United States Environmental Protection Agency

Geologic Sequestration of Carbon Dioxide

Draft Underground Injection Control (UIC) Program Guidance on Class VI Well Plugging, Post-Injection Site Care, and Site Closure

Office of Water (4606M) EPA 816-P-13-005 April 2013

Disclaimer

The *Federal Requirements under the Underground Injection Control Program for Carbon Dioxide Geologic Sequestration Wells* (75 FR 77230, December 10, 2010), referred to as the Class VI Rule, establishes a new class of injection well (Class VI).

The Safe Drinking Water Act (SDWA) provisions and EPA regulations cited in this document contain legally-binding requirements. In several chapters, this guidance document makes recommendations and offers alternatives that go beyond the minimum requirements indicated by the Class VI Rule. This is intended to provide information and recommendations that may be helpful for UIC Class VI Program implementation efforts. Such recommendations are prefaced by the words 'may' or 'should' and are to be considered advisory. They are not required elements of the Class VI Rule. Therefore, this document does not substitute for those provisions or regulations, nor is it a regulation itself, so it does not impose legally-binding requirements on EPA, states, or the regulated community. The recommendations herein may not be applicable to each and every situation.

EPA and state decision makers retain the discretion to adopt approaches on a case-by-case basis that differ from this guidance where appropriate. Any decisions regarding a particular facility will be made based on the applicable statutes and regulations. Mention of trade names or commercial products does not constitute endorsement or recommendation for use. EPA is taking an adaptive rulemaking approach to regulating Class VI injection wells. The agency will continue to evaluate ongoing research and demonstration projects and gather other relevant information as needed to refine the Rule. Consequently, this guidance may change in the future without a formal notice and comment period.

While EPA has made every effort to ensure the accuracy of the discussion in this document, the obligations of the regulated community are determined by statutes, regulations, or other legally binding requirements. In the event of a conflict between the discussion in this document and any statute or regulation, this document would not be controlling.

Note that this document only addresses issues covered by EPA's authorities under the SDWA. Other EPA authorities, such as Clean Air Act (CAA) requirements to report carbon dioxide injection activities under the Greenhouse Gas Mandatory Reporting Rule (GHG MRR), are not within the scope of this document.

Executive Summary

The *Federal Requirements Under the Underground Injection Control (UIC) Program for Carbon Dioxide Geologic Sequestration Wells* are codified in the U.S. Code of Federal Regulations [40 CFR 146.81 et seq.] and are referred to in this document as the Class VI Rule. The Class VI Rule establishes a new class of injection well, Class VI, and sets minimum federal technical criteria for Class VI injection wells that are protective of underground sources of drinking water (USDWs). This guidance is part of a series of technical guidance documents that the United States Environmental Protection Agency (EPA) is developing to support owners or operators of Class VI wells and UIC Program permitting authorities in the implementation of the Class VI Rule. The Class VI Rule and related documents are available at http://water.epa.gov/type/groundwater/uic/wells_sequestration.cfm.

The Class VI Rule includes requirements for well plugging [40 CFR 146.92] and post-injection site care (PISC) [40 CFR 146.93] that are designed to ensure that after injection ceases, the geologic sequestration (GS) project does not pose a threat to USDWs. Owners or operators must properly plug the injection well, monitor the site for a timeframe established in the permit (e.g., 50 years or an alternative timeframe), demonstrate to the UIC Program Director that conditions at the site have stabilized and do not pose a threat of endangerment to USDWs, and complete the plugging of monitoring wells to enable site closure. The activities to be conducted during these stages of the project must be detailed in the Injection Well Plugging Plan [40 CFR 146.92(b); 40 CFR 146.82(a)(16)] and the PISC and Site Closure Plan [40 CFR 146.93(a); 40 CFR 146.82(a)(17)] and documented through well plugging reports [40 CFR 146.92(d)], non-endangerment demonstrations [40 CFR 146.93(b) and (c)], and a site closure report [40 CFR 146.93(f)]. This *Draft UIC Program Guidance on Class VI Well Plugging, Post-Injection Site Care, and Site Closure* provides information to help owners or operators perform the necessary activities to successfully transition from the operational phase of a GS project to the PISC phase and, ultimately, to site closure.

After injection ceases at a GS project, the injection well must be plugged to ensure that the well does not become a conduit for fluid movement into USDWs [40 CFR 146.92]. Required injection well plugging activities include flushing the well with a buffer fluid, testing the external mechanical integrity of the well, and emplacing cement into the well in a manner that will prevent fluid movement that may endanger USDWs [40 CFR 146.92(a) and (b)]. Additionally, materials used for injection well plugging must be compatible with the injectate [40 CFR 146.92(b)(5)]. This document provides information on performing mechanical integrity testing prior to well plugging, preparing the well for plugging, and selecting plugging materials, plug depths, and emplacement methods [40 CFR 146.92(b)(4)-(6)]. Other relevant guidance documents are referenced as appropriate. The document also provides guidance on preparing the required notices of intent to plug and plugging reports. Owners or operators are encouraged to consider using similar procedures when plugging monitoring wells.

The PISC period entails monitoring as specified in the UIC Program Director-approved PISC and Site Closure Plan [40 CFR 146.93(a); 40 CFR 146.82(a)(17)]. This monitoring is an extension of the monitoring conducted during the operational phase of the project designed to ensure that USDWs are protected from endangerment. EPA anticipates that it will be similar to operational phase monitoring; however, changes to the frequency and types of monitoring may be made during the PISC period (e.g., a decrease in monitoring frequency). Changes in PISC monitoring must be made through approved revisions to the PISC and Site Closure Plan [40 CFR 146.93(a)(4)]. PISC must continue for a timeframe established in the permit (e.g., 50 years or an alternative timeframe established based on site-specific data, modeling, and other required lines of evidence as described at 40 CFR 146.93(c)) until an owner or operator can demonstrate non-endangerment. During PISC, an owner or operator may be able to demonstrate non-endangerment of USDWs in advance of the timeframe established in the permit [40 CFR 146.93(b)(1)]. Under such circumstances, the owner or operator may submit non-endangerment information to the UIC Program Director to support site closure, and the UIC Program Director may subsequently approve an amended PISC and Site Closure Plan to authorize early site closure. This guidance document includes considerations and recommendations to help owners or operators petition for an alternate PISC timeframe (i.e., other than the 50-year default) during permitting; revise the PISC timeframe during the injection operation; and make a non-endangerment demonstration for revision to the PISC and Site Closure Plan.

The guidance also discusses the information that the owner or operator must submit to demonstrate non-endangerment [40 CFR 146.93(b)(3)] showing that no additional monitoring is needed to ensure that the project does not pose a risk to USDWs before the UIC Program Director will authorize site closure. Once the non-endangerment demonstration is approved by the UIC Program Director and site closure has been authorized, 120 days' notice of intent must be submitted [40 CFR 146.93(d)]; following site closure, a site closure report must be sent to the UIC Program Director within 90 days [40 CFR 146.93(f)]. The types of documentation to be included in the notifications (e.g., well plugging, notification to authorities, records regarding the injectate) are described at 40 CFR 146.93(f). This document includes guidance on providing the necessary information that the UIC Program Director will need to make a decision regarding site closure, as well as guidance on completing requirements for the site closure report.

Table of Contents

List of Figures

List of Tables

Acronyms and Abbreviations

AoR	Area of Review
API	American Petroleum Institute
AWWA	American Water Works Association
CAA	Clean Air Act
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act (Superfund)
CFR	Code of Federal Regulations
EGR	Enhanced Gas Recovery
EOR	Enhanced Oil Recovery
EPA	United States Environmental Protection Agency
GHG MRR	Green House Gas Monitoring and Reporting Rule
GS	Geologic Sequestration
MIT	Mechanical Integrity Test
NETL	National Energy Technology Laboratory
PISC	Post-Injection Site Care
QA/QC	Quality Assurance/Quality Control
RCRA	Resource Conservation and Recovery Act
SC	Specific Conductivity
SDWA	Safe Drinking Water Act
TDS	Total Dissolved Solids
TVD	True Vertical Depth
UIC	Underground Injection Control
USDW	Underground Source of Drinking Water
USEPA	United States Environmental Protection Agency

Definitions

Key to definition sources:

1: Source: 40 CFR 144.3.
2: Class VI Rule Preamble.
3: Source: 40 CFR 146.81(d).
4: This definition was drafted for the purposes of this document.
5: EPA's UIC website (http://water.epa.gov/type/groundwater/uic/glossary.cfm).
6: Source: 40 CFR 144.6(f) and 144.80(f).

Administrator means the Administrator of the United States Environmental Protection Agency, or an authorized representative.[1]

Annulus means the space between the well casing and the wall of the borehole; the space between concentric strings of casing; the space between casing and tubing.[2]

Area of review (AoR) means the region surrounding the geologic sequestration project where USDWs may be endangered by the injection activity. The AoR is delineated using computational modeling that accounts for the physical and chemical properties of all phases of the injected carbon dioxide stream and displaced fluids, and is based on available site characterization, monitoring, and operational data as set forth in 40 CFR 146.84.[3]

Bottomhole pressure means the pressure at the bottom of the well bore. It may be measured directly with a downhole pressure transducer, or in some cases estimated from the surface pressure and the height and density of the fluid column.[4]

Brine means water that has a quantity of salt, especially sodium chloride, dissolved in it. Large quantities of brine are often produced along with oil and gas.[5]

Carbon dioxide plume means the extent underground, in three dimensions, of an injected carbon dioxide stream.[3]

Carbon dioxide stream means carbon dioxide that has been captured from an emission source (e.g., a power plant), plus incidental associated substances derived from the source materials and the capture process, and any substances added to the stream to enable or improve the injection process. This subpart [Subpart H of 40 CFR 146] does not apply to any carbon dioxide stream that meets the definition of a hazardous waste under 40 CFR part 261.[3]

Casing means pipe material placed inside a drilled hole to prevent the hole from collapsing. The two types of casing in most injection wells are (1) surface casing, the outermost casing that extends from the surface to the base of the lowermost USDW, and (2) long-string casing, which extends from the surface to or through the injection zone.[2]

Cement means material used to support and seal the well casing to the rock formations exposed in the borehole. Cement also protects the casing from corrosion and prevents movement of injectate up the borehole. The composition of the cement may vary based on the well type and purpose; cement may contain latex, mineral blends, or epoxy.[2]

Class VI wells means wells that are not experimental in nature that are used for geologic sequestration of carbon dioxide beneath the lowermost formation containing a USDW; or, wells used for geologic sequestration of carbon dioxide that have been granted a waiver of the injection depth requirements pursuant to requirements at 40 CFR 146.95; or, wells used for geologic sequestration of carbon dioxide that have received an expansion to the areal extent of an existing Class II EOR or EGR aquifer exemption pursuant to 40 CFR 146.4 and 40 CFR 144.7(d).[6]

Computational model means a mathematical representation of the injection project and relevant features, including injection wells, site geology, and fluids present. For a GS project, site specific geologic information is used as input to a computational code, creating a computational model that provides predictions of subsurface conditions, fluid flow, and carbon dioxide plume and pressure front movement at that site. The computational model comprises all model inputs and predictions (i.e., outputs).[4]

Confining zone means a geologic formation, group of formations, or part of a formation stratigraphically overlying the injection zone(s) that acts as barrier to fluid movement. For Class VI wells operating under an injection depth waiver, confining zone means a geologic formation, group of formations, or part of a formation stratigraphically overlying and underlying the injection zone(s).[3]

Corrective action means the use of UIC Program Director-approved methods to assure that wells within the AoR do not serve as conduits for the movement of fluids into USDWs.[3]

Corrosive means having the ability to wear away a material by chemical action. Carbon dioxide mixed with water forms carbonic acid, which can corrode well materials.[2]

Enhanced Oil or Gas Recovery (EOR/EGR) typically means the process of injecting a fluid (e.g., water, brine, or carbon dioxide) into an oil or gas bearing formation to recover residual oil or natural gas. The injected fluid thins (decreases the viscosity) and/or displaces extractable oil and gas, which is then available for recovery. This is also used for secondary or tertiary recovery.[3]

Fluid means any material or substance which flows or moves whether in a semisolid, liquid, sludge, gas, or other form or state.[1]

Formation or geological formation means a layer of rock that is made up of a certain type of rock or a combination of types.[2]

Geologic sequestration (GS) means the long-term containment of a gaseous, liquid, or supercritical carbon dioxide stream in subsurface geologic formations. This term does not apply to carbon dioxide capture or transport.[3]

Geologic sequestration project means an injection well or wells used to emplace a carbon dioxide stream beneath the lowermost formation containing a USDW; or, wells used for geologic sequestration of carbon dioxide that have been granted a waiver of the injection depth requirements pursuant to requirements at 40 CFR 146.95; or, wells used for geologic sequestration of carbon dioxide that have received an expansion to the areal extent of an existing Class II EOR or EGR aquifer exemption pursuant to 40 CFR 146.4 and 144.7(d). It includes the subsurface three-dimensional extent of the carbon dioxide plume, associated area of elevated pressure, and displaced fluids, as well as the surface area above that delineated region.[3]

Geophysical surveys refers to the use of geophysical techniques (e.g., seismic, electrical, gravity, or electromagnetic surveys or well logging methods such as gamma ray and spontaneous potential) to characterize subsurface rock formations.[2]

Injectate means the fluids injected. For the purposes of the Class VI Rule, this is also known as the carbon dioxide stream.[2]

Injection depth waivers refers to the provisions at 40 CFR 146.95 that allow owners or operators to seek a waiver from the Class VI injection depth requirements for GS to allow injection into non-USDW formations while ensuring that USDWs are protected from endangerment.[4]

Injection zone means a geologic formation, group of formations, or part of a formation that is of sufficient areal extent, thickness, porosity, and permeability to receive carbon dioxide through a well or wells associated with a GS project.[3]

Mechanical integrity means the absence of significant leakage within the injection tubing, casing, or packer (known as internal mechanical integrity), or outside of the casing (known as external mechanical integrity).[2]

Mechanical integrity test (MIT) refers to a test performed on a well to confirm that a well maintains internal and external mechanical integrity. MITs are a means of measuring the adequacy of the construction of an injection well and a way to detect problems within the well system.[2]

Model means a representation or simulation of a phenomenon or process that is difficult to observe directly or that occurs over long timeframes. Models that support GS can predict the flow of carbon dioxide within the subsurface, accounting for the properties and fluid content of the subsurface formations and the effects of injection parameters.[2]

Mud refers to a generic term for a wide range of drilling fluids, usually water or oil but occasionally synthetically based with high concentrations of suspended solids.[4]

Packer means a mechanical device that seals the outside of the tubing to the inside of the long-string casing, isolating an annular space.[2]

Parameter means a mathematical variable used in governing equations, equations of state, and constitutive relationships. Parameters describe properties of the fluids present, porous media, and fluid sources and sinks (e.g., injection well). Examples of model parameters include intrinsic permeability, fluid viscosity, and fluid injection rate.[4]

Plug means a watertight, gastight seal installed in a bore hole or well to prevent movement of fluids that may be mechanical or composed of cement or other material that are capable of zonal isolation.[4]

Portland cement refers to a hydraulic cement made by reacting a pulverized calcium silicate hydrate material (C-S-H), which in turn is made by heating limestone and clay in a kiln, with water to create a calcium silicate hydrate and other reaction products.[4]

Post-injection site care (PISC) means appropriate monitoring and other actions (including corrective action) needed following cessation of injection to ensure that USDWs are not endangered, as required under 40 CFR 146.93.[3]

Pressure front means the zone of elevated pressure that is created by the injection of carbon dioxide into the subsurface. For GS projects, the pressure front of a carbon dioxide plume refers to the zone where there is a pressure differential sufficient to cause the movement of injected fluids or formation fluids into a USDW.[3]

Site closure means the specific point or time, as determined by the UIC Program Director following the requirements under 40 CFR 146.93, at which the owner or operator of a GS site is released from PISC responsibilities.[3]

Supercritical fluid means a fluid above its critical temperature (31.1ºC for carbon dioxide) and critical pressure (73.8 bar for carbon dioxide).[4]

Total dissolved solids (TDS) refers to the measurement, usually in mg/L, for the amount of all inorganic and organic substances suspended in liquid as molecules, ions, or granules. For injection operations, TDS typically refers to the saline (i.e., salt) content of water-saturated underground formations.[2]

Transmissive fault or fracture means a fault or fracture that has sufficient permeability and vertical extent to allow fluids to move between formations.[3]

Tubing refers to a small-diameter pipe installed inside the casing of a well. Tubing conducts injected fluids from the wellhead at the surface to the injection zone and protects the long-string casing of a well from corrosion or damage by the injected fluids.[5]

Underground Injection Control (UIC) Program refers to the program EPA, or an approved state, is authorized to implement under the Safe Drinking Water Act (SDWA) that is responsible for regulating the underground injection of fluids by well injection. This includes setting the federal minimum requirements for construction, operation, permitting, and closure of underground injection wells.[4]

Underground Injection Control (UIC) Program Director refers to the chief administrative officer of any approved state or tribal agency or EPA Region that has been delegated to operate an approved UIC Program.[5]

Underground Source of Drinking Water (USDW) means an aquifer or its portion which supplies any public water system; or which contains a sufficient quantity of ground water to supply a public water system; and currently supplies drinking water for human consumption; or contains fewer than 10,000 mg/l total dissolved solids; and which is not an exempted aquifer. [1]

Well bore refers to the hole that remains throughout a geologic (rock) formation after a well is drilled.[4]

Well plugging refers to the act of sealing off a well so that all USDWs and producing zones are zonally isolated and the well bore, casings, and annulus can no longer act as a conduit for fluids. Plugging typically involves the injection of alternating layers of mud and cement into the well bore, casings, and annulus.[4]

Workover refers to any maintenance activity performed on a well that involves ceasing injection and removing the wellhead.[4]

1 Introduction

The Underground Injection Control (UIC) Program of the United States Environmental Protection Agency (EPA) is responsible for regulating the construction, operation, permitting, and closure of injection wells that place fluids underground. EPA's *Federal Requirements Under the Underground Injection Control Program for Carbon Dioxide Geologic Sequestration Wells* [40 CFR 146.81 et seq.], referred to as the Class VI Rule, created a new UIC injection well class, Class VI, specifically for the injection of carbon dioxide for the purpose of geologic sequestration (GS).

1.1 The Phases of a GS Project

The risk posed to underground sources of drinking water (USDWs) during the operation of a GS project increases during the injection phase as carbon dioxide is injected and subsurface pressures increase; risk will likely decrease during post-injection site care (PISC) as the carbon dioxide plume begins to dissipate and pressures stabilize. While the actual magnitude and change in project risk during these phases depend on site-specific factors, Figure 1 below illustrates how risk to USDWs changes throughout the life of a GS project.

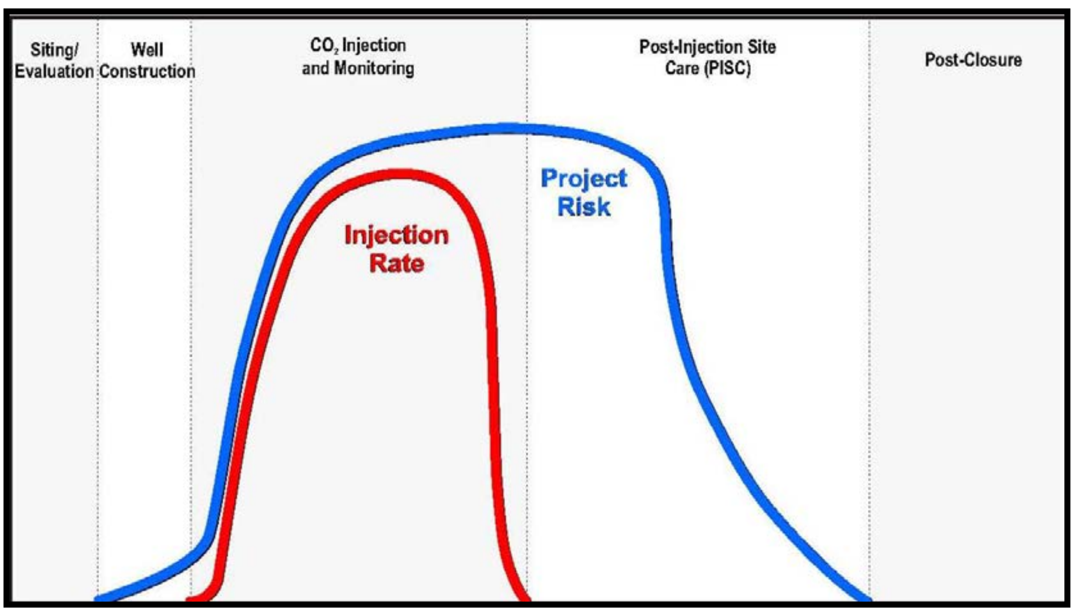

Figure 1. Risk Curve for a GS Project.

To address the risks to USDWs following the cessation of injection (i.e., during the PISC and post-closure phases in Figure 1), the Class VI Rule at 40 CFR 146.92 and 146.93 includes requirements that owners or operators must follow to properly plug their injection wells, monitor the site until it can be demonstrated that it no longer poses an endangerment risk, and close the GS site. The purpose of this guidance is to explain these requirements for Class VI well owners or operators and UIC Program Directors. EPA encourages communication between the owner or operator and the UIC Program Director throughout the process of planning for and executing all aspects of the GS project, including well plugging and PISC.

