 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.

NOTE 7—Drill rods used for air drilling jointed to ensure that the cutting's-laden return air will not be deflected to the borehole wall as it passes the return air were deflected against the borehole blasting and erosion of the borehole wall would occur.

NOTE 8—Drill rods usually require lubricants on the thread to allow easy unthreading (breaking) 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 air-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.

5.1.1.4 *Rotary Bit or Core Bit*, provides material cutting capability for advancing the hole. Therefore, a core barrel can also be used to advance the hole.

NOTE 9—The bit is usually selected to provide a borehole of sufficient diameter for insertion of monitoring-device components such as the screened intake and filter pack and installation devices such as a tremie pipe. It should be noted that if bottom-discharge bits are used in loose cohesionless materials, jetting or erosion of test intervals could occur. The borehole opening should permit easy insertion and retraction of a sampler, or easy insertion of a pipe with an inside diameter large enough for placing completion materials adjacent to the screened intake and riser of a monitoring device. Core barrels may also be used to advance the hole. Coring bits are selected to provide the hole diameter or core diameter required. Coring of rock should be performed in accordance with Practice D 2113. The user is referred to Test Method D 1586, Practice D 1587, and Practice D 3550 for techniques and soil-sampling equipment to be used in sampling unconsolidated materials. Consult the DCDMA technical manual and published materials of API for matching sets of nested casings and rods if nested casing must be used for drilling in incompetent formation materials.

5.1.1.5 *Air Compressor*, should provide 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. 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 10—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.

5.1.1.6 *Pressure Hose*, conducts the air from the air compressor to the swivel.

5.1.1.7 *Swivel*, directs the air to the rotating kelly or drill-rod column.

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

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

NOTE 11—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 12—Zones of low air return and 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 13—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.

6. Drilling Procedures

6.1 As a prelude to and throughout the drilling process, stabilize the drill rig and raise the drill-rig mast. Position the cyclone separator and seal it 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 14—Under some circumstances surface casing may be required to prevent hole collapse. Deeper casing(s) (nested casings) may also be required to facilitate adequate downhole air circulation and hole control. All casing used should be decontaminated according to Practice D 5088 prior to use.

6.2 Drilling usually progresses as follows:

6.2.1 Attach an initial assembly of a bit or core barrel, often with a single section of drill rod, below the rotary table or top-head drive unit with the bit placed below the top of the dust collector.

NOTE 15—The drill rig, drilling, hoisting and sampling tools, drilling rod and bits, 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.

6.2.2 Activate the air compressor, causing compressed air to circulate through the system.

6.2.3 Initiate rotation of the bit.

6.2.4 Continue air circulation and rotation of the drill-rod column until drilling progresses to a depth where sampling or in-situ testing will be performed or until the length of the drill-rod section limits further penetration. Air pressures at the bit should be low to prevent fracturing of the surrounding material. Monitor all air pressures during drilling. Note and document any abrupt changes or anomalies in the air pressure including the depth(s) of occurrence(s). Air-quality monitoring may be required. If air-quality monitoring is performed document the sampled intervals and air-quality data.

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

6.2.6 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 6.2.2 through 6.2.5. Record drilling behavior as drilling progresses. This recorded information should include (as a minimum): air-circulation pressures, depth(s) of low or lost circulation, depth(s) of water-/foam-additive injection(s), air-quality data, drill-cuttings description, depths of and type of sample(s)/core(s) taken from the hole, and any other data identified as necessary and pertinent to the needs of the exploration program.

NOTE 16—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 borehole wall. Drilling rates can vary from a few millimetres (less than an inch/minute) to about 1 m (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.

6.2.7 Sampling or in-situ testing can be performed at any depth in the hole by interrupting the advance of the bit, cleaning the hole of cuttings according to 6.2.5, stopping air circulation, and removing the drill-rod column from the borehole. Drill-rod removal is not necessary when a sample may be obtained or an in-situ test can be performed through the hollow axis of the drill rods and bit. Compare the 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. If bottom-hole contamination is apparent (determined by comparing the hole-cleanout depth with the sampling depth) it is recommended that a minimum depth below the sampler/bit be at least 18-in. for testing. This should be done before every sampling or in-situ testing is performed in the hole. 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.

6.3 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. The grout should be allowed to set before drilling activities are continued. Document complete casing and grouting records, including location(s) of nested casings for the hole.

7. Installation of Monitoring Devices

7.1 Subsurface water-quality monitoring devices are generally installed in boreholes drilled by direct air-rotary methods using the three-step procedure shown in Fig. 1. The three steps are: (*1*) drilling, with or without sampling, (*2*) removal of the drill-rod column assembly and insertion of the instrumentation or monitoring device, and (*3*) addition of completion materials such as filter packs, seals, and grouts. If protective casings are present in the borehole they are usually removed in incremental fashion as completion materials are added.

