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Standard Guide for Decommissioning of Groundwater Wells, Vadose Zone Monitoring Devices, Boreholes, and Other Devices for Environmental Activities[1]

This standard is issued under the fixed designation D5299/D5299M; 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 procedures that are specifically related to permanent decommissioning (closure) of the following as applied to environmental activities. It is intended for use where solid or hazardous materials or wastes are found, or where conditions occur requiring the need for decommissioning. The following devices are considered in this guide:

1.1.1 A borehole used for geoenvironmental purposes (see Note 1),

1.1.2 Monitoring wells,

1.1.3 Observation wells,

1.1.4 Injection wells (see Note 2),

1.1.5 Piezometers,

1.1.6 Wells used for the extraction of contaminated groundwater, the removal of floating or submerged materials other than water such as gasoline or tetrachloroethylene, or other devices used for the extraction of soil gas,

1.1.7 A borehole used to construct a monitoring well, and

1.1.8 Any other well or boring that houses a vadose zone monitoring device.

1.2 Temporary decommissioning of the above is not covered in this guide.

NOTE 1—This guide may be used to decommission boreholes where no contamination is observed at a site (see Practice D420 for details); however, the primary use of the guide is to decommission boreholes and wells where solid or hazardous waste have been identified. Methods identified in this guide can also be used in other situations such as the decommissioning of water supply wells and boreholes where water contaminated with nonhazardous pollutants (such as nitrates or sulfates) are present. This guide should be consulted in the event that ~~a~~ routine geotechnical ~~study indicates~~studies indicate the presence of contamination at a site. Consult and follow national, state, or local regulations as they may control required decommissioning procedures.

NOTE 2—The term "well" is used in this guide to denote monitoring wells, piezometers, or other devices constructed in a manner similar to a well. Some of the devices listed such as injection and extraction wells can be decommissioned using this guide for ~~information,~~information but are not specifically covered in detail in the text.

NOTE 3—Details on the decommissioning of multiple-screened wells are not provided in this guide due to the many methods used to construct these types of wells and the numerous types of commercially available multiple-screened well systems. However, in some instances, the methods presented in this guide may be used with few changes. An example of how this guide may be used is the complete removal of the multiple-screened wells by overdrilling.

1.3 Most monitoring wells and piezometers are intended primarily for water quality sampling, water level observation, or soil gas sampling, or combination thereof, to determine quality. Many wells are relatively small in diameter typically 2.5 to 20 cm [1 to 8 ~~in.]~~inches] and are used to monitor for hazardous chemicals in groundwater. Decommissioning of monitoring wells is necessary to:

1.3.1 Eliminate the possibility that the well is used for purposes other than intended,

1.3.2 Prevent migration of contaminants into an aquifer or between aquifers,

1.3.3 Prevent migration of contaminants in the vadose zone,

1.3.4 Reduce the potential for vertical or horizontal migration of fluids in the well or adjacent to the well, and

1.3.5 Remove the well from active use when the well is no longer capable of ~~rehabilitation,~~rehabilitation or has failed structurally; is no longer needed for monitoring; is no longer capable of providing representative samples or is providing unreliable samples; is required to be decommissioned; or to meet regulatory requirements.

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

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***A Summary of Changes section appears at the end of this standard**

NOTE 4—The determination of whether a well is providing a representative water quality sample is not defined in this guide. Examples of when a representative water quality sample may not be collected include the biological or chemical clogging of well screens, a drop in the water level to below the base of the well screen, or complete silting of the screen. These conditions may indicate that a well is not functioning correctly.

1.4 This guide is intended to provide information for effective permanent closure of wells so that the physical structure of the well does not provide a means of hydraulic communication between aquifers, with above surfaces,surfaces or react chemically in a detrimental way with the environment.

1.5 The intent of this guide is to provide procedures that when followed result in a reasonable level of confidence in the integrity of the decommissioning activity. However, it may not be practicablepractical to verify the integrity of the decommissioning procedure. At this time, Currently, methods are not available to substantially determine the integrity of the decommissioning activity.

1.6 This guide may also be used for closure or decommissioning of other systems that could allow vertical or horizontal migration of contaminants or other cross-contamination of aquifers, such as dug wells, geothermal loops, or when ordered by regulatory agencies.

1.7 *Units*—The values stated in either SI units or inch-pound units (given in brackets) are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in non-conformance with the standard.

1.8 All observed and calculated values shall conform to the guidelines for significant digits and rounding established in Practice D6026, unless superseded by this standard.

1.9 *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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.10 *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.*

NOTE 5—If state and local regulations are in effect where the decommissioning is to occur, the regulations take precedence over this guide.