1.2 Injection Well Plugging Requirements

Well plugging refers to the activities associated with removing well components, flushing the well, and installing plugs. Proper well plugging is important for ensuring that the well is properly abandoned and does not provide a conduit for fluid movement that might endanger USDWs.

Class VI well owners or operators must prepare, maintain, and comply with an Injection Well Plugging Plan [40 CFR 146.92(b)]. Specifically, the owner or operator must flush each injection well with a buffer fluid, determine bottomhole pressure, perform a final external mechanical integrity test (MIT), and plug the well with materials that are compatible with carbon dioxide. EPA also recommends that well plugging materials be compatible with the formation fluids. The requirements for plugging Class VI injection wells are included in the Class VI Rule at 40 CFR 146.92 and are discussed in detail in Section 2 of this guidance.

The procedures required at 40 CFR 146.92 apply specifically to injection wells. However, owners or operators may consider employing the same well plugging procedures when plugging monitoring wells at the end of the PISC period (see Section 4.2)]. Performing such activities on monitoring wells will help to demonstrate non-endangerment to USDWs [40 CFR 146.93(b)(2)] and help ensure that the wells do not allow movement of injection or formation fluids [40 CFR 146.93(e)].

1.3 Post-Injection Site Care Requirements

PISC refers to the time period immediately following cessation of injection until site closure. Although there is no longer injection during this phase, the project still poses some risk to USDWs due to elevated pressures and the presence of mobile-phase carbon dioxide.

Owners or operators of Class VI wells must prepare, maintain, and comply with a PISC and Site Closure Plan [40 CFR 146.93(a)]. Specifically, owners or operators must monitor the site to show the position of the carbon dioxide plume and pressure front and demonstrate that USDWs are not endangered during the approved PISC monitoring timeframe [40 CFR 146.93(b)]. The purpose of these requirements is to ensure that any risk to USDWs is detected and appropriate remediation/corrective action is taken in the case of endangerment.

Section 3 discusses PISC including monitoring, the default and alternative timeframes, and the evaluation of risk reduction to USDWs and the non-endangerment demonstration for this phase of the GS project.

1.4 Site Closure Requirements

Site closure refers to the procedures and period immediately following PISC, when an owner or operator must plug and abandon all monitoring wells to enable the end of the Class VI project and termination of the permit [40 CFR 146.93(e)]. Site closure commences only when there is no longer risk of endangerment to USDWs and when authorized by the UIC Program Director.

Site closure regulations are established to ensure that all PISC monitoring wells are plugged appropriately and to the UIC Program Director's satisfaction, that all project records are maintained, and that future land owners are made aware of the project and previous land use.

Accordingly, the owner or operator must provide the UIC Program Director with a notice of intent for site closure at least 120 days prior to site closure [40 CFR 146.93(d)], plug all monitoring wells [40 CFR 146.93(e)], submit a site closure report within 90 days of site closure [40 CFR 146.93(f)], and record a notation in the deed or similar document [40 CFR 146.93(g)]. Note that following site closure, the owner or operator is responsible for any remedial action deemed necessary to prevent USDW endangerment caused by the injection operation (see Section 4.4).

Site closure regulations are discussed in further detail in Section 4.

1.5 Relationship of this Guidance to Related Guidance Documents

This document is part of a series of technical guidance documents intended to provide information and possible approaches for addressing various aspects of permitting and operating a UIC Class VI injection well. Other UIC Program GS guidances that owners or operators performing injection well plugging, PISC, and site closure activities may find useful are available on the UIC Program's website at http://water.epa.gov/type/groundwater/uic/wells_sequestration.cfm.

2 Well Plugging

This section includes a discussion of the UIC Class VI well plugging requirements [40 CFR 146.92] and practices suitable for injection and monitoring wells associated with a GS project. Some information in this document has been incorporated from other UIC Program guidance documents (USEPA, 1982; USEPA, 1989). Guidance from the American Petroleum Institute (API, 1993) is also referenced, along with more recent literature on specialty plugging materials that may be suitable for the unique aspects of a GS project (i.e., carbon dioxide-bearing fluids in the injection zone). In addition, several testing activities discussed briefly below (e.g., mechanical integrity testing) are described in detail in the *UIC Program Class VI Well Testing and Monitoring Guidance*.

2.1 Purpose of Well Plugging

Proper plugging of injection and monitoring wells is a long-standing requirement of the UIC Program, designed to ensure that wells do not serve as conduits for fluid movement into USDWs following cessation of injection and site closure. Just as requirements and best practices for primary cementing are designed to produce properly constructed wells with mechanical integrity, the Class VI well plugging requirements [40 CFR 146.92; 40 CFR 146.93(e)] are intended to ensure that an abandoned well maintains integrity and will not pose a threat to USDWs. For this reason, well plugging activities must be described in the Injection Well Plugging Plan [40 CFR 146.92(b); 40 CFR 146.82(a)(16)], properly performed per 40 CFR 146.92(b), and documented in plugging reports [40 CFR 146.92(d)] and the site closure report [40 CFR 146.93(f)(1)] to the satisfaction of the UIC Program Director.

2.2 Timing of Well Plugging

Plugging activities will most likely begin upon cessation of injection. However, the immediate plugging of the injection well is not a requirement, as some owners or operators may elect to convert an injection well to a monitoring well. In either scenario, once injection has ceased, the injection apparatus in the well serves no further purpose; therefore, the owner or operator may either choose to plug the well and complete all plugging activities or perform some of the preparatory activities (e.g., mechanical integrity testing, well cleaning) and recomplete the well for monitoring purposes. EPA recommends that any such recompletion take place as soon as practical to allow continued acquisition of pressure data. In the case of recompletion of the injection well, the owner or operator will be required to plug the well upon demonstration of non-endangerment made for site closure [40 CFR 146.93(e)]. Regardless of the timing of injection well plugging, the plugging must be done in a manner pursuant to requirements at 40 CFR 146.92 to ensure that the well does not become a conduit for fluid movement into USDWs. The plugging must be performed according to the approved Injection Well Plugging Plan submitted with the Class VI permit application [40 CFR 146.92(b); 40 CFR 146.82(a)(16)].

The Class VI Rule, at 40 CFR 146.92(c), requires that the owner or operator notify the UIC Program Director in writing at least 60 days before plugging of an injection well (a template for notice of intent to plug is provided in Appendix B). At this time, if any changes have been made to the original Injection Well Plugging Plan, the owner or operator must also provide the revised Injection Well Plugging Plan [40 CFR 146.92(c)]. This 60-day time period allows for an ongoing dialogue between owners or operators and the UIC Program Directors regarding planned well plugging activities. Once well plugging procedures have been finalized, or confirmation has been made that no changes to the Injection Well Plugging Plan are necessary, well plugging may proceed. A well plugging report must be submitted to the UIC Program Director by the owner or operator within 60 days of plugging the injection well [40 CFR 146.92(d)].

Monitoring wells must also ultimately be plugged [40 CFR 146.93(e)]. Some (if not all) monitoring wells will need to remain in use during PISC to perform required monitoring; the locations to be sampled will be specified in the approved PISC and Site Closure Plan [40 CFR 146.93(a)(2)(iii)]. However, if any monitoring wells will not be included in the post-injection monitoring program, the owner or operator may choose to plug them at the beginning of the post-injection period. If the PISC and Site Closure Plan is amended during the PISC phase of the project [40 CFR 146.93(a)(4)], EPA recommends that the owner or operator plug monitoring wells that will no longer be used for sampling to eliminate the potential that they become conduits for fluid movement. Thus, the plugging schedule for monitoring wells may be adjusted as appropriate in consultation with the UIC Program Director and reflected in changes to the PISC and Site Closure Plan.

Because improperly abandoned monitoring wells may become conduits for fluid movement into USDWs (similar to improperly abandoned injection wells), EPA recommends that owners or operators plug their monitoring wells in a similar manner to that used to meet the requirements for injection well plugging as discussed in Sections 2.5 and 2.6. A more detailed discussion of monitoring well plugging is included in Section 4.2 of this guidance document.

At the end of PISC, and after the UIC Program Director has authorized site closure, the owner or operator must demonstrate that all monitoring and injection wells have been plugged in a manner that will not allow movement of injection or formation fluids that endangers a USDW [40 CFR 146.93(e); 40 CFR 146.93(f)(1)]. EPA also recommends that owners or operators submit notice of intent to plug monitoring wells 60 days in advance and monitoring well plugging reports within 60 days after plugging.

2.3 Development and Submittal of Injection Well Plugging Plan

The Class VI Rule at 40 CFR 146.82(a)(16) requires owners or operators to prepare and submit a proposed Injection Well Plugging Plan with the permit application for approval by the UIC Program Director. The UIC Program Director-approved plan is incorporated into the Class VI permit.

The Injection Well Plugging Plan must include a description of how the owner or operator will meet the Class VI injection well plugging requirements at 40 CFR 146.92. The plan must include the following information:

- Appropriate tests or measures to identify bottomhole reservoir pressure to determine the appropriate plugging fluid density [40 CFR 146.92(b)(1)];

- Appropriate testing methods to ensure external mechanical integrity to demonstrate that the long-string casing and cement that are left in the ground after the well is plugged will maintain their integrity [40 CFR 146.92(b)(2)];

- The type and number of plugs to be used for plugging of the injection well [40 CFR 146.92(b)(3)];

- The placement of each plug, including the elevation of the top and bottom of each plug, recommended to be submitted along with schematics and drawings, if appropriate [40 CFR 146.92(b)(4)];

- The type, grade, and quantity of material to be used in plugging. The material must be compatible with the carbon dioxide stream [40 CFR 146.92(b)(5)]; and

- The method of placement of the plugs, such as the balance method, retainer method, or two-plug method [40 CFR 146.92(b)(6)].

Stratigraphic information at the GS site, such as the location and thickness of the injection zone and USDW-containing formations, their geochemistry, well construction details, and the composition of the carbon dioxide stream or injectate are important factors to consider while developing an Injection Well Plugging Plan. Also, the UIC Program Director will evaluate the plan in conjunction with the site characterization data and other proposed plans, such as the Well Construction Plan and proposed operating conditions. Submittal, evaluation, and approval of the Injection Well Plugging Plan may be an iterative process, and ongoing communication is encouraged between the owner or operator and the UIC Program Director.

Although the Class VI Rule does not require periodic reviews and amendments to the Injection Well Plugging Plan throughout the operation/injection phase, EPA recommends that owners or operators evaluate how any changes in facility operation, any new data collected during monitoring and/or area of review (AoR) reevaluations, or any adverse events that required an emergency response may warrant amendments to the various plans, including the Injection Well Plugging Plan. If the Injection Well Plugging Plan is revised, the revised plan must be submitted when notifying the UIC Program Director of the intent to plug the well, at least 60 days prior to conducting the plugging activity [40 CFR 146.92(c)].

The development of the Injection Well Plugging Plan is described further in the *UIC Program Class VI Well Project Plan Development Guidance*, including details on what specific information must be included in the plan, how the plan should be structured, how the amendments to the plan should be made, and what underlying data must be submitted with the plan. A template/example of an Injection Well Plugging Plan is given in Appendix A of this document.

2.4 Tests to Perform Prior to Plugging

Prior to injection well plugging, the Class VI Rule requires that the owner or operator flush each Class VI injection well with a buffer fluid (discussed in Section 2.5), determine bottomhole reservoir pressure, and perform a final external MIT [40 CFR 146.92(a)]. Determination of bottomhole pressure and mechanical integrity are needed to plan any remedial activities and to ensure that plugging materials and procedures are selected correctly.

2.4.1 Determination of Bottomhole Reservoir Pressure

Bottomhole pressure refers to the pressure of the fluids at the location of the perforations (i.e., screened interval) of the injection well. Prior to the plugging of a Class VI well, the owner or operator is required to determine bottomhole pressure pursuant to requirements at 40 CFR 146.92(a), using the tests or measures described in the UIC Program Director-approved Injection Well Plugging Plan [40 CFR 146.92(b)(1)]. The purposes of testing bottomhole reservoir pressure prior to plugging are to: (1) determine the density of fluid that should be used during flushing and well cleaning; (2) determine the density of plugging (buffer) fluid needed to establish static equilibrium prior to plug emplacement; and (3) obtain a measurement of pressure at the injection well that should be used in calculations of pressure decay within the injection zone.

After injection ceases and the well is shut in, bottomhole pressure can be estimated from downhole pressure transducers or, in some cases, wellhead (i.e., surface) pressure measurements. If a single fluid phase is present in the well bore, wellhead pressure measurements may be used with knowledge of the average fluid density, and the true vertical depth (TVD) of the well. Bottomhole pressure is equal to wellhead pressure plus the hydrostatic pressure from the weight of the fluid column between the wellhead and well bottom (Figure 2). However, when separate fluid phases are present in the well bore (e.g., gas and supercritical fluid), more complex thermodynamic modeling methods will need to be used to estimate bottomhole pressure from wellhead pressure (see e.g., Nurafza and Fernagu, 2009).

Because of temperature effects and density variations in the fluid, a more robust approach for determining bottomhole pressure is to obtain actual measurements with a dedicated downhole pressure gauge or with a pressure gauge lowered into the borehole. Further information regarding measurement of well pressures is available in the *UIC Program Class VI Well Testing and Monitoring Guidance*.

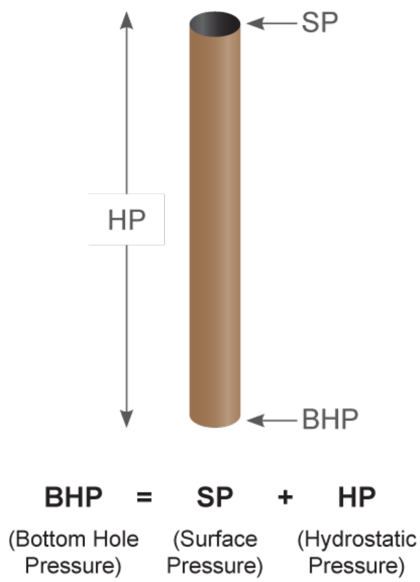

Figure 2. Relationship Between Bottomhole Pressure and Surface Pressure.
Adapted from: Drilling Formulas and Drilling Calculations (no date).

2.4.2 Mechanical Integrity Testing

Prior to injection well plugging, the owner or operator must perform a final external MIT as required at 40 CFR 146.92(a). The appropriate testing methods must be specified in the UIC Program Director-approved Injection Well Plugging Plan [40 CFR 146.92(b)(2)]. Unless an alternative test is approved by the EPA Administrator and the UIC Program Director under 40 CFR 146.89(e), the Class VI Rule at 40 CFR 146.89(c) requires that the owner or operator use at least one of the following external MITs: an approved tracer survey (e.g., oxygen activation log); a temperature log; or a noise log.

The purpose of conducting a final MIT is to verify the absence of leakage through channels adjacent to the well bore or the well's long-string casing that may result in significant fluid movement into a USDW. A demonstration of external mechanical integrity indicates that the cement and casing that are left in the ground after well plugging and site closure will maintain integrity over time. If a loss of external mechanical integrity is detected within the well, appropriate corrective action must be taken during or prior to well plugging, as described in Section 2.6.3 [40 CFR 146.88(f)(4)]. Further information regarding external MITs is available in the *UIC Program Class VI Well Testing and Monitoring Guidance.*

2.5 Preparation of Well Prior to Plugging

Preparation of the injection well for plugging is important for ensuring the establishment of solid plugs and long-term protection of USDWs. Several activities are necessary at this preparatory stage: well cleaning, remedial operations, and the establishment of static equilibrium within the well. EPA emphasizes that injection zone pressure should be controlled at all times to prevent flow out of the injection zone. This will be accomplished through the use of workover and plugging (buffer) fluids that are correctly weighted and compatible with the injectate and formation fluids. Because an improperly abandoned monitoring well can pose a risk to USDWs, EPA recommends that monitoring wells be similarly prepared for plugging.

2.5.1 Well Inspection and Initial Preparation

Prior to well plugging, EPA recommends that the owner or operator identify details on well construction, geologic information in the vicinity of the well bore, and information on the dominant geochemistry around the well bore and of formation fluids. This information may support decisions on the placement of each plug and the type, grade, and quantity of material to be used in plugging. The Class VI Rule requires that information on the plugging materials be specified in the Injection Well Plugging Plan [40 CFR 146.92(b)(5)]; if this initial preparation stage suggests that changes are needed, a revised Injection Well Plugging Plan will need to be submitted with the notice of intent to plug [40 CFR 146.92(c)]. Information on well construction, geology, and geochemistry will also allow an assessment of compatibility of the materials with the environment in the vicinity of the well, including the formation fluids.

2.5.2 Well Cleaning

2.5.2.1 Flushing of Well

Prior to removal of the injection tubing and packer, the well must be flushed [40 CFR 146.92(a)]. This is done with workover fluids, which are specially prepared brines or muds that are circulated through the well to remove any remaining injection fluids and to remove fine debris such as congealed drilling mud or small particles such as sand (USEPA, 1982). The potential for corroding well materials should be controlled, and the workover fluid should be chemically compatible with both formation fluids and solids in the downhole environment. In the case of a GS project, the workover fluid must be compatible with carbon dioxide and carbon dioxide-rich brines and must, therefore, be buffered against low pH conditions that might be encountered downhole [40 CFR 146.92(a)].

All sections of the well that will be left intact after plugging and have been in contact with injection or annular fluids should be flushed. These components include the annular space, long-string casing, perforated zone, and possibly the injection packer. If the packer has been removed prior to flushing, workover fluid may be circulated via the injection tubing (prior to its removal). If the packer has not been removed, injection of flushing fluids would need to occur via the injection tubing as well as directly into the annulus. It may also be possible to unseat both the tubing and packer for this flushing stage, and then remove them.

2.5.2.2 Removal of Well Components and Obstructions

The removal of well equipment prior to plugging is necessary to open the well for access. In general, uncemented and non-permanent components of the well should be removed. This includes downhole monitoring devices, such as pressure transducers, and the downhole shut-off device if installed. Injection tubing is almost always removed because it serves no purpose after the operational phase of the project (USEPA, 1989); removal is done with a workover rig. After circulation of the workover fluid, the tubing may be unseated and removed. The packer may be retrievable, or it may be permanent. If it is permanent and cannot be removed, it may be drilled through (USEPA, 1989). If the tubing and packer cannot be removed, the tubing may be cut above the packer.

At this stage, larger debris such as metal pins and tools can be removed using a junk basket/retriever or a "fishing" magnet. In some cases it may not be possible to remove all pieces of larger debris from the well. Pieces of equipment inadvertently lodged downhole may need to be milled or drilled through if they cannot be retrieved.

Casing that is not cemented to the formation poses a fluid migration risk. Because the surface and long-string casings in a Class VI injection well will be cemented to the surface [40 CFR 146.86(b)(2) and (3)], they will generally not be removed. For monitoring wells that predate the project, however, there may be sections of uncemented casing. If so, the casing may need to be removed, or the owner or operator may need to squeeze cement behind portions of the casing to ensure zonal isolation and prevent fluid migration that may endanger USDWs.

2.5.3 Remedial Operations

Deficiencies that may be found during well inspections at any phase of a GS project (e.g., during injection or in preparation of well plugging) include cement channeling, casing leaks, corroded sections of casing, and collapsed sections of casing (USEPA, 1989). Owners or operators are required to repair any deficiencies to ensure that the casing does not leak during or after well plugging and potentially endanger USDWs [40 CFR 146.88(f)]. In planning remedial operations, the owner or operator should take into account the results of external mechanical integrity testing [40 CFR 146.92(a)], as well as historical MIT data and records of any remedial work done during the lifetime of the well, to locate areas of concern. As information on potential remediation needs emerges, owners or operators are encouraged to include planned remedial activities in any revisions to the Injection Well Plugging Plan.

In the case of a buckled or collapsed casing, the casing may be opened up using a casing roller or swaging tool (USEPA, 1989). Squeeze cementing, however, is the most common remedial measure, and it is needed in cases of channeled or absent cement behind the casing. This procedure serves to protect against fluid movement behind the casing, and it is considered an important step in ensuring the long-term protection of USDWs.

Squeeze cementing involves placing a cement slurry across a leaking section of casing. Hydraulic pressure is used to force the cement through leaks or perforations in the casing to provide a cement seal between the casing and the formation (Figure 3). If a section of the well bore requires cementing behind the casing (e.g., defects from primary cementing), but the casing does not have leaks or perforations, it may be necessary to perforate the casing first. If a portion of casing is uncemented (e.g., in a monitoring well), and the casing is to be left in place, it may be necessary to circulate cement behind the casing through perforations to provide a new cement sheath.

Owners or operators should ensure that the squeeze pressure and cement slurry are correctly selected. The pressure will need to be sufficient to force the cement into the desired zone without fracturing the formation. The cement slurry will need to be compatible with the formation and should be formulated to control filtration of water from the cement solids (formation of filter cake). A detailed discussion of the basics of squeeze cementing is provided by Smith (1976). Additional information on cement types is provided in the *UIC Program Class VI Well Construction Guidance* and below in Section 2.6.3.