7.2 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.

7.2.1 Some materials, such as screens and risers, may require cleaning or decontamination, or both, at the job site. The user is referred to Practice D 5088 for equipment decontamination procedures.

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

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

7.3 Select filter materials, bentonite pellets, granules and chips, and grouts and install according to specific subsurface-monitoring or instrumentation requirements.

NOTE 17—Filter packs for monitoring devices, are usually installed in air-rotary drilled holes using a tremie pipe inserted in the annulus between the borehole wall and the monitoring device (minimum annulus between riser pipe and hole wall should be about 1 in. (25 mm) completely around the riser pipe). However, unless needed for silt control or seal separation between water-bearing zones, filter packing monitoring wells in competent rock adds an unnecessary source of sample contamination due to the fouling of the sand interstices by the invasion of the filter-pack material. Monitoring devices installed in a saturated zone typically have sand-sized filter packs that are selected mainly on the basis of the grain-size characteristics of the hydrologic unit adjacent to the screened intake. The coefficient of uniformity of the filter pack sand is usually less than 2.5. In most cases, a centralizer should be used to center a monitoring device requiring a filter pack in an uncased borehole. Filter packs for vadose-zone monitoring devices may be predominantly silt sized however, soil-gas monitoring devices should not use silt-sized filter packs but typically use coarse sand or gravel 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

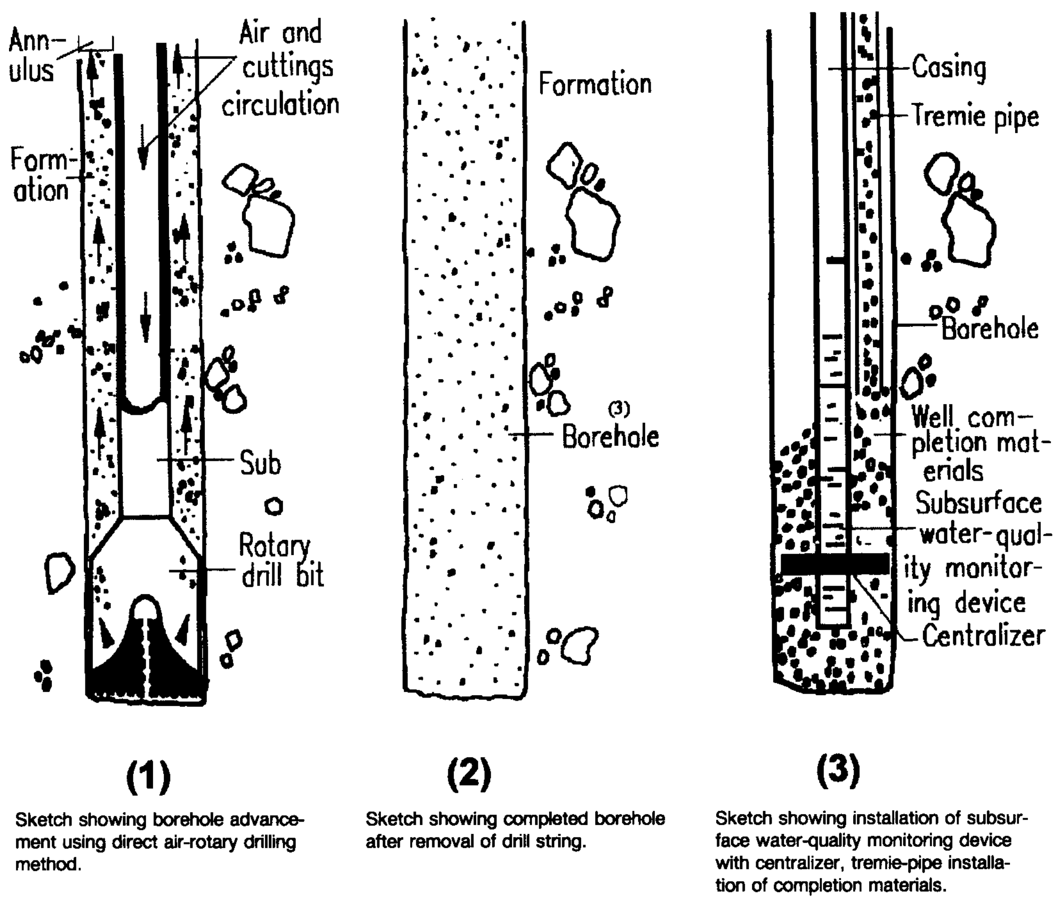

FIG. 1 Sketch Showing Basic Three-Step Procedure for Installation of Subsurface Water-Quality Monitoring Device Using Direct Air-Rotary Drilling Method

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.