1.11 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

C150 Specification for Portland Cement
D420 Guide for Site Characterization for Engineering Design and Construction Purposes
D422 Test Method for Particle-Size Analysis of Soils (Withdrawn 2016)[3]
D653 Terminology Relating to Soil, Rock, and Contained Fluids
D2487 Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)
D2488 Practice for Description and Identification of Soils (Visual-Manual Procedures)
D3740 Practice for Minimum Requirements for Agencies Engaged in Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction
D4380 Test Method for Density of Bentonitic Slurries
D5088 Practice for Decontamination of Field Equipment Used at Waste Sites
D5092 Practice for Design and Installation of Groundwater Monitoring Wells
D5434 Guide for Field Logging of Subsurface Explorations of Soil and Rock
D5608 Practices for Decontamination of Sampling and Non Sample Contacting Equipment Used at Low Level Radioactive Waste Sites
D5753 Guide for Planning and Conducting Geotechnical Borehole Geophysical Logging
D5781 Guide for Use of Dual-Wall Reverse-Circulation Drilling for Geoenvironmental Exploration and the Installation of Subsurface Water Quality Monitoring Devices
D5782 Guide for Use of Direct Air-Rotary Drilling for Geoenvironmental Exploration and the Installation of Subsurface Water-Quality Monitoring Devices

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] The last approved version of this historical standard is referenced on www.astm.org.

D5784 Guide for Use of Hollow-Stem Augers for Geoenvironmental Exploration and the Installation of Subsurface Water Quality Monitoring Devices
D5872 Guide for Use of Casing Advancement Drilling Methods for Geoenvironmental Exploration and Installation of Subsurface Water Quality Monitoring Devices
~~D5875 Guide for Use of Cable-Tool Drilling and Sampling Methods for Geoenvironmental Exploration and Installation of Subsurface Water Quality Monitoring Devices~~
~~D5876 Guide for Use of Direct Rotary Wireline Casing Advancement Drilling Methods for Geoenvironmental Exploration and Installation of Subsurface Water-Quality Monitoring Devices~~
D5978 Guide for Maintenance and Rehabilitation of Groundwater Monitoring Wells
D6026 Practice for Using Significant Digits in Geotechnical Data
D6151 Practice for Using Hollow-Stem Augers for Geotechnical Exploration and Soil Sampling
D6167 Guide for Conducting Borehole Geophysical Logging: Mechanical Caliper
D6274 Guide for Conducting Borehole Geophysical Logging - Gamma
D6282 Guide for Direct Push Soil Sampling for Environmental Site Characterizations
D6286 Guide for Selection of Drilling Methods for Environmental Site Characterization
D6724 Guide for Installation of Direct Push Groundwater Monitoring Wells
~~D6725 Practice for Direct Push Installation of Prepacked Screen Monitoring Wells in Unconsolidated Aquifers~~
~~E11 Specification for Woven Wire Test Sieve Cloth and Test Sieves~~
~~F480 Specification for Thermoplastic Well Casing Pipe and Couplings Made in Standard Dimension Ratios (SDR), SCH 40 and SCH 80~~

3. Terminology

3.1 *Definitions:*

3.1.1 For definitions of common technical terms in this standard, refer to Terminology D653.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *blowout, n—in drilling*, a sudden or violent uncontrolled escape of fluids or gas, or both, from a borehole.

3.2.2 *caliper log, n—in drilling*, a geophysical borehole log that shows to scale the variations with depth in the mean diameter of a cased or uncased borehole.

3.2.3 *cement bond (sonic) log, n—in drilling*, a borehole geophysical log that can be used to determine the effectiveness of a cement seal of the annular space of a well.

3.2.4 *channeling, n—in drilling*, the process of forming a vertical cavity resulting from a faulty cement job in the annular space.

3.2.5 *curing accelerator, n—in grouting*, a material added to cement to decrease the time for curing.

3.2.5.1 *Discussion—*

Examples are sodium chloride, calcium sulfate (gypsum), and aluminum powder.

~~3.2.6 *curing retarder, n—in grouting*, a material added to cement to increase the time for curing.~~

~~3.2.6.1 *Discussion—*~~

~~Sodium chloride in high concentrations is an example.~~

3.2.6 *decommissioning (closure), n—in drilling*, the engineered closure of a well, borehole, or other subsurface monitoring device sealed with plugging materials.

3.2.6.1 *Discussion—*

Decommissioning also includes the planning and documenting of associated activities. A synonym is abandonment.

3.2.7 *decontamination, n—in drilling*, the process of removing undesirable physical or chemical constituents, or both, from equipment to reduce the potential for cross-contamination.

3.2.8 *fallback, n—in grouting*, shrinkage, settlement, or loss of plugging material placed in a borehole or well.

3.2.9 *fire clay, n—in grouting*, a ~~silicious~~siliceous clay rich in hydrous aluminum silicates.

3.2.10 *flow log, n—in drilling*, a borehole geophysical log used to record vertical movement of groundwater and movement of water into or out of a well or borehole and between formations within a well.

3.2.11 ~~*geophysical borehole log,*~~ *grout, n—~~a log~~in grouting,* ~~obtained by lowering an instrument into a borehole and continuously recording a physical property of native or backfill material and contained fluids.~~ material consisting of bentonite, cement, or a cement-bentonite mixture mixed with water.

3.2.11.1 *Discussion—*

~~Examples include resistivity, induction, caliper, sonic, and natural gamma logs.~~Neat grout is typically without the addition of sand or other aggregates.