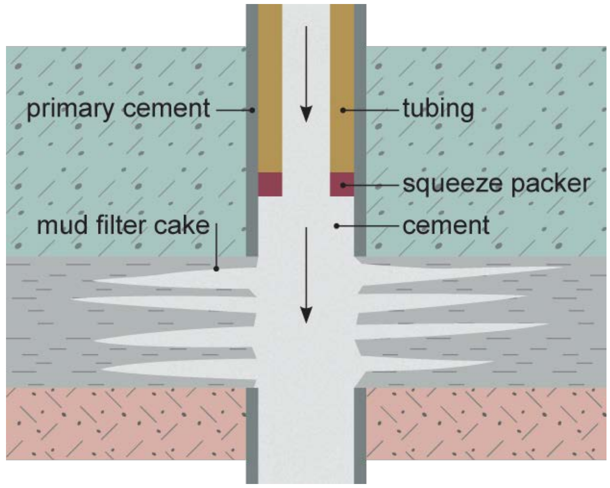

Figure 3. Typical Squeeze Cementing Operation, Showing Packer Above Perforations to Control Pressure and Cement Flow.
Adapted from: Smith (1976).

2.5.4 Establishment of Static Equilibrium

The last stage of well preparation prior to plugging is establishment of static equilibrium within the well bore. This involves introducing a plugging fluid that is free of excessive movement and for which flow into and out of the well is controlled. Because at least one long-string casing in a GS injection well must extend to the injection zone, effectively creating separation from USDWs and other formations [40 CFR 146.86(b)(3)], loss of fluid to formations along the well bore will not be a significant concern during injection well plugging. However, the plugging fluid should be able to control injection zone pressure. If there are sections of the well bore for which casing has been removed (e.g., in a monitoring well), the plugging fluid must be able to control pressure from high-pressure formations or prevent loss of fluid to low-pressure formations.

The plugging fluid should permit placement of cement plugs at the desired depth and should be suitable to remain as a fluid between the cement plugs, maintaining physical and chemical stability indefinitely (USEPA, 1982). The fluid should have uniform weight and produce minimal movement during the setting and hardening of the cement. Excessive fluid movement during setting can contaminate the slurry or cause it to migrate, resulting in a non-sealing plug with reduced strength (API, 1993; USEPA, 1989; Smith, 1976). Drilling mud is often selected as a plugging fluid, and it should be formulated to be compatible with the cement and to control pressure where necessary. The needed mud weight (density) can be estimated from bottomhole pressure [determined as required at 40 CFR 146.92(a)] and the vertical depth.

A suggested plugging fluid might contain: (1) fresh water or brine; (2) bentonite (gel or clay); (3) attapulgite (a type of clay); and (4) lost circulation material (as needed) (USEPA, 1989). A weighting material such as barite, sand, or hematite may be needed to produce a fluid with greater density. The plugging fluid will replace the fluid used for flushing, and it may require several circulations to complete the replacement. After circulation of the fluid, the fluid level in the well should be observed visually to note if there is fluid movement. Adequate circulation and establishment of static conditions with a plugging fluid of appropriate weight and viscosity will help ensure quality cement plugs. Additional information is provided by USEPA (1989).

2.5.5 Preparation for Recompletion of Injection Well

Well preparation will also be needed if an injection well is to be recompleted for use as a monitoring well, but steps may be modified as appropriate to prepare for installation of any necessary monitoring hardware. Flushing of the well should be done, small debris should be circulated out, and larger debris should be removed. The injection tubing should be pulled, and any necessary remedial actions should be performed to address casing leaks or defective cement, including those steps outlined in this guidance. After well preparation, recompletion with hardware for monitoring (e.g., downhole fluid sampling systems, sensors, etc.) may be done. If needed, new packers may be installed to isolate the injection zone and/or other zones that will be monitored.

If an owner or operator wishes to convert an injection well and has not previously provided plans for doing so, EPA recommends that the owner or operator update the monitoring well scheme and the PISC and Site Closure Plan prior to giving the required 60 days' notice of well plugging. This will allow time for the UIC Program Director to evaluate the conversion and associated specifications.

2.6 Performing Well Plugging

Establishing secure plugs pursuant to 40 CFR 146.92 is a crucial step in ensuring long-term protection of USDWs after a well is no longer in use. Plugging is achieved through the use of mechanical and cement plugs. Mechanical plugs help in isolating high pressure zones such as the injection zone. A series of strategically placed cement plugs, however, provide the primary means of ensuring long term zonal isolation in an abandoned well bore. Issues an owner or operator should consider in planning the plugging activities include: (1) the locations of critical formations such as USDWs so that there is no fluid migration; (2) the locations of any previously remediated portions of the well; (3) the design of the cement slurry; and (4) the best method of cement emplacement. At all stages, control of pressure in the injection zone will need to be maintained. If there are any uncased sections (e.g., in a monitoring well), control of exposed high- or low-pressure zones should also be maintained. Although the Class VI Rule requirements at 40 CFR 146.92 apply to plugging of the injection well, EPA recommends the use of careful plugging methods as described for injection wells for plugging of monitoring wells.

2.6.1 Mechanical (Bridge) Plugs and Inflatable Packers

A mechanical or bridge plug is a downhole tool that is used to isolate a pressurized zone such as the injection zone (Figure 4). These plugs are often placed in the casing above the injection zone or above other equipment such as a packer or tubing that cannot be removed. They are available in models made with corrosion-resistant alloys. This is important for plugs used to isolate the injection zone in a Class VI well, where the plug will be exposed to carbon dioxide and carbon dioxide-rich fluids. Bridge plugs may be permanent or temporary, and they should be made of strong but sufficiently brittle material, such that they can be drilled through, if necessary, to re-enter the well bore. Those set for the plugging of Class VI wells will likely be permanent, and cement plugs should be emplaced above them. Alternatively, if the owner or operator intends to cement across the perforated injection zone, a cement retainer may be placed at the top of the injection zone, beneath which cement will be squeezed (see Section 2.6.4). Some bridge plugs can also serve as cement retainers.

Figure 4. Bridge Plug.
From: Wyoming Completion Technologies (no date).

Inflatable packers, which have rubber and steel components, are a potential alternative to mechanical bridge plugs (e.g., Vaucher and Brooks, 2010). They can pass through restrictions and inflate to several times their original outside diameter. At this time, data are lacking on the performance of these devices in a carbon dioxide-rich environment. However, given their potential utility, interested owners or operators may wish to consult with the UIC Program Director regarding their use.

2.6.2 Cement Plugging Materials

The type, grade, and quantity of material to be used in plugging must be specified in the Injection Well Plugging Plan [40 CFR 146.92(b)(5)]. The cement used for plugs should form a bond with the casing and should be compatible (nonreactive) with the plugging fluid. It must also be compatible with the carbon dioxide stream [40 CFR 146.92(b)(5)] and should be compatible with carbon dioxide-formation fluid mixtures. In addition, the cement slurry needs to be able to be pumped into place and to set and gain strength in a reasonable amount of time (Calvert and Smith, 1994). The cement slurry should also have certain properties with respect to the plugging fluid; it should have a higher yield strength and plastic viscosity. However, differences in the densities of the cement and plugging fluid should be minimized to allow the cement to be placed at the desired depth (USEPA, 1982).

Bottomhole pressure and temperature affect the properties and setting time of the cement and should be taken into account when designing the slurry (Smith, 1976). For example, high pressures decrease the setting time, while high temperatures cause cement to lose strength and gain permeability. Depth is also important for determining the necessary placement time, and retarding agents or accelerators may be needed to control the setting time (API, 1993). Table 1 presents some of the additives used to control cement properties, generally in API cement classes. See Smith (1976) or Kosmatka et al. (2003) for a more comprehensive list of additives and their uses.

Table 1. Examples of Common Cement Additives.
From: Smith (1976).

Additive type	Examples/composition	Use/benefit
Accelerator	Calcium chloride Sodium chloride Gypsum	Faster setting, high early strength
Retarder	Lignosulfonates Organic acids CMHEC	Slower setting, increased pumping time, better flow properties
Dispersants	Organic acids Polymers Sodium chloride Lignosulfonates	Thinner slurry, decreased fluid loss, better mud removal, better placement
Silica flour	Silicon dioxide	Stabilized strength, lower permeability
Pozzolans	Fly ash	Lower density, increased durability
Heavy-weight additives	Hematite Ilmenite Barite Sand Dispersants	Greater density
Weight-reducing additives	Bentonite-attapulgite Gilsonite Diatomaceous earth Perlite Pozzolans	Lower density

USEPA (1982) suggests that most plugging needs can be met with a cement such as API Class A, G, or H. API Spec 10 provides details on the specifications for cements and materials for well cementing (API, 2002), and ASTM C150 - 11/C150M - 11 gives the standard specifications for Portland cement. Because of the corrosive nature of wet supercritical carbon dioxide and carbon dioxide-rich fluids, however, owners or operators of GS projects should consider cements that offer resistance to carbonic acid. This may entail use of non-Portland cements or Portland cements with additives. In particular, additives that reduce the percentage of carbon dioxide-reactive material (calcium hydroxide) in the cement will reduce susceptibility to carbonic acid (e.g., Moroni et al., 2009). Pozzolans, such as fly ash or silica fume, may be added to boost the portion of silica in a Portland-containing mixture and provide better resistance to carbon dioxide. Also, dispersants reduce the water content in the slurry and produce cement with lower permeability and reduced vulnerability to degradation (Calvert and Smith, 1994).

Non-Portland cements, which are non-reactive or less reactive with carbonic acid, include pozzolan-lime cement, gypsum cement, microfine cement, expanding cements, calcium aluminate cement, latex cement, resin or plastic cements, and sorel cements. In particular, calcium aluminate cement (also referred to as high aluminate cement) blended with additives has been found to be resistant to carbon dioxide-rich environments (Meyer, 2007). ASTM

International (ASTM) standards exist for some specialty cements (e.g., ASTM C1438 - 99 (2005)e1: Standard Specification for Latex and Powder Polymer Modifiers for Hydraulic Cement Concrete and Mortar; ASTM C1707 – 10: Standard Specification for Pozzolanic Hydraulic Lime for Structural Purposes). The *UIC Program Class VI Well Construction Guidance* contains additional discussion of cements that may be suitable for carbonic acid-rich environments. Also, newer commercial cements now available in the oil and gas industry are designed specifically for carbon dioxide-rich environments such as those associated with GS or enhanced oil recovery (EOR) operations.

Stresses due to variation in downhole pressure and temperature are known to contribute to cement defects, including the formation of microannuli and loss of zonal isolation (Goodwin and Crook, 1992; Thiercelin et al. 1998). Although downhole pressure and temperature conditions will be more stable after plugging than during the injection phase of a project, cement properties should be suitable for any anticipated tests and downhole conditions.

More recent literature (e.g., Liversidge and Agarwal, 2006; Le Roy-Delage et al., 2000; Nagelhout et al., 2005) has explored the use of flexible, expanding cements for plugging operations, including offshore projects. These cements include expanding agents (e.g., calcium oxide-based) and additives to increase flexibility. The resulting systems have increased elasticity and decreased compressibility and permeability, and they maintain strength. In a GS setting, the superior sealing and decreased permeability of these cements may be beneficial in providing protection from degradation of cement and resulting fluid migration. Owners or operators may wish to consider the costs and benefits of such materials and, if interested, discuss their use with the UIC Program Director.

Bentonite nodules have been studied as a plugging material for deep wells (e.g., Englehardt and Wilson, 2001; Clark and Salsbury, 2003). Compressed sodium bentonite provides good plugging capability because it hydrates (thereby providing swelling), and it has lower permeability than cement. It can also be emplaced without the need for a rig and can be easily drilled out if the well needs to be reentered. Bentonite nodules (1 to 6 inches in size) have been found to form a good plug even in high salinity conditions. Compressed bentonite in the shape of bullets has been found to produce good pressure containment as well (Towler et al., 2008). Compressed bentonite is also flexible and can adjust its shape if the casing moves, reducing the risk of formation of microannuli. However, research may still be needed on emplacement methods.

Because bentonite pellets cannot be pumped into the well, they need to be dropped through the fluid. Care needs to be taken to avoid bridging of the pellets above the desired plug depth resulting in potential improper plug placement. Compressed bentonite plugs also have poor compressive strength and have limited pressure capabilities (USEPA, 2002). Compatibility of bentonite plugs with carbon dioxide or carbon dioxide-rich brine remains to be evaluated. Choices of plugging material will ultimately be addressed in the Injection Well Plugging Plan in consultation with the UIC Program Director [40 CFR 146.92(b)(5)].

Other materials studied for use in well plugs include pumpable (fluor)silicone and perfluoro-ether silicone elastomers (e.g., Bosma et al., 2000). Although the compatibility of these materials with a carbon dioxide-rich environment has not been established, they may be sandwiched between conventional cement plugs to provide extra sealing capability.

2.6.3 Locations of Cement Plug Placement

The type and number of plugs to be installed, as well as the placement of each plug (top and bottom), must be specified in the Injection Well Plugging Plan as required at 40 CFR 146.92(b)(3) and (4). In most cases, a continuous column of cement is not necessary, but plugs should be placed at critical locations to prevent communication between the injection zone and USDWs (Figure 5). EPA recommends that owners or operators emplace plugs: (1) above the lowermost production and/or injection zone; (2) above, below, and/or through each USDW; (3) at the bottom of intermediate and surface casings; (4) across any casing stubs (pulled casing sections); and, (5) at the surface (USEPA, 1989). Owners or operators may also consider emplacing cement across the injection zone's perforated interval by squeezing cement below a retainer set above the injection zone. Plugs may also be placed at other depths and locations at the UIC Program Director's discretion.

In horizontal wells it is suggested that a bridge plug be installed above the kickoff point, with a cement plug on top of it. EPA also recommends that owners or operators consider emplacing cement across perforated sections of laterals. In addition, if a vertical pilot hole has been drilled below the kickoff point into a permeable formation, that portion of the hole should be plugged as well.

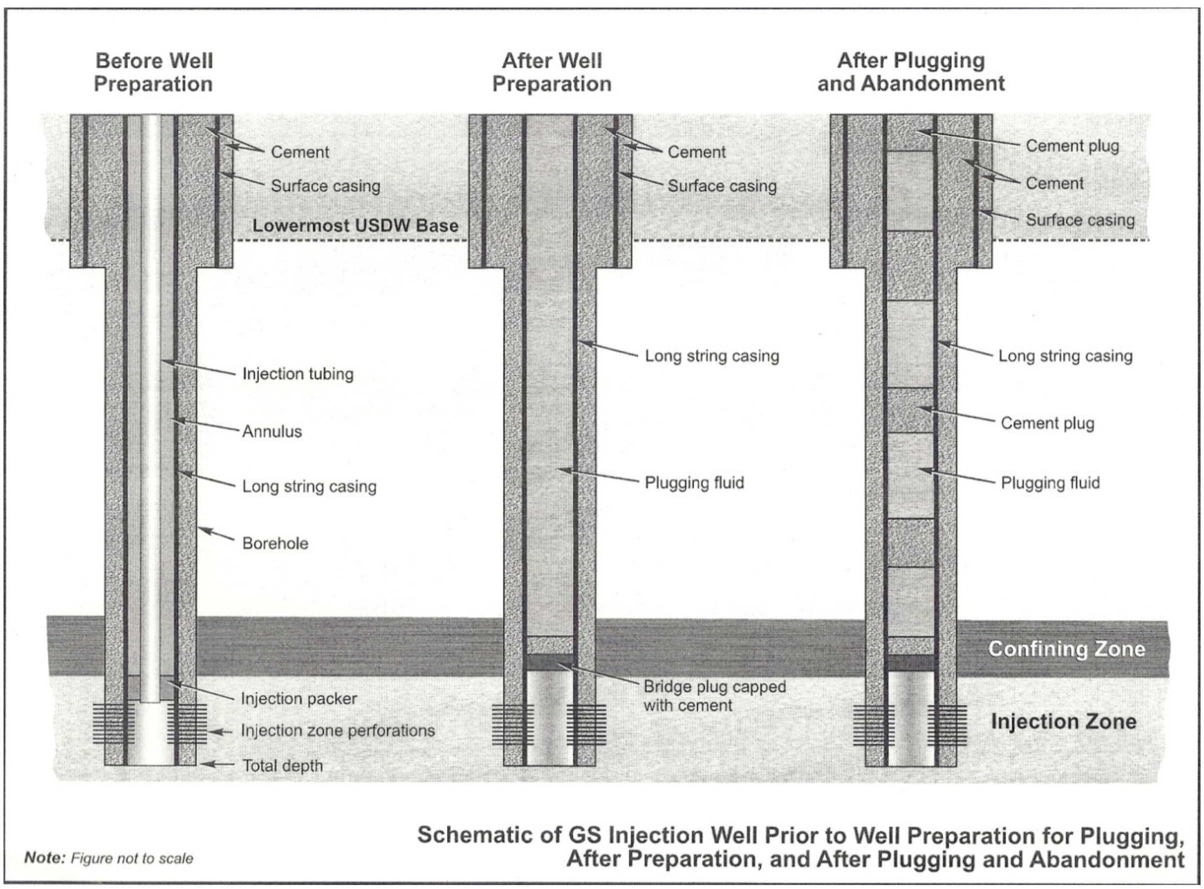

Figure 5. Schematic of Class VI Injection Well Prior to Well Preparation for Plugging, After Preparation, and After Plugging and Abandonment.

For protection of USDWs, API (1993) recommends that a 100-foot plug be set from below the base of the lowermost USDWs to the base of the USDW. EPA recommends that plugs in GS settings be at least that long. Furthermore, given the potential for the presence of carbonic acid near a Class VI well, EPA strongly recommends that owners or operators consider longer plugs, especially in critical zones such as above the injection zone.

2.6.4 Methods for Plug Emplacement

Plugs should be set sequentially from bottom of the well to the top, with adequate time in between to allow setting. A bridge plug will likely be set to isolate the injection zone. Bridge plugs may also be used to help position cement plugs at intermediate depths and prevent them from migrating. After emplacing a cement plug and allowing it to set, it may be tested by tagging, a method in which pipe is run into the well to locate the top of the plug. This indicates if the top of the plug is at the desired depth and whether it has acquired strength. It does not, however, indicate whether the cement has set properly throughout the entire plug. USEPA (1989) recommends that plugs in critical locations or that are suspected to be of inadequate quality be tagged.

Accepted and established methods for the emplacement of cement plugs that would be suitable for a GS project include: the balance method; the retainer method; and the two-plug method. Brief summaries for each are included below. The dump bailer method is generally not suitable for plugging deep wells and is not discussed in this guidance. The method(s) for plug emplacement that will be used for a specific project must be specified in the Injection Well Plugging Plan [40 CFR 146.92(b)(6)].

2.6.4.1 Balance Method

The balance method is simple and commonly used, but requires a great deal of operator skill. A drillpipe or tubing is run downhole, and cement is pumped through until the level of cement outside the tubing equals the level inside (Figure 6). Tubing should be centralized to ensure even flow of cement around the pipe. The tubing is then withdrawn from the well, excess cement is reverse circulated out of the tubing, and the cement is left in place to set (Smith, 1976; API, 1993).

As noted above, movement of the plugging fluid can compromise the integrity of the plug. Use of a small diameter tubing and slow, careful emplacement and withdrawal can be helpful in minimizing disturbance. Fluid spacers or small amounts of non-chemically treated mud may be used ahead of and behind the cement in the tubing to prevent contamination with the plugging fluid if compatibility is a concern (API, 1993). Another factor in successful plugging is careful calculation of cement, water, and displacement volumes. Further details and an example of cement volume calculations are provided in USEPA (1989).

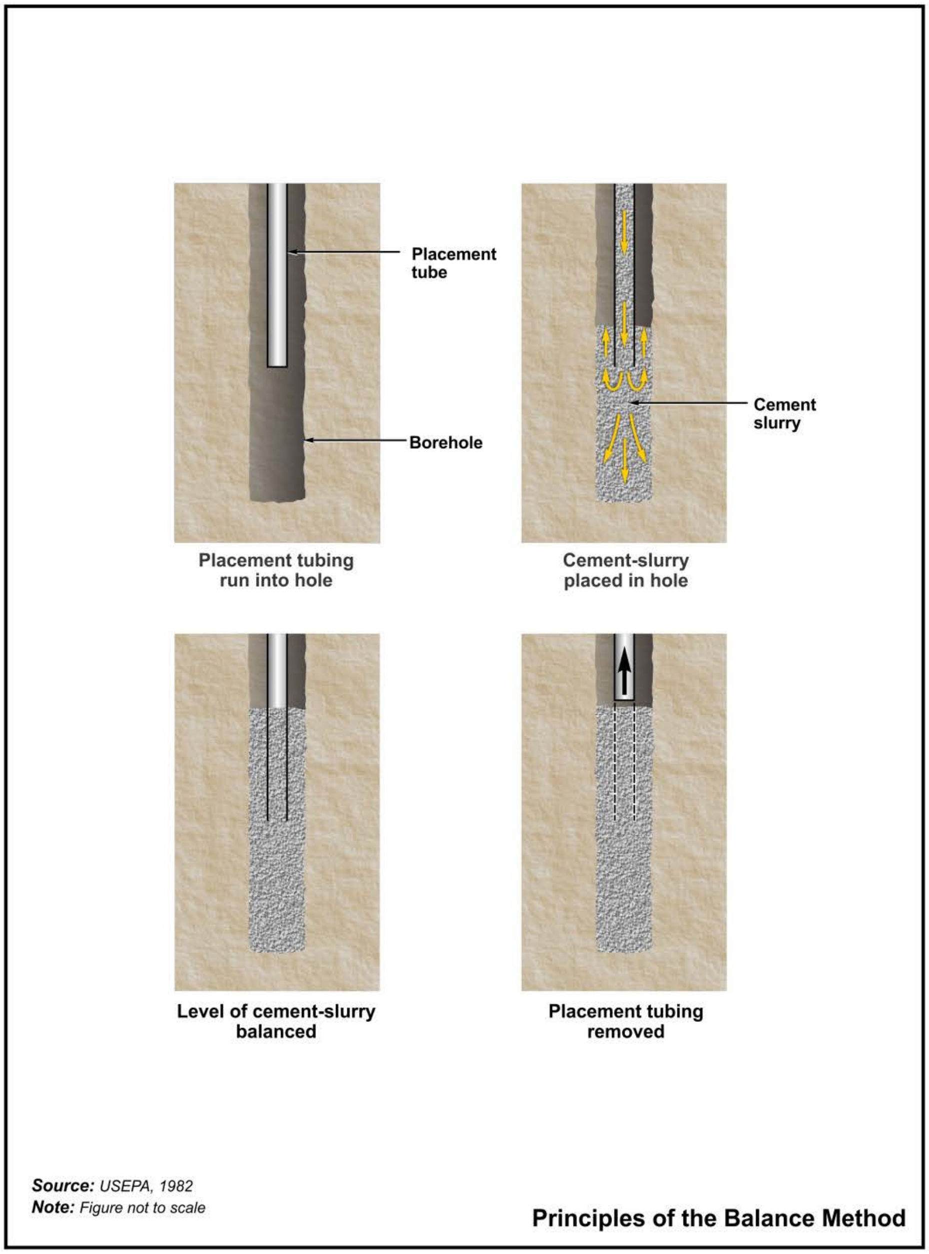

Figure 6. Principles of the Balance Method.
From: USEPA (1982).

