Recommendations for the Regulatory Management of Geologic Sequestration of CO2 under the UIC Program
March 28, 2008

Introduction

This document contains the views of an ad-hoc CO2 Workgroup regarding regulatory recommendations to the U.S. Environmental Protection Agency for the geologic sequestration of CO2. The Workgroup is a multi-stakeholder effort comprised of representative from state UIC and oil and gas agencies, environmental non-governmental organizations (NGO's), oil and gas exploration, production and service companies, national laboratories and public power companies. While this document was developed with participation by and input from several member states of the Ground Water Protection Council (GWPC), it does not represent an official position of the GWPC

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We would like to thank all of the workgroup members and other contributors who volunteered their time and expertise to the development of this document.

Workgroup recommendations were developed through a consensus process in which technical, legal and regulatory expertise was applied to a series of alternative approaches to regulation of geosequestration in a number of topic areas. Each series of alternatives was evaluated on the basis of the following criteria:

1. The intent of the approach
2. The technical merit and practical applicability of the approach
3. The consistency of the approach with the language of the Safe Drinking Water Act (SDWA), Section 1422 provisions and current Code of Federal Regulation (CFR).

The alternatives were also considered in light of comments from GWPC member states collected in response to a separate questionnaire that was circulated to obtain views for the development of recommendations to EPA. These comments are summarized in the body of the document under the "Comments" heading. Because these comments were collected separately from the assessment of alternatives, there may not be a direct correlation in some cases.

In many cases the recommendations of the workgroup mirror or emulate the language of the current CFR for the Underground Injection Control (UIC) program (40CFR 144,145 and 146). This was considered not only practical but advisable as it avoids the need to acquire additional authorities to implement a regulatory program and recognizes the existence of a framework for the application of a regulatory scheme that has a nearly forty year record of demonstrated success.

The document is organized as follows for each topic area:

- Alternative Approaches
- Comments (State Regulatory Agencies)
- Workgroup Recommendation
- Recommendation Rationale

Appendix A contains additional comments received by the workgroup during and following the recommendations development process.

This document addresses alternative approaches to regulatory requirements in the following topic areas:

1. **Geologic Characterization**
2. **Fluid Movement**
3. **Area of Review (AOR)**
4. **Well Construction**
5. **Operation**
6. **Mechanical Integrity Testing**
7. **Measurement Monitoring and Verification**
8. **Well Closure**
9. **Financial Responsibility**

1. Geologic Characterization

Alternative Approaches 1.1: Geologic System

A geologic system comprised of:

- A receiving zone of sufficient depth, area extent, thickness, porosity, and permeability;
- Lithologic description.
- Geological name.
- Thickness and depth.
- A trapping mechanism that is free of major non-sealing faults;
- A primary confining system of sufficient regional thickness and competency to allow injection at proposed rates and volumes without initiating or propagating fractures in the confining zone; and
- Where conditions warrant, a secondary containment system that extends to the base of the lowermost USDW and is completely redundant of the primary confining system and could confine the injected CO2 should the primary system fail, **OR**

A secondary containment system that extends to the base of the lowermost USDW and is completely redundant of the primary confining system and could confine the injected CO2 should the primary system fail.

Comments 1.1

1. Based upon a GWPC survey, most states (AL, CA, FL, IN, KS, NM, OH, WA) view proper site selection as an extremely high priority. States that did not specifically reference proper site selection as a major concern, typically, indicated that they were confident that current State UIC Program practices and rules ensured adequate evaluation of industry-proposed sites.
2. All surveyed states recognize the need to define reservoir-specific storage characteristics. Colorado and Nebraska are specifically concerned with CO2 solubility and geochemical reactions in the injection reservoir as they could affect storage properties at large scale sequestrations operations. While applicants are required to submit geochemical data, presumably to establish baseline geochemical information for USDW's, there does not appear to be a corresponding requirement for primary or secondary containment systems.
3. Florida commented that regulations should detail site selection requirements, and should include data and interpretation from a "regional and local context."
4. The applicant should also provide depth, areal extent, thickness, porosity, permeability, lithology (including facies relationships) for the primary and secondary confining system as wells as secondary containment systems.
5. Ideally, proposed sites should have secondary containment systems that serve as monitoring formations between the primary and secondary confining systems. However, it is recognized that not all sites have, or need, secondary containment systems.