3.2.12 *grout pipe, n—in drilling*, a pipe or tube that is used to transport cement, bentonite, or other plugging materials from the ground surface to a specified depth in a well or borehole.

3.2.12.1 *Discussion—*

The material may be allowed to flow freely or it may be injected under pressure. The term tremie pipe is frequently used interchangeably.

3.2.13 *hydraulic communication, n—in drilling*, the migration of fluids from one zone to another, with reference to this guide; especially along a casing, grout plug, or through backfill materials.

3.2.14 *multiple-screened wells, n—in drilling*, two or more monitoring wells situated in the same borehole. These devices can be either individual casing strings and screen set at a specific depth, a well with screens in more than one zone, or can consist of devices with screens with tubing or other collecting devices attached that can collect a discrete sample.

3.2.15 *neat cement, n—in grouting*, a mixture of Portland Cement (C150) and water and is not extended with sand or other aggregate.

3.2.16 *native material, n—in drilling*, in place geologic (or soil) materials encountered at a site.

3.2.17 *overdrilling, n—in drilling*, the process of drilling out a well casing and any material placed in the annular space.

3.2.18 *perforation, n—in drilling*, a slot or hole made in a well casing to allow for communication of fluids between the well and the annular space.

~~3.2.18 *permanent plugging (Closing) (Sealing), n—in grouting*, a seal that has a hydraulic conductivity that is equivalent or less than the hydraulic conductivity of the geologic formation. This term is often used with uncased boreholes.~~

3.2.19 *plow layer, n—in drilling*, the depth typically reached by a plow or other commonly used earth turning device used in agriculture.

3.2.19.1 *Discussion—*

This depth is commonly ~~one to two feet (.3 m to .6 m)~~0.3 m to 0.6 m [1 to 2 ft] below land surface.

3.2.20 *plugging material, n—in grouting*, a material that has a hydraulic conductivity equal to or less than that of the geologic formation(s) to be sealed.

3.2.20.1 *Discussion—*

Typical materials include ~~portland~~Portland cement and bentonite.

3.2.21 *pre-conditioning, n—in drilling*, an activity conducted prior to placing plugging material into a borehole in order to stabilize the hole.

3.2.22 *temporary decommissioning, n—in drilling*, the engineered closure of a well intended to be returned to service at some later date (generally no more than six months to one year).

3.2.22.1 *Discussion—*

Temporary plugging should not damage the structural integrity of the well. Plugging materials consist of sand, bentonite, or other easily removed materials.

3.3 The following terms used in this standard are available in Terminology D653 and are presented here for the convenience of the user.

3.3.1 *bleeding*—the autogenous flow of mixing water within, or its emergence from, newly placed grout caused by the settlement of the solid materials within the mass.

4. Summary of Guide

4.1 Information is provided on the significance of correctly decommissioning boreholes and wells at sites containing or formerly containing solid or hazardous waste or hazardous materials or their byproducts, or that may be affected by solid or hazardous waste materials or their byproducts in the future. This guide may be used in situations where water quality in one aquifer may be detrimental to another aquifer either above or below the aquifer. The primary purpose of decommissioning activities is to permanently decommission the borehole or monitoring device so that the natural migration of groundwater or soil vapor is not significantly influenced. Decommissioned boreholes and wells should have no adverse influence on the local geologic setting than the original geologic setting (**1**)[4].

4.2 It is important to have a good understanding of the geology, hydrogeology, well construction, historic and future land use, chemicals encountered, and the regulatory environment for successful decommissioning to occur.

4.3 Various materials suitable for decommissioning boreholes and wells are discussed, including their positive and negative attributes for decommissioning. A generalized procedure is provided that discusses the process from planning through implementation and documentation. Examples of typical practices are provided in the appendix.

5. Significance and Use

5.1 Decommissioning of boreholes and monitoring wells, and other devices requires that the specific characteristics of each site be considered. The wide variety of geological, biological, and physical conditions, construction practices, and chemical composition of the surrounding soil, rock, waste, and groundwater precludes the use of a single decommissioning practice. The procedures discussed in this guide are intended to aid the geologist or engineer in selecting the tasks needed to plan, choose materials for, and carry out an effective permanent decommissioning operation. Each individual situation should be evaluated separately and the appropriate technology applied to meet site conditions. Considerations for selection of appropriate procedures are presented in this guide, but other considerations based on site specific conditions should also be ~~taken into account.~~considered.

NOTE 6—Ideally, decommissioning should be considered as an integral part of the design of the monitoring well. Planning at this early stage can make the decommissioning activity easier to accomplish. See Practice D5092 for details on monitoring well construction.

5.2 This guide is intended to provide technical information and is not intended to supplant statutes or regulations of local governing bodies. Approval of the appropriate regulatory authorities should be an important consideration during the decommissioning process. This practice is in general accordance with other national and state guidance documents on well decommissioning (ANSI/NGWA-01-14 [1]1 and California EPA [2].