2.6.4.2 Retainer Method

The cement retainer method is useful for setting plugs in uncased boreholes (e.g., an uncased section of an abandoned well or older monitoring well) and can be used to cement across the perforated casing in the injection zone. Retainers permit cement to be emplaced beneath the packer under pressure, forcing cement into the surrounding formation. Different models of cement retainers may be emplaced by tubing, drillpipe, or wireline. Some can be converted to bridge plugs. Owners or operators should verify that any retainers used are drillable. A cement plug should be emplaced above the retainer.

Exact procedures may vary depending upon the retainer selected. In the example below, the retainer is attached to the bottom of the tubing. The tubing with the retainer is lowered to the bottom of the well, and cement is pumped through the retainer and allowed to rise up in the hole 50–100 feet above the final depth of the retainer, forming a cement plug above the depth of the retainer. The tubing is then pressurized, and cement is pumped under pressure below the retainer into the surrounding formation. The retainer valve is then closed, the tubing is disengaged and withdrawn, and the retainer remains in place with a plug of cement above it (Figure 7). Additional details are provided in USEPA (1982).

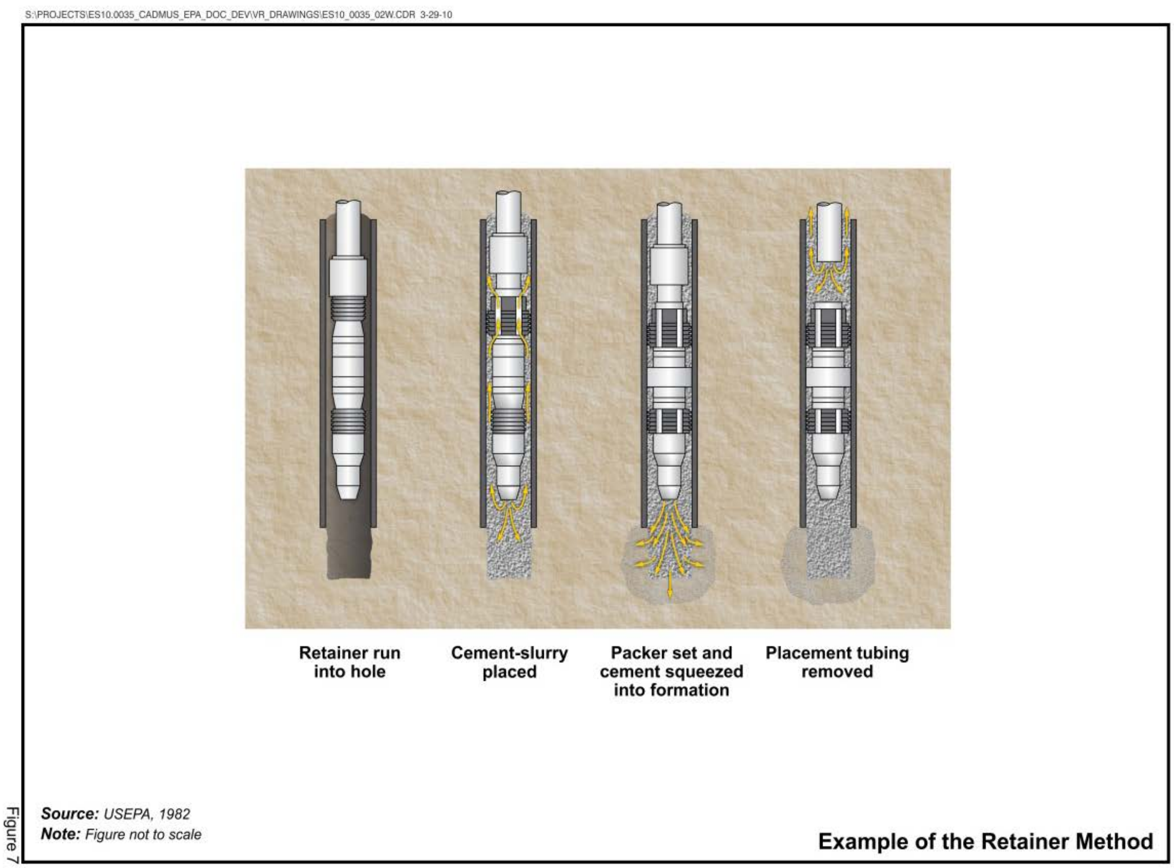

Figure 7. Example of the Retainer Method.
From: USEPA (1982).

2.6.4.3 Two-Plug Method

This method is more complex than the balance method, but provides advantages. Upper and lower tubing plugs are used to separate the plugging fluid from the cement slurry, minimizing cement contamination. It also offers good control over cement emplacement, which is especially advantageous in deep wells.

In this method, the lower tubing plug proceeds down the tubing stopping at the depth of the desired cement plug. The cement slurry is then pumped through the tubing. When the desired amount of cement has been pumped, the top tubing plug follows. It is caught in a plug-catcher tool in the tubing and does not pass into the well. A latching device prevents further displacement of fluid, allowing good control over the amount of cement emplaced and the location of the top of the cement plug. Further details are provided in USEPA (1982) and Smith (1976) (Figure 8).

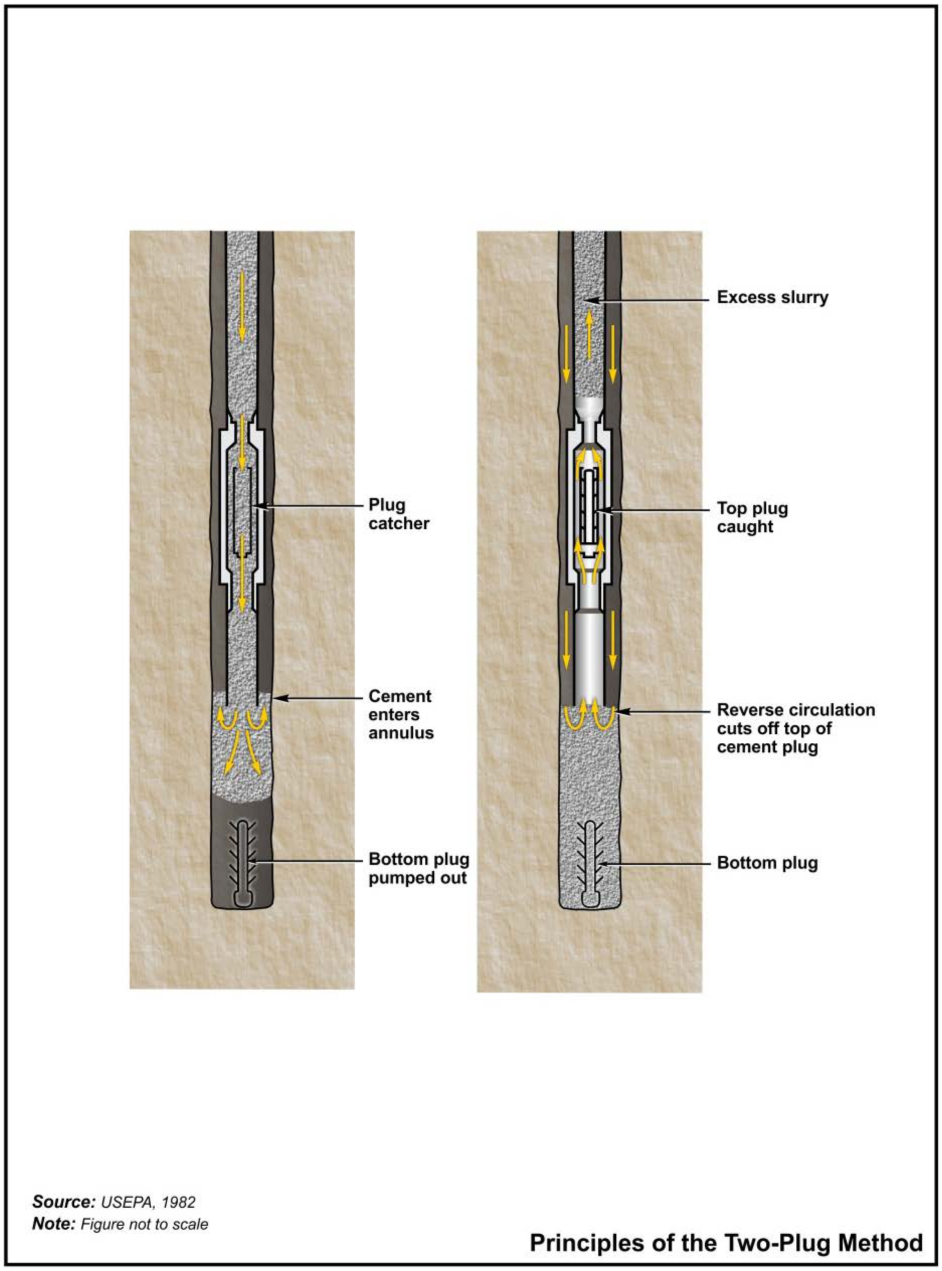

Figure 8. Principles of the Two-Plug Method.
From: USEPA (1982).

2.6.5 Considerations for Offshore Wells

Generally, plugging and abandonment of offshore injection wells will be similar to procedures for onshore wells. As with onshore wells, cement plug locations should be selected to isolate the injection zone and protect USDWs. There are, however, some additional considerations for placing cement plugs near the ocean floor in offshore environments due to the mud found at and below the sea floor. Any annuli in the well that are open to the mudline should be plugged to prevent migration of mud or other fluids down into the well or to prevent fluids in the annulus from migrating upward. Special materials and procedures may be necessary due to the lower density and unconsolidated nature of the sediment above the mudline. One recommendation is to place a top in the well within 150 feet of the mudline (Jirapongpipat, 2007).

Cementing in the mud environment near the ocean floor can be more difficult. The mud may mix with the cement, or heavier cement can displace the mud and lose its shape. Cross flow in the cementing area can also be problematic. These problems can be avoided by placing a barrier between the mud and cement such as a bentonite pill or a spacer fluid, by using circulation methods that circulate cement to the side but not vertically, and by using special cements such as lightweight cements (King, 2009). Cement evaluation logs will also be important to ensure that a proper cement job was obtained, especially above the mudline. In developing an Injection Well Plugging Plan for offshore Class VI wells, EPA recommends that owners or operators consult with professionals that specialize in well plugging for offshore projects.

2.7 Development and Submittal of Plugging Report

Within 60 days after plugging, the owner or operator must submit a plugging report to the UIC Program Director [40 CFR 146.92(d)]. The purpose of this report is to document that the plugging activities approved in the Injection Well Plugging Plan [40 CFR 146.92(b)] or any revisions to that plan were executed to the UIC Program Director's satisfaction and that the well will not be a conduit for fluid movement. The report must be certified as accurate by the owner or operator and by the person who performed the plugging operation, and the owner or operator must retain the plugging report for 10 years following site closure [40 CFR 146.92(d); 40 CFR 146.91(f)(4)].

Although a well plugging report is not explicitly required for monitoring wells, EPA encourages owners or operators to submit such reports. Proper plugging of monitoring wells is important for the long-term protection of USDWs, and although documentation is ultimately required at the time of site closure [40 CFR 146.93(f)(1)], prompt documentation of plugging done during the PISC period will help to demonstrate non-endangerment of USDWs.

Minimum documentation to provide in the well plugging report includes the following information, which will have been approved in the Injection Well Plugging Plan:

- Results of tests to determine bottomhole pressure and mechanical integrity;
- The type and number of plugs used;
- Cement type, grade, weight, and quantities for plugs;

- Method of cement plug emplacement; and
- Top and bottom of each cement plug.

A template with required elements for preparation of the well plugging report is provided in Appendix C. In addition, EPA suggests that the following information on well preparation and remediation also be included to demonstrate to the UIC Program Director that the well was in good condition for the installation of the plugs:

- Well flushing activities, required at 40 CFR 146.92(a), including fluid type and volumes used;
- Notes on removal of large debris;
- Documentation of removal of downhole components (e.g., pressure transducer, packer, shut-off devices);
- Documentation of removal of injection tubing;
- Reports on remedial activities (e.g., squeeze cementing records);
- Plugging fluid type and volume used to establish static conditions; and
- Notes on any plugs that were tagged.

3 Post-Injection Site Care (PISC)

After the injection phase of a GS project, the project must be monitored as the plume and pressure front will continue to pose a risk of endangerment to USDWs. This is because (1) injected carbon dioxide will remain mobile for site and project-specific periods of time and may continue to migrate away from the injection well(s); and (2) elevated pressure within the injection zone, and in some cases overlying zones, will persist for a site-specific period of time and continue to be a driver for fluid movement and may pose an endangerment to USDWs. (See the *UIC Program Class VI Well Area of Review Evaluation and Corrective Action Guidance* and the *UIC Program Class VI Well Testing and Monitoring Guidance* for additional discussion of plume migration.) Therefore, PISC monitoring is required by the Class VI Rule in order to track the evolution of the plume and pressure front and to demonstrate that USDWs are not endangered after the injection phase of the project [40 CFR 146.93(b)]. During PISC, EPA encourages owners or operators to build on successful monitoring strategies employed during the injection phase of the project. PISC monitoring strategies, including monitoring technologies and frequency, are based on site-specific conditions and may change over time. This section discusses monitoring techniques that may be used during PISC (Section 3.1) as well as PISC duration (Section 3.2).

3.1 PISC Monitoring

PISC monitoring is required to show the position of the carbon dioxide plume and pressure front and demonstrate that USDWs are not being endangered [40 CFR 146.93(b)]. To meet these objectives, PISC monitoring programs should be designed to track the location of carbon dioxide and other mobilized constituents within the injection zone, track fluid pressures, and monitor the integrity of monitoring wells and former injection wells.

Types of monitoring that may be applicable during PISC include mechanical integrity testing of former injection wells and monitoring wells, pressure measurements and analysis of ground water geochemistry (via monitoring wells), surface and downhole geophysical surveys and logs for imaging the carbon dioxide plume or any potential leakage, and surface air and/or soil gas monitoring. These monitoring strategies are discussed in the *UIC Program Class VI Well Testing and Monitoring Guidance* as they also pertain to monitoring during the injection phase of a GS project. Due to similarities in the application of monitoring strategies during the injection and PISC phases of a GS project, EPA refers the reader to the *UIC Program Class VI Well Testing and Monitoring Guidance* for a more detailed discussion of these monitoring techniques. This section is intended to supplement the *UIC Program Class VI Well Testing and Monitoring Guidance* by presenting additional considerations that pertain solely to monitoring during PISC.

EPA has designed a regulatory framework that allows for development of a tailored, site-specific PISC and Site Closure Plan that meets minimum Class VI requirements and is approved by the UIC Program Director. The PISC and Site Closure Plan, which is required by the Class VI Rule to be submitted with the Class VI permit application [40 CFR 146.93(a); 40 CFR 146.82(a)(17)], is intended to allow for the design of a site-specific PISC monitoring strategy (see Section 3.1.1). While allowing for site-specific conditions that will dictate the details of PISC monitoring, EPA anticipates that some of the recommendations in this and the *UIC Program Class VI Well Project Plan Development Guidance* will be applicable to most GS projects. Generally, EPA encourages owners or operators of GS projects to use monitoring strategies during PISC that were successful during the injection phase of the project. Similarly, EPA encourages a frequency and level of monitoring during the beginning of PISC that is similar to monitoring at the end of the injection phase. As potential risks to USDWs decrease over time, as reflected by monitoring data, EPA encourages owners or operators to consult with the UIC Program Director regarding the frequency and amount of site monitoring. In this way, PISC monitoring frequency can be evaluated to establish the most appropriate monitoring intervals, and PISC monitoring frequency may increase or decrease before eventually ending with final site closure (see Section 3.2).

3.1.1 PISC and Site Closure Plan and Reevaluation

GS project owners or operators are required to prepare, maintain, and comply with a plan for PISC and site closure [40 CFR 146.93(a)]. The PISC and Site Closure Plan must provide a description of proposed PISC monitoring locations, methods, and frequencies [40 CFR 146.93(a)(2)(iii)]. This plan is submitted with the permit application, is subject to UIC Program Director approval, and must be reevaluated, as discussed below. The purpose of the plan is to promote the development of a site-specific strategy for PISC monitoring and to communicate that strategy to the UIC Program Director prior to project approval. The PISC and Site Closure Plan will describe the anticipated methods that will be used to determine risk to USDWs during PISC; under what conditions risk of endangerment no longer exists, resulting in project site closure; and under what conditions the frequency of PISC monitoring may be reduced [40 CFR 146.93(a)(2)]. The structure of the plan and additional details are discussed in the *UIC Program Class VI Well Project Plan Development Guidance*.

Although the PISC and Site Closure Plan, including post-injection monitoring strategies, is initially established prior to the start of the project, owners or operators may modify the plan and resubmit it to the UIC Program Director at any time during the life of the project. The UIC Program Director will make a decision regarding approval within 30 days [40 CFR 146.93(a)(4)]. This approach allows the owner or operator to incorporate information obtained during the course of the project and refine the PISC and Site Closure Plan as needed. Owners or operators are encouraged to evaluate the necessity of revising the plan within one year of an AoR reevaluation (for details regarding AoR reevaluation, see the *UIC Program Class VI Well Area of Review and Corrective Action Guidance*), following any significant changes to the facility such as an increase in the number of injection or monitoring wells in the project AoR, or on a schedule to be determined by the UIC Program Director. The purpose of the reevaluation is to incorporate any new monitoring data or changes to the site computational model that warrant changes in PISC monitoring, or any changes in the methodology proposed to be used to demonstrate non-endangerment of USDWs.

At the cessation of injection, owners or operators are required to submit an amended PISC and Site Closure Plan or demonstrate that no revisions are necessary [40 CFR 146.93(a)(3)]. Revisions to the plan or the demonstration that no revisions are necessary should be based on monitoring data collected during injection and newer revisions of the site computational model. Box 3-1 provides an example of planned PISC monitoring at a hypothetical project and revisions based on AoR reevaluation.

Box 3-1. Hypothetical Example of PISC Monitoring Plan and Revision.

This box presents an example summary of a PISC monitoring plan for a hypothetical GS project. This example is based on the hypothetical GS project used throughout the *UIC Program Class VI Well Area of Review Evaluation and Corrective Action Guidance*. The PISC monitoring plan is a component of the PISC and Site Closure Plan, and it describes proposed monitoring techniques and frequencies (Section 3.1.1). The hypothetical project consists of three injection wells, and injection is planned for thirty years (Figure 9).

The proposed PISC monitoring program submitted with the PISC and Site Closure Plan in the initial permit application calls for an initial continuation of monitoring conducted during the injection phase, as follows:

- Fluid sampling and pressure monitoring using a series of 18 monitoring wells; some are screened within the injection zone, and others are screened above the primary confining zone:
  - Monitoring wells MW-4, MW-6, MW-13, MW-16, MW-17, and MW-18 are proposed to be constructed after injection begins, and the remaining wells are proposed to be constructed prior to injection. All wells are proposed to be constructed prior to PISC.
  - Fluid geochemical and pressure monitoring are proposed to be conducted once every 6 months at the beginning of PISC and to decrease over time based on pre-defined criteria that are listed in the plan for each monitoring well. In this way, the number of monitoring wells used will decrease over time.
  - Monitoring wells will be closed in accordance with site closure requirements at the point when they are no longer in use.
- Indirect geophysical surveys are to be conducted initially once every two years, with frequency decreasing in future years based on repeat surveys demonstrating that the carbon dioxide plume is migrating at rates slower than pre-defined criteria.
- The internal integrity of the monitoring wells will be assessed via a pressure test during every sampling event. External integrity of all monitoring wells will be evaluated at least once every three years during PISC while each well is active.

Box 3-1. Hypothetical Example of PISC Monitoring Plan and Revision.