6. Regulations should be flexible enough to accommodate differences in regional and state, geologic conditions. States such as Nebraska, have extremely thick, regionally-extensive confining systems, but not necessarily secondary containment systems. Therefore, the more general standard (highlighted) is favored, so as not to preclude permitting of facilities in other-wise geologically ideal settings.
7. Is there any language in the UIC regulations that precludes injection of CO2 within the ZEI of Class I industrial or hazardous waste injection wells? If not, perhaps that should be included as a siting prohibition or addressed in regulations as a consideration it siting, AOR, fate and transport modeling, etc.
8. The regulations for non-EOR injections for geologic sequestration in a saline reservoir should include a determination by the appropriate State jurisdictional agency that the injection operation will not adversely affect future development of oil and gas reserves or commercially valuable mineral deposits. For example, Texas law requires determination that a permitted injection well will not impair oil and gas or other mineral rights, or endanger any oil or gas reservoir. (It is recognized this requirement would be outside the scope of the SDWA.)

Workgroup Recommendation 1.1

A geologic system comprised of:
- An injection zone of sufficient depth, areal extent, thickness, porosity, and permeability;
- A confining zone that is free of transecting transmissive faults and fracture zones;
- A confining zone of sufficient areal extent and integrity to confine injected fluid and allow injection at proposed rates and volumes without reactivating transecting, transmissive faults or initiating or propagating transecting, transmissive fractures in any confining zone.

Recommendation Rationale 1.1

The elements listed in the recommendation are considered essential for the proper characterization and usage of a site for geologic sequestration. With respect to confinement, it was the consensus of the workgroup that although secondary confinement zones may seem be desirable, a requirement for secondary confinement was impractical because:

- The definition of “confining zone” allows for consideration of multiple formations to the extent necessary to provide adequate confinement because it includes: “a geological formation, group of formations, or part of a formation that is capable of limiting fluid movement above an injection zone.” We believe the definition of confining zone also includes the conceptual framework for zones that could be used for monitoring.
- The adequacy of the confining zone is more critical to the suitability of a site than the presence of secondary confinement
- A secondary confinement system may not be present and the lack of such a system should not automatically disqualify a site from consideration where there is an adequate primary confinement system;

The term transecting transmissive was added to narrow the scope of the information provided to only those structural features that could be considered potential pathways for fluid migration. Although the workgroup struggled with the technical aspects of determining transmissivity it was still believed that this was the only practical way to limit the dataset to an appropriate level of detail.

Additionally, the workgroup felt it appropriate to include the reactivation of faults as a consideration with respect to injection rates and volumes.

Finally, the workgroup inserted the word “integrity” in place of “competency” because in rock mechanics rock types such as Sandstone or Limestone are considered more competent than rocks such as Shale, but Shale typically provides a better confining layer than Sandstones because its lower vertical permeability gives it a greater ability to prevent the transmission of fluids upward through the rock matrix and its ductile character allows it to flex or flow rather than break under stress.

Alternative Approaches 1.2: Site Information

Provide information on the geologic structure of the proposed site, including:
- Maps and cross sections of local geologic structure.
- Identification of faults and fractures and determination that they would not interfere with containment.
- Information on seismic history and the presence/depth of seismic sources.
- Identification of surface exit points of potential release of CO_2, including all man-made surface structures that are intended for human occupancy.