NOTE 7—The quality of the result produced by this standard is dependent on the competence of the personnel performing it, and the suitability of the equipment and facilities used. Agencies that meet the criteria of D3740 are generally considered capable of competent and objective testing/sampling/inspection/etc. Users of this standard are cautioned that compliance with Practice D3740 does not in itself assure reliable results. Reliable results depend on many factors, Practice D3740 provides a means of evaluating some of those factors. Practice D3740 was developed for agencies engaged in laboratory testing and/or inspection of soils and rock. As such, it is not totally applicable to agencies performing this practice. However, users of this practice should recognize that the framework of Practice D3740 is appropriate for evaluating the quality of an agency performing this practice. ~~Current~~Currently, there is no known qualifying national authority that inspects agencies that perform this practice.

NOTE 8—An extensive research program on annular sealants was conducted from 2001 through 2009 and in subsequent years by the Nebraska Grout Task Force (**2**). This research included cement and bentonite grouts and the use of pellets and chips. The general finding of the study indicates all sealing methods suffer from some shrinkage in the portion of the well in the unsaturated zone. The best grouts were cement-sand, bentonite chips, neat cements and bentonite slurries with more than ~~20%~~ 20 percent solids. Especially problematic is the use of low solids content bentonite slurries in the unsaturated zone leading to a prohibition on their use in California (**3**). ~~The bentonite slurries used in this standard are high solids slurries with more than 20% solids and bentonite slurry is not recommended in the unsaturated zone regardless of solids content.~~ Regional or local regulations may specify different sealing methods and mixtures that differ from seal guideline in this standard. ~~Regional or local regulations for mixtures of bentonite and cement slurries may differ from this standard and may control mixture requirements. This practice is in general accordance with other national and state guidance documents on well decommissioning (ANSI/NGWA-01-14 [1]1 and California EPA [2].~~

NOTE 9—The decommissioning of wells that intersect openings, fractured layers or other large openings, such as caves, can make sealing and decommissioning efforts difficult. The decommissioning of wells in areas known to have these conditions should involve professionals experienced in decommissioning in these areas.

6. Materials

6.1 The materials used for construction of a monitoring well or other monitoring device to be decommissioned in part determines how it is decommissioned. Various materials are available for use in plugging boreholes and monitoring wells (**4**). This section provides information on these materials.

6.2 *Casing and Screen Materials:*

6.2.1 Various materials are used for well casing and screen. The most common materials used are: PVC, PTFE, fiberglass, carbon steel, stainless steel, and aluminum. Typically, the same material is used for casing and screen in a well, however, in some instances different materials may be used in a well to achieve a particular purpose such as corrosion protection, reduction of material costs, or improving the integrity of groundwater or soil vapor samples. This guide does not specifically address the use

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

of more than one type of casing or screen material used in a well, however, the same decommissioning methods can frequently be used when more than one material is used (for example, PVC and PTFE, or stainless steel and carbon steel) in a well.

6.2.2 In selecting a well decommissioning method, PVC, PTFE, and fiberglass wells can be decommissioned using similar methods as the three types of materials tend to be low in tensile strength and easy to drill out or perforate. Appendix X1 provides a discussion on various procedures that can be used for the decommissioning of PVC wells and by reference PTFE and fiberglass wells.

6.2.3 Wells constructed of carbon steel, stainless steel, and heavy walled aluminum can be decommissioned using similar methods as these materials tend to have a higher tensile strength that allows for the casing to be removed. Appendix X1 provides a discussion on various procedures that can be used for the decommissioning of steel wells and by reference stainless steel and aluminum wells.

6.3 *Plugging Materials:*

6.3.1 Plugging materials should be carefully chosen for well closure to be permanent. Basic material characteristics are listed as follows:

6.3.1.1 Plugging materials should not react with contaminants or adversely react with groundwater or geologic materials.

6.3.1.2 Plugging materials used in decommissioning wells, borings, and the ~~like,~~like should have hydraulic conductivity (saturated condition) that is comparable to or lower than that of the lowest hydraulic conductivity of the geologic material being sealed.

6.3.1.3 Plugging materials must have sufficient structural strength to withstand pressures expected from native conditions.

6.3.1.4 Plugging materials must maintain sealing capabilities and not degrade due to chemical interaction, corrosion, dehydration, or other physical or chemical processes. Materials should maintain their design characteristics for the length of time contamination is present at the site.

6.3.1.5 Plugging materials should not be susceptible to cracking or shrinkage.

6.3.1.6 Plugging materials must be capable of being placed at the position in the well or borehole in which they are needed and must have properties that reduce their unintended movement vertically and horizontally.

6.3.1.7 Plugging materials must be capable of forming a tight bond and seal with well casing and the formation.

6.3.1.8 Plugging materials must have properties that eliminate leaching or erosion of the material, under the conditions the material will be subjected. These include vertical or horizontal movement, or contact with groundwater or other existing conditions.

NOTE 10—The grain size of plugging material used in plugging and decommissioning operations conducted in areas where thick vadose zones occur should be coarser than materials used in areas where thin vadose zones or shallow saturated conditions occur. This is necessary as water is not transported effectively in coarse-grained materials under negative pore pressures. Coarse-grained materials should not be used where saturated conditions are likely to exist during the period of time that hazardous materials can be expected to occur at the site. It is important to determine the lithology and grain size (D422, D2487, D2488) distribution of materials adjacent to the borehole or well prior to selection of plugging materials. Well backfilling with native soils is not recommended.