The initial PISC and Site Closure Plan also describes the site-specific PISC timeframe and monitoring criteria that will be used to demonstrate non-endangerment of USDWs. In this case:

- The PISC timeframe is assumed to be 50 years (for a total project timeframe of 80 years). The Plan does not include a demonstration that would allow for an alternative PISC timeframe other than 50 years.
- Several risk-based site-specific criteria are given that will be used to demonstrate non-endangerment of USDWs. These include:
    - Return of pressure within the injection zone to pre-injection conditions at all monitoring wells that remain in use.
    - Stable or decreasing levels of carbon dioxide in sampled fluids.
    - Stable or increasing pH in sampled fluids above the confining zone.
    - Levels of any drinking water contaminants are below actionable levels (i.e., maximum contaminant levels or secondary standards) and are stable or decreasing over time for at least two years in any fluids sampled above the primary confining zone.
    - The results of at least three consecutive geophysical surveys that demonstrate the separate-phase carbon dioxide plume is no longer growing in size, either laterally or vertically.
    - All artificial penetrations, including former injection and monitoring wells, within 1 mile of the extent of the separate-phase plume and pressure front, have been evaluated and determined to not pose a risk of endangerment to USDWs. This may include monitoring of USDWs and soil gas in the direct vicinity of all artificial penetrations.

The UIC Program Director approved of these specifications listed in the initial PISC and Site Closure Plan that was submitted with the permit application. After the commencement of injection, the AoR was reevaluated every 5 years. During the first three AoR reevaluations (5 years, 10 years, 15 years), it was demonstrated that the initial AoR delineation was adequate, and no model calibration was necessary. At 20 years, based on comparison of modeling and monitoring data, it was determined that the computational model should be recalibrated, and a revised AoR resulted. The revised AoR extended further towards the east than the initial AoR (Figure 9).

Box 3-1. Hypothetical Example of PISC Monitoring Plan and Revision

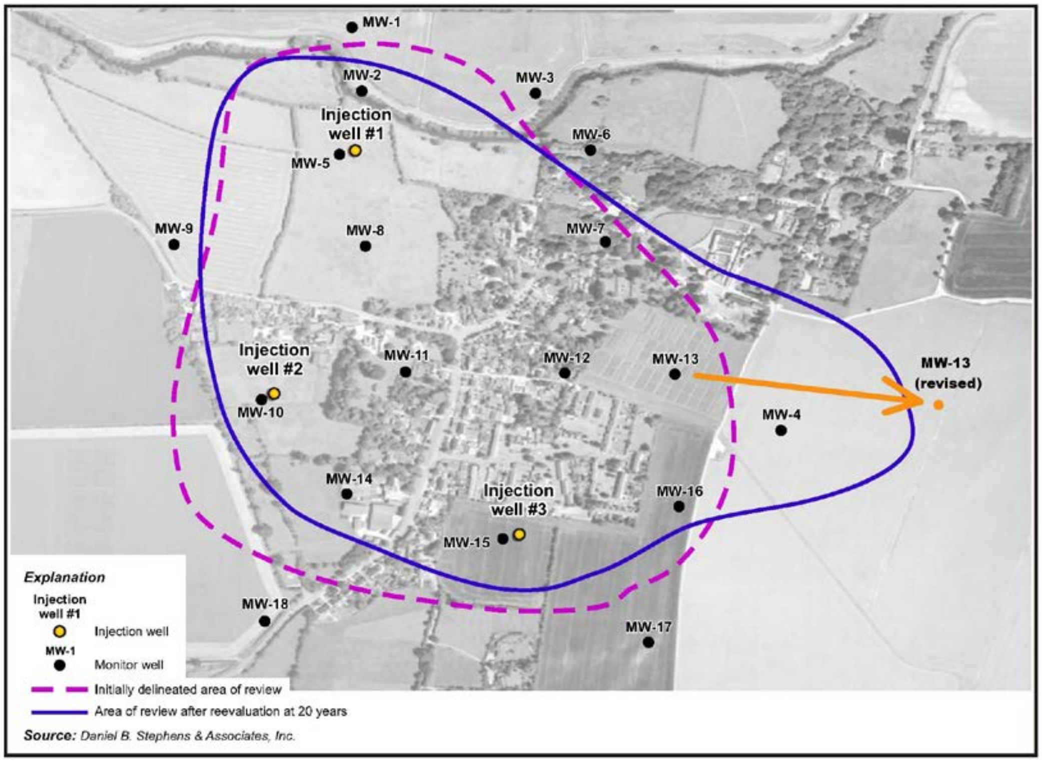

Figure 9. Hypothetical GS Project Showing Initial and Revised AoR.
The location of MW-13 is revised after AoR reevaluation, as shown by the orange arrow.

Upon reevaluation of the AoR at 20 years, the PISC and Site Closure Plan was also revised. The following major changes were made to the plan:

- MW-13 had not been constructed as of 20 years after injection. The location of MW-13 was revised to be located in the predominant direction of plume migration and outside of the revised AoR (Figure 9). The plan specifies that MW-13 will remain as an active monitoring well until final site closure.
- Artificial penetrations in the newly identified area of eventual plume migration were identified, and a plan was outlined for assessment and monitoring of those penetrations.
- New criteria for the USDW non-endangerment demonstration were added for MW-13. Non-endangerment criteria include no detection through direct and indirect monitoring of separate-phase carbon dioxide fluids from MW-13, no presence of elevated pressure, and no change in geochemistry that indicates fluid changes beyond allowable levels. If any of these criteria are violated, the owner or operator has committed to reevaluation of the PISC and Site Closure Plan at that time and establishment of additional non-endangerment criteria.

3.1.2 Use of Monitoring Wells in PISC Monitoring

During the injection phase of the GS project, the use of monitoring wells is required. Data acquired using monitoring wells is necessary to gather in situ measurements of fluid pressures [40 CFR 146. 90(g)(1)], collect ground water samples above the confining zone for geochemical analysis [40 CFR 146.90(d)], and provide verification of geophysical surveys.

During the beginning of PISC, EPA encourages owners or operators to continue to use any monitoring wells screened within the injection zone, above the primary confining zone, and within any USDWs. Owners or operators may use monitoring wells that have been previously constructed and used for monitoring during the injection phase of the project. Former carbon dioxide injection wells may also be considered for use as monitoring wells. Additional monitoring wells may need to be installed during PISC if there is evidence from existing monitoring and/or modeling that the carbon dioxide plume may be continuing to migrate away or in new directions vertically or laterally from the location of the injection well (see Box 3-1). These wells should be screened in any zone(s) anticipated to exhibit separate-phase carbon dioxide, such as in newly identified plume migration areas. To directly monitor for USDW endangerment, wells may also be located within overlying USDWs. If the owners or operators determine that additional monitoring wells are necessary for protection of USDWs, they must revise the PISC and Site Closure Plan and re-submit it to the UIC Program Director for approval prior to the construction of any new wells [40 CFR 146.93(a)(4)]. At the time that the owner or operator, in consultation with the UIC Program Director, determines that a monitoring well is no longer needed for site monitoring, EPA encourages the owner or operator to plug such wells in a manner that will not lead to the endangerment of a USDW. All monitoring wells must be plugged prior to site closure [40 CFR 146.93(e)].

Constituents of interest to monitor using monitoring wells may include carbon dioxide, major anions and cations, organics, total dissolved solids (TDS), pH, temperature, any mobilized or injected drinking water contaminants of concern, the presence of formation fluids that may be displaced as a result of injection, and, if required by the UIC Program Director, tracers that have been co-injected with carbon dioxide during the project. The *UIC Program Class VI Well Testing and Monitoring Guidance* discusses appropriate methods for collection and analysis of ground water samples from monitoring wells, interpretation of results, and reporting to the UIC Program Director. Generally, increasing carbon dioxide concentration, decreasing pH, or a change in the geochemical signature of water may indicate fluid migration. A stabilization of these parameters may indicate that fluid migration rates are decreasing, particularly at those monitoring wells located farther from the injection well(s).

Monitoring well data may become more ambiguous and difficult to interpret at the outer portions of the carbon dioxide plume, depending on the number and location of monitoring wells. Concentrations of key constituents will be smaller in these areas and more difficult to differentiate from background sources. Additionally, the supercritical carbon dioxide plume may exhibit thin, laterally extensive zones at the top of the injection zone (i.e., gravity tongues, see e.g., Ide et al., 2007). Water sampled from monitoring wells with a relatively long perforated interval may dilute carbon dioxide present in this thin zone. Uncertainty analysis of monitoring well data may include plotting of historical trends for comparison to recently collected data and conducting statistical comparisons for significance. Although increasing the number of monitoring wells in the network may be costly, installation of new monitoring wells may be used to reduce uncertainty in interpretation of ground water monitoring results. Methods exist for determination of well placement to reduce uncertainty (e.g., Meyer and Brill, 1988). As discussed below, geophysical methods may also be used to reduce monitoring data uncertainty.

In addition to monitoring to ensure ground water quality, monitoring wells may be used to directly measure reservoir pressure through the use of pressure transducers or, for the case of relatively shallow wells, the measurements of the static fluid level within the well. Methods for determination of reservoir pressure from monitoring wells are also described in the *UIC Program Class VI Well Testing and Monitoring Guidance*. During PISC, fluid pressures within the injection zone are anticipated to decrease over time because injection is no longer occurring and pressure dissipates. Elevated fluid pressure is a key driver of risks to USDWs, and EPA therefore encourages pressure monitoring to be a primary focus of PISC monitoring. An observed sustained decrease in fluid pressures over time will be a key justification for a UIC Program Director to consider allowing PISC monitoring to decrease and eventually end. Importantly, the rate of fluid pressure decline may not be steady within particular zones due to heterogeneity in the subsurface, as it depends on site-specific geologic properties of the injection zone and overlying zones. Fluid pressures may also fluctuate due to external factors, including local fluid extraction and injection, and ground water recharge.

3.1.3 Geophysical Surveys during PISC

The Class VI Rule, at 40 CFR 146.90(g), requires the use of both indirect (i.e., geophysical) and direct methods for carbon dioxide plume and pressure-front tracking during the injection phase of a project, unless the UIC Program Director determines, based on site-specific considerations, that indirect methods are not suitable. Generally, these same site-specific considerations apply to the use of geophysical techniques during PISC. If geophysical techniques have been used during the injection phase of the project, EPA encourages the owner or operator to continue periodic geophysical surveys during PISC.

Geophysical monitoring techniques provide broad, non-point measurements and can be used to estimate the extent of the separate-phase carbon dioxide plume and, in some cases, pore pressure. Although they are not quantitative and may be subject to uncertainties in interpretation, geophysical methods complement the point measurements collected using monitoring wells. Applicable geophysical methods that may be used for PISC monitoring include seismic, electromagnetic, gravity surveys, and ground displacement (e.g., interferometric synthetic aperture radar, or InSAR). As discussed in the *UIC Program Class VI Well Testing and Monitoring Guidance*, monitoring uncertainty is reduced when monitoring well and geophysical data are both collected and interpreted in a complementary fashion.

Time-lapse application of geophysical surveys involves repeat measurements in the same locations over time to evaluate changes in subsurface conditions. Comparison among sequential surveys is contingent upon geophysical methods being geo-referenced and, in some cases, being located at exactly the same coordinates. Changes in near-surface conditions such as soil-water saturation may also have a large impact on comparability among geophysical surveys. Due to the potentially long PISC duration, repeatability and comparability of repeat geophysical surveys may be challenging at GS projects. EPA encourages 'truthing' of geophysical data with data collected at monitoring wells to help potentially reduce error from changes in near-surface conditions and aid in comparison of repeat geophysical surveys.

These geophysical monitoring techniques are used in many applications including the injection of carbon dioxide for EOR and enhanced gas recovery (EGR). Some geophysical techniques as applied to Class VI projects, however, remain in the research and development stage as the GS industry continues to evolve (NETL, 2009). EPA anticipates that application and interpretation of geophysical monitoring techniques will improve during the lifetime of early GS projects. As with other injection well technologies and UIC well classes, EPA encourages owners or operators to consider adopting any newly accepted geophysical techniques that develop during the lifetimes of their GS projects, including during PISC, in consultation with their UIC Program Directors.

3.1.4 Additional PISC Monitoring

In addition to tracking the carbon dioxide plume and pressure front using monitoring wells and geophysical techniques, owners or operators may need to continue additional monitoring to demonstrate that USDWs are not being endangered [40 CFR 146.93(b)]. For example, EPA encourages owners or operators to perform periodic mechanical integrity and corrosion testing of monitoring wells to ensure that they maintain integrity and do not allow for fluid movement that may endanger a USDW. Furthermore, other monitoring techniques, including surface air and/or soil gas monitoring, may be used to complement geophysical techniques and monitoring wells in evaluating endangerment of USDWs. The reader is referred to the *UIC Program Class VI Well Testing and Monitoring Guidance* for further details regarding these monitoring techniques.

3.1.5 Frequency of PISC Monitoring

The appropriate frequency of monitoring and reporting is influenced by site-specific conditions and will therefore change over time during PISC. During the initial stage of PISC, EPA encourages monitoring at a similar frequency as was performed during the end of the injection phase. The frequency of PISC monitoring activities may be reduced over time if a demonstration can be made that the risk of endangerment to USDWs is decreasing and monitoring data are relatively stable. Some parameters (e.g., pressure, temperature) may be monitored continuously using permanent downhole equipment. For those parameters, summary data (monthly average, minimum, and maximum values) may be submitted with the same frequency as parameters that are periodically measured, such as geochemical data.

EPA encourages the owner or operator to submit with the PISC and Site Closure Plan specific benchmarks that can indicate a demonstrated decrease in risk to USDWs, thus allowing the UIC Program Director to consider decreasing the frequency of PISC monitoring. For example, reduction in PISC monitoring frequency may be based on:

- Observation of continual decrease in reservoir pressure toward pre-injection conditions;
- Steady or favorable trends in observed geochemical monitoring data over a pre-defined period;

- Several repeat demonstrations of monitoring well integrity with MITs; and

- A demonstration that reduced monitoring will not lead to endangerment of USDWs.

When benchmarks listed in the PISC and Site Closure Plan are met, the owner or operator is encouraged to consult with the UIC Program Director regarding reduction in the frequency of monitoring at the site.

3.1.6 Reporting of PISC Monitoring Results

The GS project owner or operator must submit a proposed schedule for reporting the results of PISC monitoring with the PISC and Site Closure Plan [40 CFR 146.93(a)(2)(iv)]. EPA encourages the owner or operator to submit monitoring results on an annual basis, or more frequently, dependent on site conditions. EPA recommends that the following information be submitted with all reports:

- A list of all monitoring events that have taken place during the reporting period and all monitoring dates;

- Identification of any data gaps;

- Identification of any changes to the monitoring program during the reporting period (e.g., drilling of new monitoring wells, closure of monitoring wells);

- Presentation, synthesis, and interpretation of the entire historical data set of monitoring results, with respect to any change in risk of endangerment to USDWs;

- Any necessary changes to the project PISC and Site Closure Plan to continue protection of USDWs;

- For ground water geochemistry monitoring using wells:
  - The most recent and up-to-date historical database of all ground water monitoring results and Quality Assurance/Quality Control (QA/QC) monitoring results;
  - Interpretation of any changing trends and evaluation of fluid leakage and migration, including uncertainty analysis (if appropriate). This may include graphs of relevant trends and interpretive diagrams (e.g., Piper and Stiff diagrams);
  - A map showing all monitoring wells and indicating those wells that are believed to be in the location of the separate-phase carbon dioxide plume;
  - An evaluation of data quality for each sampling event;
  - If required by the UIC Program Director, copies of all laboratory analytical reports;
  - Records of calibration of all field instrumentation;
  - A description of all sampling equipment and sampling methods used;

    - Sample chain of custody records;
    - The name and contact information for the EPA-certified laboratory conducting the analysis; and
    - Documentation of the monitoring well construction specifications (or reference to previously submitted documentation), sampling procedure, laboratory analytical procedure, and QA/QC standards.

- For ground water pressure monitoring:
    - Measured depth to fluid, or pressure transducer readings in all wells, fluid density, and fluid temperature;
    - If using pressure transducers, records of the most recent calibration or verification of the measurement instruments;
    - Records of the surveying of wellhead and measurement point elevations (or reference to previously submitted documentation);
    - Calculated pressure in all wells; and
    - Time-series graphs and pressure or head maps used in interpretation of pressure data.

- For geophysical surveys:
    - A description and technical justification of all survey techniques and methodologies used (or reference to previously submitted documentation);
    - A map showing the location of all survey equipment positions during the test;
    - If required by the UIC Program Director, all raw data collected by the survey equipment, a description of all data processing steps taken, and the major assumptions used during data processing;
    - An interpretation of all geophysical surveys relating to the position of the plume and/or pressure front, and fluid leakage, including any available information on method sensitivity and any out of zone anomalies that require follow up; and
    - Maps showing the interpreted location of separate-phase carbon dioxide in the injection zone and its location in any additional zones in which it was detected.

3.2 PISC Monitoring Timeframe

As required by the Class VI Rule, the default PISC monitoring timeframe is 50 years after the cessation of injection [40 CFR 146.93(b)(1)]. However, at the time of permit submission, the owner or operator may propose a PISC timeframe other than 50 years [40 CFR 146.93(c)]. As discussed below, the proposal for an alternative PISC timeframe must be based on a detailed demonstration that the project will no longer cause a risk of endangerment to USDWs at the end of the proposed timeframe. The proposed timeframe is subject to UIC Program Director approval. The PISC timeframe, either 50 years or an alternative timeframe, must be provided in the PISC and Site Closure Plan [40 CFR 146.93(a)(2)(v)].

Regardless of the PISC timeframe defined in the PISC and Site Closure Plan, the owner or operator must continue PISC monitoring until the owner or operator has demonstrated and the UIC Program Director has approved the demonstration that there is no longer a risk of endangerment to USDWs [40 CFR 146.93(b)(3)]. If the owner or operator can demonstrate prior to the end of the pre-defined PISC timeframe that there is no longer risk of endangerment to USDWs (hereafter referred to as the USDW non-endangerment demonstration), the UIC Program Director may approve site closure. Alternatively, if at the end of the pre-defined PISC timeframe there is evidence of risk of endangerment to USDWs, the UIC Program Director may require PISC to continue until those risks no longer exist [40 CFR 146.93(b)(4)].

It is important to note that, as discussed above (Section 3.1.5), PISC monitoring scope and frequency may change over time and may decrease substantially over time based on site conditions. For example, geochemical monitoring using wells may decrease from a frequency of quarterly initially after injection ceases, to annually at the end of PISC. In this way, the burdens associated with PISC may decrease over time, even prior to the end of PISC. Any changes to the monitoring program must be based on pre-defined criteria in the PISC and Site Closure Plan or be proposed in a revised PISC and Site Closure Plan that is subject to UIC Program Director approval [40 CFR 146.93(a)(4)].

3.2.1 Class VI Rule Default Timeframe

The default PISC timeframe required by the Class VI Rule is 50 years [40 CFR 146.93(b)(1)]. Unless the owner or operator proposes and the UIC Program Director approves an alternative timeframe (see Section 3.2.2), the owner or operator should be prepared to continue PISC monitoring for 50 years after the cessation of injection and should base all planned data collection and reporting on this PISC duration. EPA defined the default PISC timeframe based on a review of research studies, industry reports, and existing environmental programs. Owners or operators should also refer to the *UIC Program Class VI Financial Responsibility Guidance* for information on demonstrating that monitoring costs and any potential leakage encountered during PISC can be covered financially.

3.2.2 Alternative PISC Timeframe

The owner or operator has the option of submitting to the UIC Program Director a demonstration for a PISC timeframe other than the 50 year default [40 CFR 146.93(c)]. This application, submitted with the Class VI permit application, is based on a demonstration that an alternative timeframe is appropriate and ensures non-endangerment of USDWs, and it is based on detailed site-specific analyses. The Class VI Rule at 40 CFR 146.93(c)(1) establishes several data sources and analyses that must be considered and documented in this demonstration and that must be considered by the UIC Program Director. Also, 40 CFR 146.93(c)(2) lists additional criteria that must be met.

The alternative PISC timeframe demonstration should state the timeframe requested by the owner or operator and provide substantial documentation to support the petition. The UIC Program Director will evaluate the demonstration and will verify that the methods used are consistent with accepted protocols and requirements in the Class VI Rule. EPA suggests that to meet the requirements at 40 CFR 146.93(c), a demonstration of an alternative PISC timeframe should include the sections listed below. The owner or operator is encouraged to consult with the UIC Program Director regarding additional information that should be submitted based on site-specific conditions [40 CFR 146.93(c)(xi)].

3.2.2.1 Modified PISC Timeframe

The owner or operator may, at any time during the life of a GS project, submit information to support establishing a revised PISC timeframe other than the timeframe initially established in the original PISC and Site Closure Plan (or subsequent revisions). This demonstration must be based on monitoring and operational data collected during site operations and modeling of the extent of the carbon dioxide plume and pressure front [40 CFR 146.93(c)]. EPA recommends that if the owner or operator opts to establish a PISC timeframe as part of a PISC and Site Closure Plan update, they should submit information that meets all of the criteria at 40 CFR 146.93(c) to demonstrate that the timeframe is appropriate and protective of USDWs.

This option is available to either amend an alternative PISC timeframe that was included in the original PISC and Site Closure Plan submitted with the Class VI permit application or to justify that an alternative timeframe is appropriate if the Class VI permit included the default PISC timeframe. If the UIC Program Director approves the alternative PISC timeframe, it would be incorporated into the PISC and Site Closure Plan and the Class VI operating permit. Such a change would require the UIC Program Director to modify the Class VI permit [40 CFR 144.39(a)(5)(iv)]. A permit modification under 40 CFR 144.39 would require notification to the public and an opportunity for comment.