7.4 Sealing materials consisting of either bentonite pellets, chips, or granules are usually placed directly above the filter pack.

NOTE 18—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 the principal filter and the seal from intrusion of grout installed above the seal.

7.5 The backfill that is placed above the annular seal of a monitoring device is usually a bentonite or cement-base grout.

NOTE 19—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 Methods D 4428.

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

NOTE 20—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.

7.5.2 Control the initial position of the tremie pipe and grouting pressures 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).

7.5.3 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 of grout has been deposited above the underlying filter or seal). Additional grout should be discharged at a depth of approximately 1.5 to 3 m 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 21—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.

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

8. Development

8.1 Most monitoring device installations should be developed to remove any air that may have been introduced into the formation by the drilling method, suspended solids from drilling fluids, and disturbance of geologic materials during installation and to improve the hydraulic characteristics of the filter pack and the hydrologic unit adjacent to the monitoring device intake. The method(s) selected and time expended to develop the installation and the changes in quality of water discharged at the surface should be carefully observed and documented. For suggested well-development methods and techniques the user is referred to Test Method D 5099.

NOTE 22—Under most circumstances, development should be initiated as soon as possible following completion, however, time should be allowed for setting of grout.

9. Field Report and Project Control

9.1 The field report should include information recommended under Guide D 5434, and identified as necessary and pertinent to the needs of the exploration program.

9.2 Other information in addition to Guide D 5434 should be considered if deemed appropriate and necessary to the needs of the exploration program. Additional information should be considered as follows:

9.2.1 *Drilling Methods*:

9.2.1.1 Description of the air-rotary system including the air compressor, air-circulation, and discharge system.

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

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

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

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

9.2.3 *In Situ Testing*:

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

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

9.2.4 *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.

10. Keywords

10.1 air-rotary drilling method; drilling; geoenvironmental exploration; ground water; vadose zone

APPENDIX

(Nonmandatory Information)

X1. ADDITIONAL REFERENCES

(**1**) Aller, L., et al, *Handbook of Suggested Practices for the Design and Installation of Ground-Water Monitoring Wells*, EPA/600/4-89/034, NWWA/EPA Series, National Water Well Assn., Dublin, OH, 1989.

(**2**) American Petroleum Institute, *API Specifications for Casing, Tubing, and Drill Pipe, API Spec 5A*, American Petroleum Institute, Dallas, TX, 1978.

(**3**) *Australian Drilling Manual*, Australian Drilling Industry Training Committee Limited, P.O. Box 1545, Macquarie Centre, NSW 2113, Australia, 1992.

(**4**) Baroid, *Baroid Drilling Fluid Products for Minerals Exploration*, NL Baroid/NL Industries, Houston, TX, 1980.

(**5**) Bowen, R., *Grouting in Engineering Practice*, 2nd Edition, Applied Science Publishers, Halstad Press, New York, NY, 1981.

(**6**) Campbell, M. D., and Lehr, J. H., *Water Well Technology*, McGraw-Hill Book Co., New York, NY, 1973.
DCDMA Technical Manual, Drilling Equipment Manufacturers Assn., 3008 Millwood Ave., Columbia, SC, 29205, 1991.

(**7**) *Drillers Handbook*, T. C., Ruda and P. J., Bosscher, eds., National Drilling Contractors Assn., 3008 Millwood Ave., Columbia, SC, 29205, June 1990.

(**8**) Driscoll, F. G., *Groundwater and Wells*, Johnson Filtration Systems, 2nd Edition, St. Paul, MN, 1989.

(**9**) Heinz, W. F., *First Edition*, South African Drilling Association, Johannesburg, Republic of South Africa, 1985.

(**10**) Morrison, Robert D., *Ground Water Monitoring Technology, Procedures, Equipment and Applications*, Timco Manufacturing, Inc., Prairie Du Sac, WI, 1983.

(**11**) *Handbook of Ground Water Development*, Roscoe Moss Co., Los Angeles, CA, John Wiley and Sons, Inc., New York, NY, 1990.

(**12**) Russell, B. F., Hubbell, J. M., and Minkin, S. C., "Drilling and Sampling Procedures to Minimize Borehole Cross-Contamination." *Proc. Third Nat. Outdoor Action Conf. on Aquifer Restoration, Ground Water Monitoring and Geophysical Methods*, National Water Well Assn., Dublin, OH, 1989, pp. 81–93. (Air and mud rotary.)

(**13**) Shuter, E., and Teasdale, W. E., "Application of Drilling, Coring, and Sampling Techniques to Test Holes and Wells," *U.S. Geological Survey Techniques of Water-Resource Investigations*, TWRI 2-F1, 1989.