NOTE 11—If coarse-grained materials are used to decommission the borehole or well, a layer of fine-grained material (such as cement or bentonite, or both) ~~.3~~0.3 or ~~.6~~0.6 m [1 or 2 ft] thick should be placed at 3 m [10 ft] intervals in the borehole in the saturated zone. This layer should extend ~~.6~~0.6 to ~~.9~~0.9 m [2 to 3 ft] above the highest expected level saturation is expected based on historical information on the water table for unconfined aquifers. A similar thickness of these materials should be used for confined aquifers. A similar ~~1.5-m [5-ft]~~ 1.5 m [5 ft] seal of a low-permeability material should be placed near the ground surface to reduce the potential for entrance of fluids at the ground surface.

~~6.4 *Commonly Used Materials*—Subsections 6.2 and 6.3 introduced the general criteria that must be evaluated during the process of selecting the appropriate procedure and material for plugging a specific well. Because well construction and local geological conditions are site specific, a wide variety of materials and procedures may be used to complete the closure.~~

~~6.4.1 Section 6.4 presents a review of the plugging materials most commonly used to decommission monitoring wells. Table 1 summarizes these materials and lists the most important considerations (positive and negative) for their use. A detailed discussion of each material is presented in the following subsections.~~

~~6.4.2 *Portland Cement*—Portland cement may be used in any of its various forms to meet placement, strength, and durability criteria listed in 6.1. The amount of shrinkage or settling of neat cement is dependent on the amount of water used. Higher water to cement ratios tend to increase shrinkage (**5**), (**6**).~~

~~NOTE 12—A typical cement based grout consists of water and cement with the water/cement ratio between .44 and .53. Any excess water will cause bleed water and excessive shrinkage. The use of additives may decrease the amount of water required for neat cements and the further reduce the amount of shrinkage during setting.~~

~~6.5 *Specification C150:*~~

~~6.5.1 *Type I*—Type 1 cement, a general-purpose material, is the most commonly used cement. This material has a tendency to develop a relatively high heat of hydration when used in confined situations and has relatively low-sulfate resistance.~~

~~6.5.2 *Type II*—Somewhat slower strength development than Type I; however, Type II cement has moderate heat of hydration and moderate sulfate resistance.~~

~~6.5.3 *Type III*—Type III cement is used when high early strength is desired. This material is not commonly used in decommissioning activities because of its ability to quickly set. Care must be used in working with this material.~~

TABLE 1 Properties of Common Plugging Materials

Plugging Material	Description	Positive Attributes	Negative Attributes
ASTM C-50 Portland Cement			
~~Type I~~	~~Most commonly used type of cement for plugging.~~	~~Forms a good seal when used with bentonite in 3 to 5 % concentration. Commonly available and can be purchased premixed on site.~~	~~High heats of hydration may be a problem in PVC-cased wells. Can shrink and crack; low-sulfate resistance. Should not be used in the presence of strong acids or in low-pH environments.~~
Type I	Most commonly used type of cement for plugging.	Forms a good seal when used with bentonite in 3 to 5 percent concentration. Commonly available and can be purchased premixed on-site.	High heats of hydration may be a problem in PVC-cased wells. Can shrink and crack; low-sulfate resistance. Should not be used in the presence of strong acids or in low-pH environments.
Type II	Similar to Type I, but with a moderate heat of hydration.	Moderate heat of hydration. Moderate resistance to sulfate.	Somewhat slower strength development than Type I; expensive. Can shrink and crack. Can be difficult to use. Should not be used in the presence of strong acids or in low-pH environments.
Type III	High early strength.	May prove useful in situations where high early strength is needed, such as borehole walls that have a tendency to collapse.	Not a common cement. Can set very quickly before decommissioning is completed. Should not be used in the presence of strong acids or in low-pH environments.
Type IV	Low heat of hydration.	May prove useful in situations where a low heat of hydration is needed	Not a common cement. Should not be used in the presence of strong acids or in low-pH environments.
~~Type V~~	~~Similar to Type I, with high resistance to sulfate and brine.~~	~~High resistance to sulfate and brine. Low heat of hydration.~~	~~Ultimate strength is less than Types I and III. Expensive; should not be used in the presence of strong acids or in low-pH environments. Can be difficult to use. Can shrink or crack.~~
Type V	Similar to Type I or CEM IV, with high resistance to sulfate and brine.	High resistance to sulfate and brine. Low heat of hydration.	Ultimate strength is less than Types I and III. Expensive; should not be used in the presence of strong acids or in low-pH environments. Can be difficult to use. Can shrink or crack.
~~K~~	~~Expansive cement.~~	~~Basically Type I or Type II Portland Cement with additions (tricalcium sulfo aluminate for example) to provide for expansion. Expansion is generally in the range from 0.05 to 0.20 % Good resistance to sulfate attack.~~	
K	Expansive cement.	Type I or Type II Portland Cement with additions (tricalcium sulfo aluminate for example) to provide for expansion. Expansion is generally in the range from 0.05 to 0.20 percent. Good resistance to sulfate attack.	
EN 197 European Cement Types			
CEM I	Portland Cement.	Commonly available and can be purchased premixed on-site.	High heats of hydration may be a problem in PVC-cased wells. Can shrink and crack; low-sulfate resistance. Should not be used in the presence of strong acids or in low-pH environments.
CEM II	Portland-composite Cement	May prove useful in situations where low heat of hydration is needed	Dependent on the actual composition utilized
CEM III	Blastfurnace Cement	May prove useful in situations where low heat of hydration is needed	Dependent on the actual composition utilized
CEM IV	Pozzolanic Cement	High resistance to sulfate and brine. Low heat of hydration. Good resistance to corrosive conditions and in reducing the permeability of cement.	Expensive; should not be used in the presence of strong acids or in low-pH environments. Can be difficult to use. Can shrink or crack. Many types of materials can be used that can result in variable results.
CEM V	Composite Cement	Dependent on the actual composition utilized	Dependent on the actual composition utilized
API 10			