EPA acknowledges that some owners or operators of Class VI wells may plan to eventually produce the carbon dioxide from the injection zone or are interested in preserving this option (e.g., to sell the carbon dioxide for EOR/EGR). Owners or operators are encouraged to consider the planned withdrawal of the carbon dioxide as a factor in developing an alternative PISC timeframe or revising their PISC timeframe during the life of the GS operation. EPA recommends that owners or operators plan a post-injection monitoring period and regime that extends for at least as long as the carbon dioxide is to remain in the ground and until a significant quantity of it is produced such that a demonstration of non-endangerment can be made that pressures and mobile carbon dioxide do not pose a risk to USDWs. As withdrawal of the carbon dioxide proceeds and subsurface pressures begin to decline, the owner or operator may choose to discuss modifying the monitoring schedule (or plans for conducting the non-endangerment demonstration) with the UIC Program Director. However, PISC must continue until pressure reductions and plume stabilization are observed and non-endangerment can be demonstrated pursuant to requirements at 40 CFR 146.93(b)(1). The UIC Program Director will not be able to authorize site closure until non-endangerment is demonstrated based on monitoring data, as required at 40 CFR 146.93(b)(3). The owner or operator should also recognize that if planned production of the carbon dioxide does not occur, the PISC and Site Closure Plan might need to be amended and the permit modified following the requirements at 40 CFR 144.39(a)(5)(iv).

EPA encourages the owner or operator and the UIC Program Director to coordinate and discuss monitoring and operating data and other information about the facility if the owner or operator seeks to amend the PISC timeframe. See the UIC Program Class VI Well Project Plan Development Guidance for additional information on preparing and updating the PISC and Site

Closure Plan and the UIC Program Class VI Implementation Manual for State Directors for additional information about the procedures for modification of Class VI permits and the related plan amendments.

3.2.2.2 Results of Computational Modeling Performed for Delineation of the AoR [40 CFR 146.93(c)(i)]

The Class VI Rule requires that the AoR be delineated using sophisticated computational modeling that accounts for separate phase flow of carbon dioxide and water [40 CFR 146.84]. Computational modeling performed for AoR delineation is discussed in the *UIC Program Class VI Well Area of Review Evaluation and Corrective Action Guidance*. EPA recommends that the alternative PISC demonstration be based in part on the results of this computational modeling. Modeling results may be used to demonstrate the timeframes of pressure decline and rates of plume migration after injection ceases (see below). EPA recommends that comprehensive results of computational modeling, including results for the post-injection period, be presented as well. For more information on how to report modeling results, please see the *UIC Program Class VI Well Area of Review Evaluation and Corrective Action Guidance*. Importantly, EPA recommends that model uncertainty analysis, including sensitivity analyses and evaluation of model calibration, be presented with any model submittals. Model uncertainty analysis is discussed in the *UIC Program Class VI Well Area of Review Evaluation and Corrective Action Guidance*. Presentations of modeling results and additional criteria for modeling as they pertain to PISC are discussed in the following sections.

3.2.2.3 Predicted Timeframe for Pressure Decline [40 CFR 146.93(c)(1)(ii)]

A prediction of the timeframe for pressure decline upon the cessation of injection must be included with the alternative PISC demonstration [146.93(c)(1)(ii)]. EPA recommends that the prediction of pressure decline be based at least in part on results of computational modeling performed for delineation of the AoR. Importantly, any modeling used for the alternative PISC demonstration must be calibrated to existing site data where sufficient data are available [40 CFR 146.93(c)(2)(iv)].

Fluid pressures that pose a risk of endangerment to USDWs are discussed in detail in the *UIC Program Class VI Well AoR Evaluation and Corrective Action Guidance.* A threshold minimum pressure within the injection zone, termed the 'pressure front' ($P_{i,f}$), is defined by calculation of the pressure increase within the injection zone that could potentially force fluids through a hypothetical open conduit into an overlying USDW:

$$P_{i,f} = P_u + \rho_i g \cdot (z_u - z_i) \qquad \text{[Eq.1]}$$

where P_u is the initial pressure within the lowermost USDW, ρ_i is the fluid density of the injection zone, z_i and z_u are the representative elevation of the USDW and injection zone, respectively, and g is the acceleration due to gravity. Importantly, Eq. 1 is only valid for GS projects that are not located in over-pressurized formations (i.e., the hydraulic head in the injection zone is equal to or lesser than the hydraulic head in the USDW prior to injection). Regions of the injection zone with pressures equal to or greater than $P_{i,f}$ are at enhanced risk of

USDW endangerment. When pressures decline to less than $P_{i,f}$, there is no longer risk of endangerment from increased pressures within the injection zone.

The owner or operator is encouraged to identify the timeframe after cessation of injection when pressures are less than or equal to $P_{i,f}$. Alternatively, the owner or operator is encouraged to identify the timeframe after which pressures will decline to pre-injection conditions. The estimated timeframes may be based on computational modeling results, and/or additional quantitative analysis. See the *UIC Program Class VI Well Area of Review Evaluation and Corrective Action Guidance* for further discussion of pressure calculation. The owner or operator is also required to identify the distance between the injection zone and the nearest USDWs above and/or below the injection zone [40 CFR 146.93(c)(1)(x)]. As shown by Eq. 1, this distance is a key determinant of the threshold pressure that may lead to fluid movement that endangers a USDW.

The rate of pressure decay is a function of injection zone permeability, compressibility, the injected volume of carbon dioxide, the areal extent and thickness of the formation, and the presence of lateral stratigraphic confining features. The sensitivity of these parameters must be evaluated and related uncertainty assessed when making a demonstration [40 CFR 146.93 (c)(2)(vi)].

3.2.2.4 Predicted Rate of Plume Migration [40 CFR 146.93(c)(1)(iii)]

A prediction of the timeframe for carbon dioxide plume migration to cease must be included [40 CFR 146.93(c)(1)(iii)] and should be based at least in part on results of computational modeling performed for delineation of the AoR. The owner or operator is encouraged to estimate, based on the modeling results, the timeframe for separate-phase carbon dioxide to cease moving/growing laterally and vertically away from the injection wells. Modeled plume migration rates will be sensitive to the dip of the confining zone/injection zone interface, permeability, porosity, and relative-permeability characteristic curve parameters of the injection and confining zones. If the site geology includes a structural trap (e.g., dome, fault, or stratigraphic pinch-out), horizontal migration of carbon dioxide will be limited once the plume reaches such structural features. This should be taken into account when predicting plume migration and formulating PISC plans. The sensitivity of these parameters should be evaluated and related uncertainty assessed [40 CFR 146.93(2)(vi)].

EPA recognizes that in some cases, modeled plume migration rates may be very slow while not completely "stopping." Owners or operators are encouraged to evaluate the time it would take for the plume to reach potential receptors (e.g., active or abandoned wells). When the plume is migrating so slowly that this timeframe becomes exceedingly long (e.g., hundreds or thousands of years), the plume migration rate may be considered sufficiently minor as to no longer pose a risk to USDWs.

3.2.2.5 Trapping Processes and Predicted Rate of Carbon Dioxide Trapping [40 CFR 146.93(c)(1)(iv)–(vi)]

Specific processes leading to carbon dioxide trapping at the site must be identified, including physical entrapment and immobilization at the injection zone/confining zone interface, capillary trapping, dissolution of carbon dioxide into ground water, mineralization, and any additional relevant processes [40 CFR 146.93(c)(1)(iv)]. The trapping rate for each of these processes must also be estimated [40 CFR 146.93(c)(1)(v)]. The physical trapping effects of structural features (e.g., domes, faults, or pinch-outs) should also be considered in predicting carbon dioxide trapping. These predictions may be based in part on the results of computational modeling performed for AoR delineation and should incorporate a good geologic conceptual model, which should be updated during injection operations as part of the AoR reevaluation required at 40 CFR 146.84(e). EPA expects, however, that prediction of dissolution and mineralization rates may require additional quantitative methodologies beyond what will typically be conducted for AoR modeling. For example, detailed geochemical modeling, which is expected to be beyond the scope of many AoR modeling efforts, may be necessary to estimate trapping rates. Owners or operators may also conduct literature studies or perform laboratory tests or field-specific studies to better estimate trapping rates. Alternatively, the owner or operator may estimate trapping rates based on observations at similar projects, under similar conditions. The owner or operator is encouraged to consult the UIC Program Director in choosing an appropriate methodology for estimation of trapping rates at the site.

Relevant assumptions and parameters used for estimation of trapping rates for each process should be discussed. Additionally, the results of laboratory analyses, research studies, and/or field studies used to estimate trapping rates must be identified [40 CFR 146.93(c)(1)(vi)]. The extent to which the owner or operator expects that carbon dioxide trapping will lead to changes in risks to USDWs over time should be discussed.

3.2.2.6 Confining Zone Characterization [40 CFR 146.93(c)(1)(vii)]

The owner or operator is required to present results of characterization of the confining zone, including a demonstration that it is free of transmissive faults, fractures, and micro-fractures, and that it is of appropriate thickness, permeability, and integrity to impede fluid movement [40 CFR 146.93(c)(1)(vii)]. Where relevant, EPA recommends that structural traps (e.g., faults, domes, or pinch-outs) that can serve important roles in containing the carbon dioxide also be noted. The owner or operator is encouraged to draw on information and data collected pursuant to requirements at 40 CFR 146.82(a)(3)(ii) and (iii) and 146.83(a)(2). Beyond the information and data collected pursuant to 40 CFR 146.82, the owner or operator should consider regions of the confining zone predicted to come into contact with the carbon dioxide plume or mobilized fluids for the first time during post-injection. The owner or operator is also encouraged to explain how the data summarized in this section were used in computational modeling and demonstrations of pressure decline, plume migration, and trapping (see above).

3.2.2.7 Assessment of Potential Conduits for Fluid Movement [40 CFR 146.93(c)(1)(viii)–(x)]

The owner or operator must identify potential conduits for fluid movement including planned injection wells and project monitoring wells associated with the GS project or any other projects in areas that may be reasonably expected to come into contact with supercritical carbon dioxide and/or mobilized fluids [40 CFR 146.93(c)(1)(viii)]. The owner or operator is encouraged to draw on data collected pursuant to requirements at 40 CFR 146.82(a)(4). Of particular importance are any potential leakage pathways, such as surrounding injection or production wells, that are predicted to come into contact with mobilized fluids only after the cessation of injection.

For all abandoned wells within the AoR, the owner or operator must present information on construction and an assessment of the quality of plugs [40 CFR 146.93(c)(1)(ix)]. The owner or operator is encouraged to draw on data collected pursuant to 40 CFR 146.84(c)(2). EPA also suggests that these data be collected and presented for any artificial penetrations outside of the initial AoR that may be reasonably expected to come into contact with mobilized fluids, based on modeling and analyses used to predict plume migration and pressure dissipation. The reader is referred to the *UIC Program Class VI Area of Review Evaluation and Corrective Action Guidance* regarding the evaluation of abandoned wells.

EPA encourages the owner or operator to provide a demonstration that potential conduits for fluid movement will not pose an endangerment to USDWs beyond the alternative timeframe requested in the application. The owner or operator is also required to identify the distance between the injection zone and the nearest USDWs above and/or below the injection zone [40 CFR 146.93(c)(1)(x). This distance is a key determinant of the risks posed to USDWs by artificial penetrations.

3.2.2.8 Additional Criteria for Alternative PISC Timeframe Demonstration

The Class VI Rule requires that information submitted with this application meet the following criteria [40 CFR 146.93(c)(2)]:

- *All analyses and tests must be accurate, reproducible, and performed in accordance with established quality assurance standards* [40 CFR 146.93(c)(2)(i)]. The owner or operator is encouraged to follow accepted protocols, including the use of peer-reviewed methods, to ensure that all analyses meet these criteria. Furthermore, the owner or operator is required to submit a QA/QC plan to demonstrate that all analyses meet these standards (see below).

- *Estimation techniques must be appropriate, and EPA-certified test protocols must be used where available* [40 CFR 146.93(c)(2)(ii)]. Computational modeling and the resulting interpretation to evaluate changes in risks to USDWs may be prone to uncertainty and error. To minimize error in analyses, the owner or operator is encouraged to use accepted methods, including EPA-certified methods and standards approved by ASTM, the American Water Works Association (AWWA), or similar entities.

- *Predictive models must be appropriate and tailored to the site conditions, composition of the carbon dioxide stream and injection and site conditions over the life of the GS project* [40 CFR 146.93(c)(2)(iii)]. The reader is referred to the *UIC Program Class VI Well Area of Review Evaluation and Corrective Action Guidance* regarding model development and appropriateness using site-specific information and parameters.

- *Predictive models must be calibrated using existing information (e.g., at Class I, Class II, or Class V experimental technology well sites) where sufficient data are available* [40 CFR 146.93(c)(2)(iv)]. Model calibration refers to adjustment of model parameters in order to match model results to monitored site observations. For example, model calibration may consist of adjusting site permeability values within a reasonable range such that previously observed pressure measurements are consistent with model results. Where data that may be used for model calibration are readily available, owners or operators must perform model calibration prior to use of computational modeling results in the alternative timeframe demonstration. The reader is referred to the *UIC Program Class VI Well Area of Review Evaluation and Corrective Action Guidance* for additional information regarding model calibration.

- *Reasonably conservative values and modeling assumptions must be used and disclosed to the UIC Program Director whenever values are estimated on the basis of known, historical information instead of site-specific measurements* [40 CFR 146.93(c)(2)(v)]. In some cases in computational modeling or other quantitative analyses, parameter values from peer-reviewed literature sources may be used when site-specific data are not available. Typically, literature searches result in a range of reasonable parameter values. In these cases, the owner or operator must select values from the reported range that are reasonably conservative (i.e., values that result in a longer estimated PISC timeframe) and are also consistent with other data used to model site-specific information. This is of particular importance for those modeling parameters for which the model has been shown to be highly sensitive. The owner or operator must also disclose the source of all parameters used.

- *An analysis must be performed to identify and assess aspects of the alternative PISC timeframe demonstration that contribute significantly to uncertainty. The owner or operator must conduct sensitivity analyses to determine the effect that significant uncertainty may contribute to the modeling demonstration* [40 CFR 146.93(c)(2)(vi)]. Analyses used in the alternative timeframe demonstration, including computational modeling, are prone to uncertainty. Model uncertainty is a result of the uncertainties related to the underlying science of the governing equations and the uncertainty in the parameter values input to represent the actual system (USEPA, 2003). There is significant uncertainty in modeling predictions of GS due to a number of factors: difficulties in determining the structural geology and the permeability field throughout the area likely to be affected by large injection volumes; a relative lack of data on the behavior of supercritical carbon dioxide in the subsurface; the drastic changes in transport behavior of carbon dioxide caused by changes in pressure and/or temperature; and the buoyant nature of carbon dioxide relative to native formation fluids. The impact of parameter uncertainty on modeling results can be characterized through a model sensitivity analysis, which consists of sequentially varying a single parameter in successive model simulations while keeping all other model features constant. Sensitivity analyses provide an indication of those modeling parameters that most affect predictions of carbon dioxide migration, trapping, and pressure changes, and provide guidance regarding which parameters to focus on during data collection, parameter estimation, and model calibration.

- *An approved QA/QC plan must address all aspects of the demonstration* [40 CFR 146.93(c)(2)(vii)]. A QA/QC project plan must be submitted with the demonstration. It will describe all QA/QC standards to which the owner or operator will adhere. The purpose of the QA/QC plan is to outline all steps taken by the owner or operator during development of the demonstration to ensure that data and analyses are accurate, reproducible, and complete. EPA encourages the owner or operator to review relevant federal EPA and state guidance regarding development of QA/QC project plans. Applicable federal EPA guidance includes USEPA (2002).

3.2.2.9 Adjustment of Computational Model During Injection

During the injection phase of the project, the owner or operator is required to reevaluate the AoR periodically to compare model predictions to monitoring results [40 CFR 146.84(e)]. When computational model predictions and site monitoring data differ significantly, this reevaluation may result in adjustment of the computational model by calibration. The geologic conceptual model should also be updated as needed to address any new information obtained about the site geology; the revisions to the geologic conceptual model should also be reflected in updates to the computational modeling. (See the *UIC Program Class VI Well Area of Review Evaluation and Corrective Action Guidance*.) Following calibration, the owner or operator is encouraged to submit a revised PISC and Site Closure Plan that describes how changes to the model affect predictions of pressure dissipation, plume migration rates, trapping, and additional processes that affect risks to USDWs and the alternative PISC timeframe demonstration. In some cases, this model reevaluation may indicate a need to lengthen the alternative PISC timeframe, and such results should be reported to the UIC Program Director with all appropriate documentation. Using this information, the UIC Program Director may reevaluate the alternative PISC timeframe following model calibration and may lengthen the timeframe accordingly. Alternatively, such information may substantiate a revised, shorter PISC as discussed in Section 3.2.2.

3.3 Demonstration of USDW Non-Endangerment

During PISC, the owner or operator may submit a demonstration of non-endangerment of USDWs to reduce the initial permitted PISC monitoring timeframe. The UIC Program Director may reduce the PISC monitoring timeframe to less than the default of 50 years (or UIC Program Director-approved alternative timeframe) based on this demonstration [40 CFR 146.93(b)(2)]. In all cases, including in the event that PISC has occurred for the default of 50 years, the owner or operator must submit the demonstration of USDW non-endangerment prior to the approval of the end of PISC [40 CFR 146.93(b)(3)]. If the UIC Program Director determines that risks to USDWs persist at the site, he/she may extend PISC beyond the previously established PISC timeframe [40 CFR 146.93(b)(4)].

The demonstration of USDW non-endangerment differs from the demonstration for an alternative PISC timeframe (Section 3.2.2) because the non-endangerment demonstration occurs during PISC rather than initially during the project permitting phase, and it is based primarily on collected site monitoring data rather than modeling predictions. EPA encourages the owner or operator to include within the PISC and Site Closure Plan details regarding how the non-endangerment demonstration will be made on a site-specific basis and the information and conditions that the owner or operator intends to use to confirm and demonstrate non-endangerment. The non-endangerment demonstration should take the form of a detailed report submitted to the UIC Program Director. This report should include all relevant monitoring data and interpretations upon which the non-endangerment demonstration is based and any other information necessary for the UIC Program Director to replicate the analysis. EPA suggests that the non-endangerment demonstration report include the information described in the following subsections.

3.3.1 Summary of Existing Monitoring Data

A summary of all previous monitoring data at the site, including data collected during the injection and PISC phases of the project, should be submitted to help demonstrate non-endangerment. Data submittals may take the forms of databases or tables and raw data (e.g., laboratory reports, geophysical survey data), which must be submitted in an electronic format [40 CFR 146.90(e)]. Accompanying the data submittal should be a narrative explanation of monitoring activities, including the dates of all monitoring events, changes to the monitoring program over time, and an explanation of all monitoring infrastructure that has existed at the site. Data should also be compared with baseline data on fluid chemistry collected during the site characterization process as required at 40 CFR 146.82(a)(6) and 146.87(d)(3); see the *UIC Program Class VI Well Site Characterization Guidance*. EPA's suggested format for PISC monitoring reporting is provided in Section 3.1.6.

3.3.2 Comparison of Monitoring Data and Model Predictions and Model Documentation

The results of computational modeling used for AoR delineation and for demonstration of an alternative PISC timeframe may be used by the owner or operator to support the demonstration of USDW non-endangerment. The owner or operator is encouraged to provide a detailed comparison of monitoring data collected during PISC with modeled predictions of plume migration and pressure dissipation during PISC. The objective of this comparison is to assess if modeling predictions have been reasonably valid for understanding system behavior after the cessation of injection and to validate the non-endangerment demonstration. If PISC monitoring results and model predictions agree well, this suggests that modeling results may be useful for supporting the non-endangerment demonstration. See the *UIC Program Class VI Well Area of Review Evaluation and Corrective Action Guidance* for examples of the comparison of monitoring results and model predictions and discussion of model uncertainty analysis. If modeling predictions are going to be used for non-endangerment demonstration, EPA encourages the owner or operator to additionally submit all model documentation and supporting data. Refer to the *UIC Program Class VI Well Area of Review Evaluation and Corrective Action Guidance* for reporting of model predictions.

3.3.3 Evaluation of Carbon Dioxide Plume

Under certain conditions, the separate-phase and aqueous-phase carbon dioxide plumes may continue to migrate after injection ceases, as influenced by (1) the presence or lack of a stratigraphic trap; (2) the presence or lack of a structural trap; (3) carbon dioxide moving up-dip at the injection zone/confining zone interface; (4) the presence of significant highly permeable pathways that lead to preferential plume migration; and (5) the persistence of a pressure differential that results in fluid movement. If the carbon dioxide plume comes into contact with a vertical leakage pathway, it may pose a risk of endangerment to USDWs. Therefore, risk of endangerment to USDWs decreases substantially when plume migration ceases or is extremely slow.