Comments 1.2

1. Indiana recommends that regulations preclude permitting operations at locations at known fault zones. Applicants should be required to list distances to the nearest known fault(s).
2. Most surveyed states recognize the importance of identifying any faults within the AOR or ZEI that transect the primary and secondary containment units. If faults transect the injection reservoir, applicants could provide data demonstrating that fault plans are non-transmissive. Some states indicate that they would need technical guidance to make such determinations.
3. Mississippi specifically recommends a 3D Seismic Survey for identification of faults in the AOR or ZEI.
4. What is meant by "surface exit points"? Are we asking the applicant to provide an up-to-date map of every house, business, etc. within an AOR that may exceed 100 square miles? Extremely onerous. This will constantly change during the 30 – 50 year life span of a major project. What value does this serve? The last bullet appears to address conduits to the surface, and ignores conduits to USDW's, oil and gas bearing zones, or other commercially valuable mineral deposits.
5. Add a requirement for identification of all water wells (or, wells with public-domain records); or a specified subset of wells. (Note: See Workgroup Recommendation 3b for information relative to this comment)

Workgroup Recommendation 1.2

Provide information on the geologic structure and hydrologic properties of the proposed site, including:
- Geological names and Lithologic descriptions of the injection zone, confining zone, and interspersed formations;
- Maps and cross sections of local geologic structure;
- Known faults and fracture zones in the confining zone and an assessment of their effect on confinement;
- Tectonic seismic history showing the location, depth and magnitude of seismic events

Recommendation Rationale 1.2

The workgroup felt that a requirement to provide information on all faults and fractures for the proposed site would be impractical as it would necessitate extensive seismic surveys. Similar to recommendation 1.1, the workgroup revised the proposed language to reflect "known faults and fracture zones" but also added a provision for the assessment of their potential to affect confinement. The outcome from these assessments could be used to determine if a fault or fracture zone was transecting and transmissive as noted in 1.1. With respect to the seismic history, it was believed that the importance of this provision centered less on the sources of seismicity and more on the location, depth and magnitude of seismic events as these are better predictors of potential future seismic activity that could result in a loss of confinement.

Alternative Approaches 1.3: Site Characterization

Characterize the overburden and subsurface structures, and trapping mechanisms based on:

- Data on the size, capacity, porosity, and permeability of the receiving formation and the confining systems, including any geology/facies changes, based on geologic cores, outcrop data, 3-dimensional seismic surveys, and well logs.
- Geomechanical information on fractures, stress, rock strength, and in situ fluid pressures within the cap rock and storage reservoir.
- Maps and cross sections illustrating regional geology.

Comments 1.3

1. Would this language require applicants to run 3-D seismic surveys, regardless of project size; or simply require analysis of existing seismic data? While some surveyed states (In.) support requiring 3-D seismic surveys, others favor a more general approach that indicates the type of data needed for submission, leaving the permitting agencies to determine the details.
2. Geomechanical information will be very sparse on saline reservoirs and, in particular, predictions of values and distance from wells which can be logged and cored could be very unreliable.
3. "Do state UIC regulators have the expertise to evaluate 3-D seismic results?"

Workgroup Recommendation 1.3

Characterize the overburden and subsurface structures, and confining zone within the AOR based on:

- Data on the areal extent, thickness, porosity, and permeability of the injection zone and confining zone, including any geology/ facies changes, based on geologic cores, outcrop data, seismic surveys, well logs or other data acceptable to the Director;
- A estimation of the capacity of the injection zone using a methodology acceptable to the Director;
- Geomechanical information describing natural and induced fractures, stress, rock strength, and in-situ fluid pressures within the confining zone;
- Maps and cross sections illustrating regional geology, including the regional stress state.

Recommendation Rationale 1.3

The key change to the proposed language in this recommendation is the removal of the provision for 3-D seismic. The workgroup was concerned that limiting seismic to 3-D profiles was not advisable because of the potential costs, availability, and evaluation capability limitations inherent to 3 dimensional seismic surveys. It was also felt that the regulatory authority should have the ability to specify other forms of data acceptable for characterizing the geologic features in the AOR.