~~6.5.4 *Type IV*—Type IV cement is used where a low heat of hydration is desired. It is not commonly used in decommissioning activities.~~

TABLE 1 *Continued*

~~Class A~~	~~Similar to ASTM Type I.~~	~~Can be used to a depth of 1800 m [6000 ft]. Forms a good seal when used with bentonite in 3 to 5 % concentration. Commonly available and can be purchased premixed on-site.~~	~~High heats of hydration may be a problem in PVC-cased wells. Can shrink and crack; low-sulfate resistance. Should not be used in the presence of strong acids or in low-pH environments.~~
Class A	Similar to ASTM Type I.	Can be used to a depth of 1800 m [6000 ft]. Forms a good seal when used with bentonite in 3 to 5 percent concentration. Commonly available and can be purchased premixed on-site.	High heats of hydration may be a problem in PVC-cased wells. Can shrink and crack; low-sulfate resistance. Should not be used in the presence of strong acids or in low-pH environments.
Class B	Similar to ASTM Type II.	Can be used to depth of 1800 m [6000 ft]. Moderate heat of hydration. Moderate resistance to sulfate. Available as a high-sulfate resistant variety.	Somewhat slower strength development than Type I; expensive. Can shrink and crack. Can be difficult to use. Should not be used in the presence of strong acids or in low-pH environments.
Class C	Similar to ASTM Type III.	Can be used to a depth of 1800 m [6000 ft].	Can set very quickly before decommissioning is completed. Should not be used in the presence of strong acids or in low-pH environments. Can shrink and crack.
~~Class G~~	~~Useful in a wide range of temperatures and depths through the use of accelerators or retarders.~~	~~Can be used to a depth of 2400 m [8000 ft]. Available as a sulfate-resistant variety.~~	~~Should not be used in the presence of strong acids or in low-pH environments. Can shrink and crack.~~
Class G	Useful in a wide range of temperatures and depths using accelerators or retarders.	Can be used to a depth of 2400 m [8000 ft]. Available as a sulfate-resistant variety.	Should not be used in the presence of strong acids or in low-pH environments. Can shrink and crack.
~~Class H~~	~~Useful in a wide range of depths and temperatures through the use of accelerators or retarders.~~	~~Can be used to a depth of 2400 m [8000 ft]. Available only as a moderate sulfate type.~~	~~Should not be used in the presence of strong acids or in low-pH environments. Can shrink and crack.~~
Class H	Useful in a wide range of depths and temperatures using accelerators or retarders.	Can be used to a depth of 2400 m [8000 ft]. Available only as a moderate sulfate type.	Should not be used in the presence of strong acids or in low-pH environments. Can shrink and crack.
Class J	Intended for use from a depth 3600 to 4900 m [12 000 to 16 000 ft].	Has use where very high temperatures and pressures occur.	Should not be used in the presence of strong acids or in low-pH environments. Can shrink and crack.
~~Pozzolanic cement~~	~~Addition of silicious materials to ASTM Type V or API Class A cement.~~	~~Good resistance to corrosive conditions and in reducing the permeability of cement.~~	~~Many types of materials can be used that can result in variable results.~~
Pozzolanic cement	Addition of siliceous materials to ASTM Type V or API Class A cement or CEM IV.	Good resistance to corrosive conditions and in reducing the permeability of cement.	Many types of materials can be used that can result in variable results.
~~Epoxy cements~~	~~Vinyl ester resins.~~	~~Good chemical resistance to acids and bases. Can use available equipment to place cement.~~	~~Very expensive. Poor chemical resistance to chlorinated hydrocarbons and acetic aid. Should be used only by experienced personnel. Water accelerates curing, must use diesel oil to precondition hole (diesel may increase contamination of site if hydrocarbons are a concern).~~
Epoxy cements	Vinyl ester resins.	Good chemical resistance to acids and bases. Can use available equipment to place cement.	Very expensive. Poor chemical resistance to chlorinated hydrocarbons and acetic acid. Should be used only by experienced personnel. Water accelerates curing, must use diesel oil to precondition hole (diesel may increase contamination of site if hydrocarbons are a concern).
Bentonite			
~~Pellets~~	~~Granular bentonite compressed into a tablet~~	~~Uniform in size. Easy to use. Produces a low permeability seal.~~	~~Must be hydrated after placement. Shrinkage may occur when desiccated or when in contact with high concentrations of organic compounds (greater than 2 %) or materials that are strongly acidic or alkaline. Expensive.~~
Pellets	Granular bentonite compressed into a tablet	Uniform in size. Easy to use. Produces a low permeability seal.	Must be hydrated after placement. Shrinkage may occur when desiccated or when in contact with high concentrations of organic compounds (greater than 2 percent) or materials that are strongly acidic or alkaline. Expensive.