For the separate-phase carbon dioxide plume, the risk to USDWs will decrease when the extent of pure-phase carbon dioxide ceases to grow either laterally or vertically. This condition may be met if the vast majority of carbon dioxide is trapped via trapping mechanisms and, for the case of relatively non-dipping formations, if formation pressure differentials decline such that there is no longer a driving force for carbon dioxide movement. The aqueous-phase carbon dioxide plume will continue to migrate via advection with regional ground water flow and diffusion away from the separate-phase source. Although the separate-phase source may be stabilized, the aqueous phase plume may continue to provide a risk of endangerment to USDWs within areas of the injection zone with elevated pressures. As carbon dioxide concentrations decrease further from the separate-phase source, risks associated with the plume itself concomitantly decrease. Risks associated with the pressure front surrounding the plume, however, can persist regardless of the carbon dioxide concentration (See Section 3.3.5).

For both the separate- and aqueous-phase plumes, the risk to USDWs may be low even in the event of some plume migration. This is the case if plume migration rates are extremely small, and/or if a demonstration can be made that no leakage pathways exist in the direction(s) of plume migration within long timeframes (e.g., hundreds to thousands of years).

Monitoring data are integral to the determination of plume migration rates and stabilization. As discussed above, a suite of monitoring technologies are available and may be applied in the PISC stage of a GS project. These include monitoring wells, which may be used to assess risk to USDWs if there are enough of them to allow a reasonable inference of plume migration rates. If downgradient monitoring wells screened within the injection zone do not reveal separate-phase carbon dioxide in sampling events over an extended period of time, this can be used as evidence that the plume has not migrated into that area, and upper and lower bounds of the plume migration rates can be estimated. Furthermore, monitoring wells screened above the confining layer may be used to determine aqueous-phase concentrations of carbon dioxide and mobilized constituents in order to assess USDW endangerment.

Geophysical surveys provide data over large areas and thus can be more useful in demonstrating plume migration compared to monitoring wells. By comparing the results of geophysical surveys conducted over time, plume migration rates can be estimated.

Supplementary to monitoring data, modeling results can be used to assess the risk posed to USDWs. Modeling may be used to estimate the phase-state and degree of trapping of carbon dioxide over time. If a demonstration can be made, in conjunction with monitoring data, that a vast majority of the carbon dioxide has been immobilized via trapping mechanisms, this is strong evidence that the risk to USDWs posed by the carbon dioxide plume has decreased. Modeling may also be used to estimate future plume migration. Modeling results, including sensitivity analyses, may be used to demonstrate that plume migration rates are negligible based on available site characterization, monitoring, and operational data.

3.3.4 Evaluation of Mobilized Fluids

In addition to carbon dioxide, mobilized fluids may pose an ongoing risk to USDWs. These include native fluids that are high in TDS and therefore may impair a USDW, and fluids containing mobilized drinking water contaminants (e.g., arsenic, mercury, hydrogen sulfide). Geochemical data collected from monitoring wells is integral to a demonstration that mobilized fluids no longer pose a risk to USDWs. Of particular importance are any monitoring wells that are screened above the primary confining zone, within any USDWs, and in the vicinity of any known leakage pathways. Monitoring data indicating steady or decreasing trends of potential drinking water contaminants below actionable levels (e.g., secondary and maximum contaminant levels) is necessary for this demonstration. The acceptable levels of TDS and all potential drinking water contaminants in any relevant zones should be defined in the PISC and Site Closure Plan. Additionally, the duration, in years, of observed steady or decreasing trends that may indicate USDW non-endangerment, should also be listed.

3.3.5 Evaluation of Reservoir Pressure

Pressure decline is integral to the decrease of risk to USDWs. Increased pressure is the primary driving force for fluid movement that may endanger a USDW. Pressure differentials will decay over time after the cessation of injection. The rate of pressure decay is a function of injection zone permeability, compressibility, the injected volume of carbon dioxide, the areal extent and thickness of the formation, and the presence of lateral stratigraphic confining features.

To demonstrate that there is no risk of endangerment to USDWs, the pressures within the injection zone should decline until there is no risk of fluid movement into a USDW or, alternatively, to pre-injection conditions. Monitoring using downhole pressure transducers is the most reliable metric of pressure decline over time; commercial systems are available to provide continuous downhole monitoring for pressure and temperature, and these may be a useful option (see the *UIC Program Class VI Well Testing and Monitoring Guidance*). Pressure should be emphasized as one of the key measurements during PISC monitoring. Models, including robust numerical simulators and simpler analytic or semi-analytic methods, can be used to estimate pressure decay. Models may be used to supplement monitoring data in order to estimate pressure in areas with little or no monitoring data as well as to estimate future trends. When interpreting and reporting model results, uncertainty analyses are recommended, including sensitivity analysis (see the *UIC Program Class VI Well Area of Review Evaluation and Corrective Action Guidance*).

Box 3-2. Demonstration of USDW Non-Endangerment.

This box provides an example of some of the data that may be used in the USDW non-endangerment demonstration, based on the hypothetical project presented above in Box 3-1 and the *UIC Program Class VI Area of Review Evaluation and Corrective Action Guidance*. The owner or operator had included a PISC timeframe of 50 years in the *PISC and Site Closure Plan*. However, 40 years after the cessation of injection (70 years total from the beginning of injection), the owner or operator has determined that sufficient data exist to demonstrate no ongoing risk of USDW endangerment. Data used in this demonstration include assessment of the location and migration rate of the carbon dioxide plume and mobilized fluids, results of MITs, and pressure monitoring results within the injection zone. This box focuses on pressure measurement data and modeling.

At 40 years after the cessation of injection, three monitoring wells remain in use at the project: MW-9, MW-12, and MW-13 (see Figure 9). Recall that MW-13 had been re-sited to be outside of the expected influence of the project, in the direction of preferential fluid movement. Historical pressure measurements are plotted versus time in years from the beginning of injection. Model results are also plotted, and are based on the most recently calibrated model. As can be seen, model predictions and observed pressure data agree reasonably well, which increases confidence in use of the model for evaluating future trends.

At 40 years after the cessation of injection, pressure has declined to pre-injection levels in all three wells (Figure 10). Based on risk-based criteria listed in the PISC and Site Closure Plan, pressure decline to pre-injection levels is one factor indicative of USDW non-endangerment. Model results confirm that pressures will continue to decline or be steady at levels that do not pose an endangerment to USDWs. Importantly, elevated pressure has not been observed in MW-13, consistent with the AoR reevaluation that occurred 20 years after the beginning of injection (see Box 3-1).

Box 3-2. Demonstration of USDW Non-Endangerment.

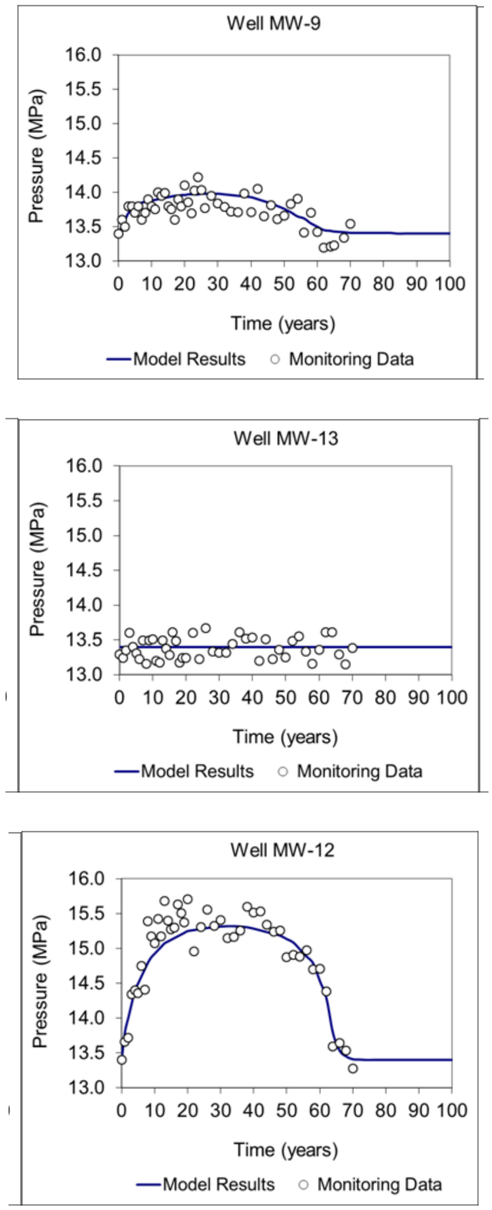

Figure 10. Historical Reservoir Pressure Data within the Injection Zone and Model Predictions for Three Monitoring Wells at Hypothetical GS Project.

3.3.6 Evaluation of Potential Conduits for Fluid Movement

Potential conduits for fluid movement, or leakage pathways, include active and abandoned wells, faults, and fractures. The demonstration of USDW non-endangerment should include an assessment of all potential conduits for fluid movement in the vicinity of the project. The demonstration may include a narrative explanation of all analyses that have been conducted to identify potential conduits (i.e., aeromagnetic surveys, records review), a listing of all potential conduits, and an explanation of why each conduit no longer poses any risk of endangerment of a USDW. Relevant supporting analyses may include assessment of the proximity of conduits to USDWs, monitoring for carbon dioxide in the local region around potential conduits, and well integrity testing.

4 Site Closure

Site closure activities required at 40 CFR 146.93(d) through (h) include: notifying the UIC Program Director of intent to close the site; plugging all monitoring wells; submitting a site closure report; and recording a notation on the deed to the facility or other documents that the land has been used to sequester carbon dioxide. Additional site closure activities may include removing all surface equipment and restoring the site to its prior land surface condition (e.g., site restoration, site grading, and planting vegetation) or to a condition approved by the UIC Program Director.

Site closure requirements are established to ensure that all PISC monitoring wells are plugged appropriately and to the UIC Program Director's satisfaction, that all GS project records are maintained, that necessary documentation is provided to the UIC Program Director, and that the future land owners are made aware of the injection operation and that carbon dioxide is stored under the surface.

Site closure may only occur after the UIC Program Director releases the owner or operator of a GS site from PISC responsibilities following a demonstration that the site no longer poses a risk of endangerment to USDWs pursuant to requirements at 40 CFR 146.93(b) (see Section 3). Additionally, with the conclusion of site closure, the owner or operator will be released from financial responsibility requirements associated with the GS project (40 CFR 146.85(b)(1); see the *UIC Program Class VI Financial Responsibility Guidance*).

While not required, EPA recommends that owners or operators describe in their PISC and Site Closure Plan how they plan to conduct site closure following the conclusion of the PISC period. For Class VI projects with plans that include proposed site closure procedures, activities will proceed accordingly as required at 40 CFR 146.93(a) and should be carried out in fulfillment of the requirements at 40 CFR 146.93(d) through (h). See the *UIC Program Class VI Well Project Plan Development Guidance* for more information regarding the preparation of the PISC and Site Closure Plan and Section 3.1.1 of this guidance document for how to conduct reevaluations of this plan.

4.1 Site Closure Notification

Owners or operators are required to notify the UIC Program Director in writing at least 120 days prior to planned site closure [40 CFR 146. 93(d)]. At this time, if any changes have been made to the original PISC and Site Closure Plan, the owner or operator must also provide the revised plan. A notification period shorter than 120 days may be allowed by the UIC Program Director prior to a planned site closure. For details of submitting the notification and the revised plan to the EPA electronic reporting system, see the *UIC Program Class VI Well Recordkeeping, Reporting, and Data Management Guidance for Owners and Operators.*

A site closure notice submitted by the owner or operator of a Class VI well to the UIC Program Director may include:

- Facility information, such as the facility name and location;

- A list of contact personnel (e.g., names, titles, phone numbers, email addresses) for allowing timely direct communication to resolve any pressing issues; and

- A projected closure date, no less than 120 days following the site closure notification submission, unless the UIC Program Director has approved a different period prior to notice submission.

EPA envisions that this notification would take the form of a letter from the owner or operator to the UIC Program Director with all of the information described above. Appendix F provides a template of such a letter.

EPA recommends that upon receipt of this notification, the UIC Program Director and the owner or operator discuss the planned site closure activities to ensure that all parties agree on the activities that must be performed.

4.2 Monitoring Well Plugging

The primary activity during site closure will be plugging of all monitoring wells at the site in a manner that prevents movement of injection or formation fluids that would endanger a USDW [40 CFR 146.93(e)]. Proper plugging of injection and monitoring wells is a long-standing requirement in the UIC Program designed to ensure that injection or monitoring wells do not serve as conduits for fluid movement following cessation of injection and site closure in order to ensure protection of USDWs.

Because improperly abandoned monitoring wells may become conduits for fluid movement into USDWs (similarly to improperly abandoned injection wells), EPA recommends that owners or operators plug their monitoring wells using procedures similar to those used to plug injection wells, particularly regarding the use of plugging materials that are resistant to carbon dioxide and carbon dioxide-rich brines. While advance notification of monitoring well plugging is not explicitly required (i.e., 60 days before plugging as is required for injection wells at 40 CFR 146.92(c)], EPA recommends that the owner or operator notify the UIC Program Director in advance of plugging monitoring wells. This notification may take the form of a letter similar to the notification of plugging the injection well presented in Appendix B.

The requirements at 40 CFR 146.92 for plugging a Class VI injection well are discussed in Section 2 of this guidance document. Owners or operators may consider the same types of information when selecting methods for monitoring well plugging as they do for injection well plugging. Relevant information includes well depth and construction, borehole diameter, location, well type, subsurface formations penetrated by the well, and how the composition of the carbon dioxide may affect plugging materials. This information will help determine the type and number of plugs that are necessary for monitoring wells, the method of emplacement, and the type, grade, and quantity of material to be used. As required for injection well plugging, the materials used for plugging monitoring wells also need to be compatible with the carbon dioxide stream and/or formation fluids with which they will be in contact. See Section 2 above for additional information and appropriate well plugging methods. Information on plugging monitoring wells is also provided in "Region V Guidelines for Class I Well Monitoring Plans," available at: http://www.epa.gov/r5water/uic/r5guid/monitor_well.htm#partii.

4.3 Site Closure Reporting and Recordkeeping

The Class VI Rule requires the owner or operator to submit a site closure report to the UIC Program Director within 90 days of site closure [40 CFR 146.93(f)]. The purpose of the report is to document appropriate closure procedures as well as provide information about the operation that may be of interest to future land owners and planners. Such information is needed to help authorities impose appropriate conditions on subsequent drilling activities that may penetrate the injection or confining zone(s).

The site closure report must document appropriate injection and monitoring well plugging as specified in 40 CFR 146.92 and described in Sections 2 and 4.2 of this guidance document [40 CFR 146.93(f)(1)]. The report should include a description of pre-plugging activities and the plugging procedures used to demonstrate that plugging requirements have been met.

The report must also contain a copy of a survey plat that has been submitted to the local zoning authority designated by the UIC Program Director [40 CFR 146.93(f)(1)]. The survey plat must indicate the location of the injection well relative to permanently surveyed benchmarks. In addition, EPA recommends that the plat also identify the locations of all monitoring wells. The owner or operator must submit a copy of the survey plat to the Regional Administrator of the appropriate EPA regional office within 90 days of site closure.

The site closure report must also include documentation of appropriate notification and information to state, local, and tribal authorities that have authority over drilling activities [40 CFR 146.93(f)(2)]. This notification will enable them to impose appropriate conditions on subsequent drilling activities that may penetrate the injection and confining zone(s). The purpose of any such conditions would be to avoid compromising the containment of injected carbon dioxide and potentially endangering USDWs. Such documentation may include information such as the names of entities being informed; copies of letters sent to accompany the information; maps of the AoR indicating the location of the injection well, plume, and pressure front; important dates (e.g., operation period, PISC period, site closure); and site characterization information.

The site closure report must also include records reflecting the nature, composition, and volume of the carbon dioxide stream [40 CFR 146.93(f)(3)]; this may take the form of historical analyses of injectate. EPA recommends that the results of any other geochemical analyses conducted at the site also be submitted.

The site closure report submitted to the UIC Program Director must be retained by the owner or operator for 10 years following site closure [40 CFR 146.93(f)]. Concurrently, a copy of the report will be submitted to EPA and will be retained in the EPA electronic reporting system [40 CFR 146.91(e)]. The UIC Program Director has authority to require the owner or operator to retain any records for longer than 10 years after site closure [40 CFR 146.91(f)(5)].

Appendix G presents a recommended template for a site closure report. More information on the format and details of the site closure report and how to submit it can be found in the *UIC Program Class VI Well Recordkeeping, Reporting, and Data Management Guidance for Owners and Operators.*

Following site closure, each owner or operator of a Class VI injection well must record a notation on the deed to the facility property or any other document that is normally examined during a title search by a potential purchaser of the property [40 CFR 146.93(g)]. The notation must include the following information:

- That the land has been used for GS;
- The name of the state agency, local authority, and/or tribe with which the survey plat was filed, as well as the address of the EPA Regional Office to which it was submitted; and
- The volume of fluid injected, the injection zone(s), and the period over which the injection occurred.

4.4 Post-Site Closure Activities

Following site closure, the owner or operator is responsible for any remedial action deemed necessary for USDW endangerment caused by the injection operation. Therefore, the owner or operator is still financially liable for the site. Under the final Class VI Rule, once an owner or operator has met all regulatory requirements under 40 CFR Part 146 for Class VI wells and the UIC Program Director has approved site closure pursuant to requirements at 40 CFR 146.93, the owner or operator will generally no longer be subject to enforcement for regulatory noncompliance. Separate from EPA's authority to enforce regulatory compliance, an owner or operator may be subject to a response order under Section 1431 of SDWA even after proper site closure is approved under 40 CFR 146.93. Under Section 1431 of SDWA, the Administrator may require an owner or operator to take necessary response measures if he or she receives information that a contaminant is present or is likely to enter a public water system or a USDW, which may present an imminent and substantial endangerment to the health of persons, and the appropriate state and local authorities have not acted to protect the health of such persons. The action may include issuing administrative orders or commencing a civil action for appropriate relief against the owner or operator of a Class VI well. If the owner or operator fails to comply with the order, they may be subject to a civil penalty for each day in which such violation occurs or failure to comply continues. Furthermore, after site closure an owner or operator may remain liable under tort and other remedies, or under other federal statutes including, but not limited to, the Clean Air Act (CAA), 42 U.S.C. 7401-7671; the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), 42 U.S.C. 9601-9675; and the Resource Conservation and Recovery Act (RCRA), 42 U.S.C. 6901-6992.

Additional information related to post-closure activities is available in the *UIC Program Class VI Financial Responsibility Guidance.* Additionally, in a 2008 paper, EPA provided information on different approaches to stewardship of carbon dioxide GS sites after site closure (USEPA, 2008). Although the SDWA does not explicitly provide EPA the authority to transfer liability from the owner or operator of a Class VI well to another entity, the paper intended to inform readers on important concepts that may be useful in developing an approach to post-site-closure stewardship.

5 References

American Petroleum Institute (API), 1993. Environmental Guidance Document: Well Abandonment and Inactive Well Practices for U.S. Exploration and Production Operations. API Bulletin E3. January 31, 1993.

API, 2002. API Specification 10A – Specification on Cements and Materials for Well Cementing (includes Addendum 1). (23rd ed.)

ASTM Standard C1438-99(2005)e1, "Standard Specification for Latex and Powder Polymer Modifiers for Hydraulic Cement Concrete and Mortar," ASTM International, West Conshohcken, PA, 2005, DOI: 10.1520/C1438-99R05E01, www.astm.org.

ASTM Standard C150 - 11 / C150M – 11, "Standard Specification for Portland Cement." ASTM International, West Conshohcken, PA, DOI: 10.1520/C0150_C0150M-11, www.astm.org.

ASTM Standard C1707-10, "Standard Specification for Pozzolanic Hydraulic Lime for Structural Purposes," ASTM International, West Conshohcken, PA, DOI: 10.1520/C1707-10, www.astm.org.

Bosma, M.G.R., Cornelissen, E.K., and Schwing, A., 2000. Improved experimental characterisation of cement/rubber zonal isolation materials. Society of Petroleum Engineers, SPE 64762.

Calvert, D.G., and Smith, D.K., 1994. Issues and techniques of plugging and abandonment of oil and gas wells. Society of Petroleum Engineers, SPE 28349.

Clark, J., and Salsbury, B., 2003. Well abandonment using highly compressed sodium bentonite – an Australian case study. Society of Petroleum Engineers, SPE 80592.

Drilling Formulas and Drilling Calculations, no date. Available on the Internet at: http://www.drillingformulas.com/tag/hydrostatic-pressure-equation/.

Englehardt, J., and Wilson, M.J., 2001. New abandonment technology new materials and placement techniques. Society of Petroleum Engineers, SPE 66496.

Goodwin, K.J., and Crook, R.J., 1992. Cement sheath stress failure. SPE Drilling Engineering, Vol. 7: 291-296.

Ide, S.T., Jessen, K., and Orr, F.M. Jr., 2007. Storage of CO_2 in saline aquifers: Effects of gravity, viscous, and capillary forces on amount and timing of trapping. International Journal of Greenhouse Gas Control, Vol. 1: 481-491.

Jirapongpipat, P., 2007. Well Plugging & Abandonment Guide. Available on the Internet at: http://www.thaidecom.com/files/Well%20Plugging%20and%20Abandonment%20Guideline.pdf.

King, G.E., 2009. Plug and Abandonment Basics. Available on the Internet at: http://gekengineering.com/Downloads/Free_Downloads/Plug-and_Abandonment_Basics.pdf.

Kosmatka, S.H., Kerkhoff, B., and Panarese, W.C., 2003. Design and Control of Concrete Mixtures. Portland Cement Association.