Alternative Approaches 1.4: USDW Information

Provide the geologic name and depth of all USDWs that may be affected by the injection.
Provide geochemical information on subsurface aquifers, including all USDWs:

- Baseline geochemistry.
- Maps and cross sections of USDWs, **OR**

Provide geochemical information on subsurface aquifers, including all USDWs:

- Baseline geochemical data on water-rock- CO_2 geochemistry and mineral reactions.
- Maps and cross sections of USDWs.

Comments 1.4

Question: What is meant by "geochemical information"? Is this requirement intended to establish baseline ground-water chemistry, aquifer-lithologic properties, for USDW's within the AOR/ZEI; or both. Is it intended to provide a basis for modeling/predicting water-rock-CO2 reactions as they relate to SDWA water-quality standards?

Workgroup Recommendation 1.4

Provide the geologic name, depth, maps and cross sections of all USDW's that may be affected by the injection
Provide geochemical and hydrogeologic information on the injection zone, the confining zone, subsurface aquifers, and all USDWs within the AOR including:

- Baseline fluid chemistry and geochemistry
- Baseline data on porosity, permeability, formation pressure, and specific storage or, a poroelastic parameter acceptable to the Director.

Recommendation Rationale 1.4

In addition to geochemical information, the workgroup felt it was critical to provide hydrogeologic information on not only aquifers and USDWs but also on the injection zone, and confining zone as monitoring in formations within these zones may plays a critical role in any evaluation of the success of confinement. Further it was felt that the information to be submitted needed to be constrained to a specific area and that the AOR seemed to be the most reasonable and practical boundary for this purpose.

Alternative Approaches 1.5: AOR Information

Provide information on the area of review:

- Maps and cross sections of the AOR.
- List of penetrations into the injection zone.
- List penetrations of secondary containment system.

Comments 1.5

None

Workgroup Recommendation 1.5

Recommendation incorporated into 3.2

Recommendation Rationale 1.5

See Recommendation 3.2

2. Fluid Movement

Alternative Approaches 2: Fluid Movement

The well must be constructed, operated, maintained, and plugged such that injection activities will not cause movement of any fluids into a USDW.

Comments 2

1. Is this the appropriate standard? Should the rules simply prohibit movement of fluid into a USDW that causes a violation of primary MCLs or poses a public health risk? Language should be consistent with the 144.12 An endangerment standard. Further, 144.12 (b) only applies to classes I, II and III; the interpretation of allowance of no fluid movement into a USDW is problematic, particularly where a non-USDW injection zone transitions horizontally into a USDW at distance from an injection well. See GWPC position on "no fluid movement" interpretation.
2. The terms confining zone and confining bed defined in the CFR are nearly synonymous with one another. Consequently, the term confining zone should be redefined in the CFR as "a system of strata containing confining beds capable of preventing vertical fluid migration and non-confining beds capable of being used to monitor leakage through a confining bed". **OR**

   Add the term Confining System as follows: Confining system means "a sequence of confining and non-confining beds capable of preventing vertical fluid migration and capable of being used to monitor leakage through a confining bed"

Workgroup Recommendation 2

Wells must be constructed, operated, maintained, converted, plugged, and abandoned in a manner that prevents the movement of fluid containing any contaminant into underground sources of drinking water, if the presence of that contaminant may cause a violation of any primary drinking water regulation under 40 CFR part 142 or may otherwise adversely affect the health of persons.

Recommendation Rationale 2

The critical consideration in this recommendation is the standard to be applied to the movement of fluid. The workgroup agreed that the current regulations at 40 CFR 144.12(a) established a fluid migration standard that was both practical and appropriate for this purpose and should be applied. Consequently, this standard was applied in this recommendation and throughout the other recommendations in the document. Additionally, the workgroup felt that the addition of "converted" to the list of activities to which fluid migration prevention applied was appropriate to deal with those cases where a well may have served another purpose but was going to be used for injection of CO_2 for geologic sequestration.