TABLE 1 *Continued*

Chips	Raw mined montmorillonite in the form of chunks .60 to 2 cm [¼ to ¾ in.] in size.	Inexpensive. No mixing equipment needed. Forms a low-permeability seal.	Difficult to place. Must be hydrated after placement. Less swelling than beneficiated bentonite. Shrinkage may occur when desiccated when in contact with high concentrations of organic compounds (greater than 2 %) or materials that are strongly acidic or alkaline.
Chips	Raw mined montmorillonite in the form of chunks 0.60 to 2 cm [¼ to ¾ in.] in size.	Inexpensive. No mixing equipment needed. Forms a low-permeability seal.	Difficult to place. Must be hydrated after placement. Less swelling than beneficiated bentonite. Shrinkage may occur when desiccated when in contact with high concentrations of organic compounds (greater than 2 percent) or materials that are strongly acidic or alkaline.
Granular	Raw mined montmorillonite crushed and seared to a #8 to #20-mesh size. 0.841 to 2.38 mm [.331 to .0937 in.]	Can be placed at depth in dry holes. Forms a low-permeability seal.	Difficult to place in holes containing water as it quickly hydrates. Can bridge in hole. May desiccate when in contact with high concentrations of organic compounds (greater than 2 %) or materials that are strongly acidic or alkaline causing shrinkage.
Granular	Raw mined montmorillonite crushed and seared to a #8 to #20-mesh size. 0.841 to 2.38 mm [0.331 to 0.0937 in.]	Can be placed at depth in dry holes. Forms a low-permeability seal.	Difficult to place in holes containing water as it quickly hydrates. Can bridge in hole. May desiccate when in contact with high concentrations of organic compounds (greater than 2 percent) or materials that are strongly acidic or alkaline causing shrinkage.
Powdered	Pulverized and seared bentonite that passes a #200- mesh .074 mm [.0029 in.] screen. Used as drilling mud or as an additive to cement.	Used with cement to compensate for shrinkage (under saturated conditions). Other additives can be used to inhibit swelling. Retards cement set; lowers heat of hydration.	May not be a desirable plugging material in deep vadose zones due to the drying out of the material, resulting in cracking. Difficult to place in holes containing water, as it quickly hydrates. Can bridge in hole. May desiccate when in contact with high concentrations of organic compounds (greater than 2 %) or materials that are strongly acidic or alkaline causing shrinkage.
Powdered	Pulverized and seared bentonite that passes a #200- mesh 0.074 mm [0.0029 in.] screen. Used as drilling mud or as an additive to cement.	Used with cement to compensate for shrinkage (under saturated conditions). Other additives can be used to inhibit swelling. Retards cement set; lowers heat of hydration.	May not be a desirable plugging material in deep vadose zones due to the drying out of the material, resulting in cracking. Difficult to place in holes containing water, as it quickly hydrates. Can bridge in hole. May desiccate when in contact with high concentrations of organic compounds (greater than 2 percent) or materials that are strongly acidic or alkaline causing shrinkage.
High solids clay grout	Powdered bentonite (#200 mesh) .074 mm [.0029 in.] mixed with fresh water to form a slurry with 20 % solids or more and a density of 1126 Kg/m^3 g/L [9.4 lb/gal]. This would be approximately 0.9 kg [2 lb] of bentonite for each 3.8 L [gal] of water.	Does not shrink during curing. Low density reduces formation losses. Forms a low- permeability seal that stays flexible as long as it is hydrated.	May not be a desirable plugging material in deep vadose zones due to the drying out of the material, resulting in cracking. May desiccate when in contact with high concentrations of organic compounds (greater than 2 %) or materials that are strongly acidic or alkaline causing shrinkage. A low-strength material subject to expansion under low-pressure differentials such as artesian conditions.
High solids clay grout	Powdered bentonite (#200 mesh) 0.074 mm [0.0029 in.] mixed with fresh water to form a slurry with 20 percent solids or more and a density of 1126 Kg/m^3 g/L [9.4 lb/gal]. This would be approximately 0.9 kg [2 lb] of bentonite for each 3.8 L [gal] of water.	Does not shrink during curing. Low density reduces formation losses. Forms a low-permeability seal that stays flexible as long as it is hydrated.	May not be a desirable plugging material in deep vadose zones due to the drying out of the material, resulting in cracking. May desiccate when in contact with high concentrations of organic compounds (greater than 2 percent) or materials that are strongly acidic or alkaline causing shrinkage. A low-strength material subject to expansion under low-pressure differentials such as artesian conditions.
Low solids grouts	Less than 20 % solids	Easily placed and flowable	Excessive shrinkage initially and over time may lead to inadequate plugging.