LeRoy-Delage, S., Thiercelin, M., and Vidick, B., 2000. New cement systems for durable zonal isolation. Society of Petroleum Engineers, SPE 59132.

Liversidge, D., and Agarwal, S.T., 2006. Permanent plug and abandonment solution for the North Sea. Society of Petroleum Engineers, SPE 100771.

Meyer, J.P., 2007. API Summary of Carbon Dioxide Enhanced Oil Recovery Injection Well Technology. Prepared for API. Available on the Internet at: http://www.api.org/policy/environment/.

Meyer, P.D., and Brill, E.D. Jr., 1988. A Method for Locating Wells in a Groundwater Monitoring Network Under Conditions of Uncertainty. Water Resources Research, Vol. 24: 1277-1282.

Moroni, N., Santra, A., Ravi, K., and Hunter, W., 2009. Holistic design of cement systems to survive CO_2 environment. Society of Petroleum Engineers, SPE 12473.

Nagelhout, C.G., Bosma, M.G.R., Mul, P.J., Krol, G.G., van Velzen, J.F.G., Joldersma, J.S., James, S.G., Dargaud, B., Schreuder, G.J.R., and Thery, F., 2005. Laboratory and field validation of a sealant system for critical plug and abandon situations. Society of Petroleum Engineers, SPE/IADC 97347.

National Energy Technology Laboratory (NETL), 2009. Best Practices for Monitoring, Verification, and Accounting of Carbon Dioxide Stored in Deep Geologic Formations. First Edition. DOE/NETL-311/081508. Available on the Internet at: http://www.netl.doe.gov/technologies/carbon_seq/infrastructure/bestpractices.html.

Nurafza, P.R., and Fernagu, J., 2009. Estimation of Static Bottom Hole Pressure From Well-Head Shut-in Pressure for a Supercritical Fluid in a Depleted HP/HT Reservoir. Society of Petroleum Engineers, SPE 124578.

Smith, D.K., 1976. Cementing. Monograph Volume 4 of the Henry L. Doherty Series. Society of Petroleum Engineers of American Institute of Mining, Metallurgical, and Petroleum Engineers.

Thiercelin, M.J., Dargaud, B., Baret, J.F., and Rodriguez, W.J., 1998. Cement design based on cement mechanical response. Society of Petroleum Engineers, SPE Drilling & Completion, December 1998, SPE 52890.

Towler, F., Victorov, H., Zamfir, G., and Ignat, P., 2008. Plugging wells with hydrated bentonite, Part 2: Bentonite bars. Society of Petroleum Engineers, SPE 115524.

United States Environmental Protection Agency (USEPA), 1982. Technical Manual: Injection Well Abandonment. Prepared by Geraghty and Miller, Inc. Available on the Internet at: http://www.epa.gov/ogwdw/uic/pdfs/Historical/techguide_uic_tech_manual_abandonmt.pdf.

USEPA, 1989. Technical Assistance Document: Cementing for the Plugging and Abandonment of Injection Wells. Prepared by Engineering Enterprises, Inc. Available on the Internet at: http://www.epa.gov/ogwdw/uic/pdfs/Historical/techguide_uic_cementing_plug_1989.pdf

USEPA, 2002. Guidance for Quality Assurance Project Plans for Modeling. EPA QA/G-5M. Available on the Internet at: http://www.epa.gov/QUALITY/qs-docs/g5m-final.pdf.

USEPA, 2003. Draft Guidance on the Development, Evaluation, and Application of Regulatory Environmental Models. Prepared by The Council for Regulatory Environmental Modeling. Available on the Internet at: http://www.modeling.uga.edu/tauc/other_papers/CREM%20Guidance%20Draft%2012_03.pdf.

USEPA, 2008. Approaches to Geologic Sequestration Site Stewardship After Site Closure. EPA 816-B-08-002. Available on the Internet at: http://www.epa.gov/ogwdw000/uic/pdfs/support_uic_co2_stewardshipforsiteclosure.pdf.

Vaucher, D., and Brooks, R., 2010. Advantages of inflatable packer technology for temporary or permanent well abandonment in the Gulf of Mexico. Society of Petroleum Engineers, SPE 130270.

Wyoming Completion Technologies. No date. High pressure, ball type, fluid control valve. Available on the Internet at: http://wct.directairnet.com/products.html.

Appendix A.

Sample Template of an Injection Well Plugging Plan

Appendix A: Sample Template of an Injection Well Plugging Plan

<u>Facility Information</u>

Facility name:

Facility contacts (names, titles, phone numbers, email addresses):

Location (town/county/etc.):

Planned tests or measures to determine bottomhole reservoir pressure:

Planned external MIT(s):

Information on Plugs:

	Plug #1	Plug #2	Plug #3	Plug #4	Plug #5	Plug #6	Plug #7
Diameter of Boring in Which Plug Will be Placed							
Depth to Bottom of Tubing or Drill Pipe							
Sacks of Cement to be Used (each plug)							
Slurry Volume to be Pumped							
Slurry Weight							
Top of Plug							
Bottom of Plug							
Type of Cement or Other Material							
Method of Emplacement (e.g., balance method, retainer method, or two-plug method)							

Attachments:

Injection well construction plan/schematics showing depth to tubing stub, exposed formation intervals, casing diameters, depths, etc.

Information on formations, depths to USDWs, etc.

Schematic/drawings of the placement of all plugs.

Appendix B.

Sample Template of a Notice of Intent to Plug a Class VI Injection Well

Appendix B: Sample Template for a Notice of Intent to Plug an Injection Well

[Today's Date]

Insert Name of Owner or Operator
Insert Return Address

To: ***Insert Name of UIC Program Director***

In compliance with 40 CFR 146.92(c) of the United States Code of Federal Regulations (CFR), this is to provide to the Director of the UIC Class VI Program notice of ***[insert name of owner or operator]***'s intention to plug ***[insert identifying information about the injection well]*** at the ***[insert name of facility]*** geologic sequestration (GS) project. The Class VI well is located at: ***[insert location of well (e.g., latitude/longitude)]***.

Plugging is anticipated to occur on: ***[insert projected plugging date/time, no less than 60 days after the date of the letter]***.

Use one of the following two paragraphs as appropriate depending on whether changes to the Injection Well Plugging Plan are needed:

Please note that ***[insert name of owner or operator]*** intends to plug the well as described in the approved Injection Well Plugging Plan that was submitted to satisfy the permit application requirements at 40 CFR 146.82 for ***[insert permit number]***.

OR

Please note that, based on a review of information collected since submittal of the Injection Well Plugging Plan to satisfy the permit application requirements at 40 CFR 146.82 for ***[insert permit number]***, ***[insert name of owner or operator]*** has identified some needed changes to the Injection Well Plugging Plan. A revised Injection Well Plugging Plan is attached to this letter.

If you have any questions about the planned plugging of ***[insert name of project/facility]***, please contact me or any of the following staff:

Primary contact:	***Insert name, title, phone, number/email address***
Additional contact (e.g., legal contact):	***Insert name, title, phone, number/email address (as necessary)***
Additional contact (e.g., chief engineer):	***Insert name, title, phone, number/email address (as necessary)***

Sincerely,

Insert name of owner or operator contact
Insert title

Appendix C.

Sample Template of a Class VI Injection Well Plugging Report

Appendix C: Template for an Injection Well Plugging Report

Facility Information

Facility Name:

Facility Address:

Facility Contacts (names, titles, phone numbers, email addresses):

Location (town/county/etc.):

Permit Number:

Injection Well Plugging *(Repeat as needed for each injection well associated with the project.)*

Results of tests or measures to determine bottomhole reservoir pressure:

Results of external MIT(s):

Information on Plugs:

	Plug #1	Plug #2	Plug #3	Plug #4	Plug #5	Plug #6	Plug #7
Diameter of Boring in Which Plug Was Placed							
Depth to Bottom of Tubing or Drill Pipe							
Sacks of Cement Used (each plug)							
Slurry Volume that was Pumped							
Slurry Weight							
Top of Plug							
Bottom of Plug							
Type of Cement or Other Material							
Method of Emplacement (e.g., balance method, retainer method, or two-plug method)							

Casing and Tubing Record after Plugging

Size	Weight (lb/ft)	To be put in Well (ft)	To be left in Well (ft)	Diameter of Boring

Checklist and Additional Information Attached

- Injection well construction schematics showing actual depth to tubing stub, exposed formation intervals, casing diameters, depths, others.
- Information on formations, depths to USDWs, other.
- Schematic/drawings of the placement of all plugs showing their actual depth.

Retain Copy of Report

A copy of this well plugging report will be retained by ***[insert name of owner or operator]*** for 10 years following the date of site closure, ***[list date of site closure]***.

Certification I certify under the penalty of law that I have personally examined and am familiar with the information submitted in this document and all attachments and that, based on my inquiry of those individuals immediately responsible for obtaining the information. I believe that the information is true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment. (Ref. 40 CFR 144.32)		
Name and Official Title (Please type or print)	**Signature**	**Date Signed**

Appendix D.

Sample Template of a Class VI Post-Injection Site Care and Site Closure Plan

Appendix D: Sample Template of a PISC and Site Closure Plan

Facility Information

Facility name:

Facility contacts (names, titles, phone numbers, email addresses):

Location (town/county/etc.):

Pre- and Post-Injection Pressure Differential

Figure: Predicted pressure changes (pre-injection to the cessation of injection).
Source: AoR delineation modeling.

Predicted Position of the Carbon Dioxide Plume and Associated Pressure Front at Site Closure

Figure: Map showing the extent of the carbon dioxide plume and pressure front at site closure.
Source: AoR delineation modeling.

Post-Injection Monitoring Plan

Ground Water Quality Monitoring

Monitoring well name/location/map reference: **Well depth/formation(s) sampled:**	
Parameter/Analyte	**Frequency**
Aqueous and pure phase carbon dioxide	
Total dissolved solids	
pH	
Specific conductivity (SC)	
Temperature	
Other parameters (e.g., major anions and cations; trace metals; tracers; hydrocarbons; and volatile organic compounds)	

Sampling methods:

Analytical techniques:

Laboratory to be used/ chain of custody procedures:

Quality assurance and surveillance measures:

Plan for guaranteeing access to all monitoring locations:

Carbon Dioxide Plume and Pressure Front Tracking

Direct Pressure Monitoring

Well Location/Map Reference	Depth(s)/Formation(s)	Frequency

Quality assurance and surveillance measures:

Plan for guaranteeing access to all monitoring locations:

Indirect Carbon Dioxide Plume and Pressure Front Tracking

- *Describe indirect methods to be used (e.g., types of indirect surveys to be performed, the planned areal extent/resolution of geophysical surveys, and planned frequency/schedule) and their associated quality assurance and surveillance measures, and plans to record and report the results.*

Direct Geochemical Plume Monitoring

- *If it is determined that direct geochemical monitoring of the plume is necessary, describe the locations where samples will be taken and parameters to be monitored.*

Monitoring Location/Map Reference	Frequency

Sampling methods:

Analytical techniques:

Laboratory to be used/ chain of custody procedures:

Quality assurance and surveillance measures:

Plan for guaranteeing access to all monitoring locations:

Surface Air and/or Soil Gas Monitoring (*if required by the UIC Program Director*)

Monitoring Location/Map Reference	Frequency

Sampling methods:

Analytical techniques:

Laboratory to be used/ chain of custody procedures:

Quality assurance and surveillance measures:

Plan for guaranteeing access to all monitoring locations:

Additional Monitoring (*if required by the UIC Program Director*)

- *Describe testing techniques and equipment and their associated quality assurance and surveillance measures, testing frequency (e.g., anticipated test dates), and plans to record and report the results.*

Proposed Schedule for Submitting Post-Injection Monitoring Results

Planned Testing/Monitoring	Reporting Schedule
Ground Water Quality Monitoring Data	*E.g., quarterly*
Carbon Dioxide Plume and Pressure Front Tracking Data	
Direct Pressure Monitoring Data	
Indirect Carbon Dioxide Plume and Pressure Front Tracking Data	
Surface Air and/or Soil Gas Monitoring Data (if required by the UIC Program Director)	
Additional Monitoring Data (if required by the UIC Program Director)	

Alternative Post-Injection Site Care Timeframe

Describe the alternative post-injection site care timeframe and provide the demonstration made under 40 CFR 146.82(a)(18), if that demonstration has been approved by the UIC Program Director. The demonstration of an alternative post-injection site care timeframe must meet the criteria under 40 CFR 146.93(c)(1) and (2). The description here should include expected dates that a non-endangerment demonstration may be made and advanced schedules for PISC and site closure.

Site Closure Plan

Planned Remedial/Site Restoration Activities:

Describe plans for removing all surface equipment and restoring vegetation.

Information on Plugs for Monitoring Well #1:

	Plug #1	Plug #2	Plug #3	Plug #4	Plug #5	Plug #6	Plug #7
Diameter of Boring in Which Plug Will be Placed							
Depth to Bottom of Tubing or Drill Pipe							
Sacks of Cement to be Used (each plug)							
Slurry Volume to be Pumped							
Slurry Weight							
Top of Plug							
Bottom of Plug							
Type of Cement or Other Material							
Method of Emplacement (e.g., balance method, retainer method, or two-plug method)							

Include additional tables for other monitoring wells.

Appendix E.

Sample Template of a Class VI Non-Endangerment Demonstration

Appendix E: Sample Template of a USDW Non-Endangerment Demonstration

Facility Information

Facility name:

Facility contacts (names, titles, phone numbers, email addresses):

Location (town/county/etc.):

Introduction

- Summary explanation of why owner or operator believes that USDWs are no longer endangered, and primary supporting rationale. Include reference to later sections and supporting data.
- List of all USDWs that are in the vicinity of the GS project and information on depth, presence of artificial penetrations, water quality, and use as a drinking water source.
- Operational history, including total amount of carbon dioxide injected, characteristics of the carbon dioxide stream, and total areal size of the area of review.

Summary of Existing Monitoring Data

- Narrative description of all monitoring activities that have taken place at site, including dates, types of monitoring, changes to monitoring.
- All supporting information for any submitted monitoring data, as listed at Section 3.1.6.
- Attachment 1: Series of tables summarizing ground water geochemistry data and pressure measurements over time
- Attachment 2: Series of graphs showing time-series trends at all site monitoring wells for carbon dioxide, pH, TDS, any identified drinking water contaminants, and reservoir pressure
- Attachment 3: Final electronic submittal of all monitoring data, in database or accepted format
- Attachment 4: Maps showing most recent data on the extent of separate-phase carbon dioxide, based on data from monitoring wells and geophysical surveys.
- Attachment 5: Maps showing most recent pressure data as measured from monitoring wells.

Comparison of Monitoring Data and Model Predictions

- Narrative comparison of monitoring data and model predictions from most recently calibrated computational model.
- All supporting information for modeling submittals, as described in the *UIC Program Class VI Well Area of Review Evaluation and Corrective Action Guidance*.
- Attachment 6: Series of time-series graphs and/or maps comparing model predictions and monitoring results of reservoir pressure.

- Attachment 7: Series of maps comparing evolution of the separate-phase carbon dioxide plume based on monitoring results and modeling predictions.
- Attachment 8: Series of tables and/or other supporting data that document model calibration procedures, and relative difference in model predictions and calibration target data.

Evaluation of Carbon Dioxide Plume

- Narrative evaluation of the risks to USDWs posed by the carbon dioxide plume (both separate-phase and dissolved) over time, including current conditions.
- Quantitative evaluation of current plume migration rates in all directions away from the injection well, including vertically. If plume migration is still occurring, calculation of estimated timeframes for plume to reach any known migration pathways and/or USDWs.

Evaluation of Mobilized Fluids

- Narrative evaluation of the extent of fluid migration at the project over time and the risks posed to any USDWs by fluid mobilization.
- Listing of all drinking water contaminants present in the injection zone and any overlying zones impacted by the project, and identification of the original source of all drinking water contaminants (e.g., contaminant in the carbon dioxide stream, dissolution of mineral matrix).
- Quantitative or semi-quantitative prediction of the fate and transport of any drinking water contaminants in the future.
- Evaluation of areas exhibiting elevated levels of TDS and evaluation of future migration of high TDS water.

Evaluation of Reservoir Pressure

- Narrative evaluation of the risks to USDWs posed by elevated pressure historically at the site and currently.
- Quantitative comparison of current pressure to thresholds necessary to force fluid from the injection zone into the lowermost USDW and/or comparison of current reservoir pressure levels and pre-injection levels.
- Predictions of future pressure trends and reference to any supporting analyses (e.g., modeling).

Evaluation of Potential Conduits for Fluid Movement

- Reference to listing of all artificial penetrations present in vicinity of GS project that may penetrate the confining zone. This list should be included in the permit application as required by 40 CFR 146.83(f)(4).
- For each artificial penetration, explanation of any assessments/tests conducted to evaluate risks to USDWs.

Appendix F.

Sample Template of a Notice of Intent to Close a GS Project

Appendix F: Sample Template for a Notice of Intent to Close a GS Project

[Today's Date]

Insert Name of Owner or Operator
Insert Return Address

To: ***Insert Name of UIC Program Director***

In compliance with 40 CFR 146.93(d) of the United States Code of Federal Regulations (CFR), this document is to provide notice to the Director of the UIC Class VI Program of ***[insert name of owner or operator]***'s intention to close the ***[insert name of facility]*** geologic sequestration (GS) project. The GS project to be closed is located at: ***[insert location of facility (e.g., town, county)].***

Closure is anticipated to occur on: ***[insert projected closure date, no less than 120 days after the date of this letter]***.

Use one of the following two paragraphs as appropriate depending on whether changes to the site closure plan are needed:

Please note that ***[insert name of owner or operator]*** intends to close the project as described in the approved Post-Injection Site Care and Site Closure Plan that was submitted to satisfy the permit application requirements at 40 CFR 146.82 for ***[insert permit number]***.

OR

Please note that, based on a review of information collected since submittal of the Post-Injection Site Care and Site Closure Plan to satisfy the permit application requirements at 40 CFR 146.82 for ***[insert permit number]***, ***[insert name of owner or operator]*** has identified some needed changes to the site closure plan. A revised site closure plan is attached to this letter.

If you have any questions about the planned closure of ***[insert name of project/facility]***, please contact me or any of the following staff:

Primary contact:	***Insert name, title, phone, number/email address***
Additional contact (e.g., legal contact):	***Insert name, title, phone, number/email address (as necessary)***
Additional contact (e.g., chief engineer):	***Insert name, title, phone, number/email address (as necessary)***

Sincerely,

Insert name of owner or operator contact
Insert title

Appendix G.

Sample Template of a GS Project Closure Report

Appendix G: Template for a Site Closure Report

Facility Information

Facility Name:

Facility Address:

Facility Contacts (names, titles, phone numbers, email addresses):

Location (town/county/etc.):

Permit Number:

Injection Well Plugging *(Attach copies of the plugging reports for all injection wells associated with the project.)*

Monitoring Well Plugging

Results of tests or measures to determine bottomhole reservoir pressure:

Results of external mechanical integrity test(s):

Information on Plugs for Monitoring Well #1: (to be repeated for each monitoring well)

Monitoring Well Location							
Monitoring Well Depth							
	Plug #1	Plug #2	Plug #3	Plug #4	Plug #5	Plug #6	Plug #7
Diameter of Boring in Which Plug Was Placed							
Depth to Bottom of Tubing or Drill Pipe							
Sacks of Cement Used (each plug)							
Slurry Volume that was Pumped							
Slurry Weight							

	Plug #1	Plug #2	Plug #3	Plug #4	Plug #5	Plug #6	Plug #7
Top of Plug							
Bottom of Plug							
Type of Cement or Other Material							
Method of Emplacement (e.g., balance method, retainer method, or two-plug method)							

Casing and Tubing Record after Plugging

Size	Weight (lb/ft)	That was put in Well (ft)	That was left in Well (ft)	Diameter of Boring

Remedial/Site Restoration Activities:

Include a description of completed site restoration activities such as removing all surface equipment and restoring vegetation (or status, as appropriate).

Survey Plat

- Name of the agency with which the survey plat was filed.
- A copy of a survey plat that has been submitted to the local zoning authority designated by the UIC Program Director. It must indicate the location of the injection well relative to permanently surveyed benchmarks, pursuant to 40 CFR 146.93(f)(1). EPA recommends including the locations of all monitoring wells relative to permanently surveyed benchmarks.

Notifications

Provide/attach copies or evidence of:

- Notation on the deed to the facility property that the land has been used for GS.
- The name of the state agency, local authority, and/or tribe with which the survey plat was filed, as well as the address of the EPA Regional Office to which it was submitted.
- Documentation of appropriate notification and information to state, local, and tribal authorities that have authority over drilling activities.
- The volume of fluid injected, the injection zone(s) into which carbon dioxide was injected, and the time period of injection.
- Information on the source and composition of the carbon dioxide (recommended).

Insert/attach laboratory reports (or a representative report, if the carbon dioxide stream was relatively constant in composition). Include the name of the laboratory, analytical techniques, and quality assurance and surveillance measures.

Analyte	**Representative Percentage**
Carbon dioxide	
H_2S	
Nitrogen	
Other hydrocarbon gases (e.g., methane, ethane)	
Others	

Certification		
I certify under the penalty of law that I have personally examined and am familiar with the information submitted in this document and all attachments and that, based on my inquiry of those individuals immediately responsible for obtaining the information. I believe that the information is true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment. (Ref. 40 CFR 144.32)		
Name and Official Title (Please type or print)	**Signature**	**Date Signed**