TABLE 1 *Continued*

Low solids grouts	Less than 20 percent solids	Easily placed and flowable	Excessive shrinkage initially and over time may lead to inadequate plugging.

6.5.5 *Type V*—Type V cement has high resistance to sulfate, and brine solutions. This material has ultimate strength development somewhat less than either Types I or II.

6.5.6 Type K cement is expansive and can be used to compensate for shrinkage. This cement is basically Type I or more commonly Type II Portland Cement with additives to produce expansion. It can be of use in plugging situations where water-tightness is important. Type K cement contains calcium sulfoaluminate. When mixed with water, the hydration causes an expansion ranging from approximately 0.05 to 0.20 % (**7**).

NOTE 13—When type K cements are not available, additives such as Aluminum Oxide powder can be added and mixed into the grout. Additives are commercially available and use should be in accordance with the manufacturer's instructions.

NOTE 14—Portland Cement Specifications that provide equivalent properties are typically available in other national or regional standards (**8**) as an example).

6.4 *API Cements Commonly Used Materials*—(Subsections9 6.2) and 6.3: introduced the general criteria that must be evaluated during the process of selecting the appropriate procedure and material for plugging a specific well. Because well construction and local geological conditions are site specific, a wide variety of materials and procedures may be used to complete the closure.

6.6.1 *Class A*—Class A cement corresponds closely to ASTM Type 1. This cement is intended to be used from the surface to a depth of 1800 m [6000 ft].

6.6.2 *Class B*—Class B cement corresponds closely to ASTM Type II. It is intended for use from the surface to a depth of 1800 m [6000 ft] and is also available as a high-sulfate resistant variety.

6.6.3 *Class C*—Class C cement corresponds closely to ASTM Type III. It is intended for use from the surface to a depth of 1800 m [6000 ft]. It is also available as a high-sulfate resistant variety.

6.6.4 *Class G*—Class G cement is intended for use from the surface to a depth of 2400 m [8000 ft] and can be used with accelerators or retarders to cover a wide range of depths and temperatures. The cement is also available as a high-sulfate resistant variety.

6.6.5 *Class H*—Class H cement is intended for use from the surface to a depth of 2400 m [8000 ft]. It can be used with a wide variety of accelerators and retarders to cover a wide range of depths and temperatures. It is available only as a moderate-sulfate resistant type.

6.6.6 *Class J*—This cement is intended for use from a depth of 3600 to 4900 m [12 000 to 16 000 ft] where very high temperatures and pressures can be expected to occur.

6.4.1 *Other Cements*—Other cementsSection 6.4 have been developed that may have applicability in decommissioning activities. These include the following:presents a review of the plugging materials most commonly used to decommission monitoring wells. Table 1 summarizes these materials and lists the most important considerations (positive and negative) for their use. Table 2 provides a comparison of sulfate resistance between ASTM Type V cement with and without pozzolans. Cole also reported resistance to various chemicals for epoxy cements (see Table 3).

6.6.7.1 Ultralight cements with a slurry density that can be as low as 720 cm Kg/L [6 lb/gal]. This material can be made by foaming the cement with nitrogen or through the addition of hollow glass microspheres between 60 and 315 µm [.002362 to .01240154 in.] in diameter. The latter forms a slurry of between 1080 and 1440 Kg/L [9 and 12 lb/gal]. Ultralight cements and microspheres have been reported (**10**) for cement unconsolidated sands and for plugging cavernous formations and lost circulation zones. Reference (**11**) provided similar information on microspheres. Microspheres can also be used in high-pressure applications when it may be desirable to limit density increases. Another advantage is the low water/cement ratio due to the low water absorbency and low density (**11**).

6.6.7.2 *Pozzolanic-Portland Cements*—These cements consist of silicious materials that develop into a cement in the presence of lime and water. Both natural materials of volcanic origin such as perlites (volcanic ashes), heat-treated clays, shales, tuffs, opaline cherts, diatomaceous earth and artificial materials consisting of byproducts from glass factories, furnace slag, and fly ash have been used (**7**, **10**, **12**). The large variety of materials that can be used as a source for pozzolans may result in variable results.

TABLE 2 Comparison of ASTM Type V Cement With and Without Pozzolan Materials[A]

Cement Type	Relative Degree of Sulfate Attack	Percentage of Water Soluble Sulfate (as SO_4) in Soil, ppm	Sulfate (as SO_4) in Water Samples, ppm
V	Severe	0.20 to 2.00	1 500 to 10 000
V (plus pozzolan)	Very severe	2.00 or more	10 000 or more

[A]See Ref (**105**).