3. Area of Review (AOR)

Alternative Approaches 3.1: AOR Determination

The AOR may be determined by a calculating a fixed radius or by modeling, **OR**

The AOR should be determined based on state-of-the-art techniques (e.g., modeling) that define, in three dimensions, the extent of the CO_2 plume and associated pressure front for a specified period of time (e.g., 100 years) based on proposed injection rates and volumes. Models must account for the buoyant, two-phase nature of the injected CO_2, **OR**

The AOR should be determined using state-of-the-art models that define, in three dimensions, the extent of the CO_2 plume and associated pressure front for a specified period of time (e.g., 10,000 years) based on proposed injection rates and volumes. Models must account for the buoyant, two-phase nature of the injected CO_2.

Comments 3.1

1. Based upon a GWPC survey, this is an area of significant state-concern. For deep saline-reservoir projects models will likely be based on formations with few penetrations (ideal) and therefore inadequate information to formulate an adequate subsurface geologic interpretation (catch 22). California points out that they approved a gas storage project in the LA Basin based upon 3-D seismic surveys, but the project was eventually terminated due to leakage.
2. Florida comments that the focus of AOR/ZEI reviews should be “deep” wells, with less emphasis placed on “shallow” wells and surface features.
3. Ohio EPA comments – This may be one of the most critical aspects of regulatory development. Regulations need to specify appropriate modeling using accurate site specific information for inputs to better ensure accurate area of review determinations. Poorly abandoned borings and wells in the AOR are the most likely pathways for the CO2 to breach the confinement zone, further emphasizing the need for an accurate determination. Due to the number of facilities that may be interested in CO2 sequestrations, interference between pressure zones from nearby injection may need a greater consideration than in the past.
4. AOR reviews should include evaluations of underground mines, and especially the quality of plug jobs for well penetrations in the affected areas of underground mines. (Again, falls outside scope of SDWA)
5. Washington has developed the following definition to define the AOR/ZEI boundary. “The boundaries of the geologic sequestration project which shall be calculated to include the area containing 95 percent of the injected CO2 mass, 100 years after the completion of all CO2 injection, or the plume boundary at the point in time when expansion is less than 1 percent per year, whichever is greater, or another method approved by the department.”
6. Texas law requires determination of 99% sequestration of CO2 for 1,000 years; such requirement may impact considerations of AOR, modeling of fate and transport, monitoring, etc.
7. Other reviewers also commented that the AOR boundary should be defined based upon plume/pressure front stabilization criteria vs. an arbitrary timeframe (or, whichever is greater).
8. It seems possible or likely that the size and shape of the AOR determined in the characterization phase will change during the life of the project as MMV and modeling progress. We need to recommend that the regulations be flexible enough to handle changes to the AOR. As long as the changes are not the result of a leak out of the primary confining system.

Workgroup Recommendation 3.1

The AOR should be determined and re-evaluated during the life of project as necessary, based on generally accepted and site relevant techniques, such as modeling, that define, in three dimensions, the maximum extent of the modeled CO2 plume and associated pressure front. Any models used must account for the buoyant nature and specific properties of separate phases of injected CO2, and the multi-phase nature of fluids within the injection zone.

Recommendation Rationale 3.1

The determination of the AOR is a critical factor in the development of regulatory implementation of CO2 geologic sequestration. One of the Alternative Approaches limited the AOR by imparting an artificial time barrier and it was felt that this was not appropriate. Instead the workgroup recommended that the language reflect a “maximum extent” with respect to the plume and associated pressure front. It was believed that this would work better within a modeling regime, yet provide assurance that the full effect of CO2 migration in the subsurface would be taken into account.

The workgroup clearly believed that using a fixed radius to establish the AOR was inappropriate for the geosequestration of CO2. However, it did incorporate the possible use of modeling as a means for determining the areal extent of the AOR because such techniques can be validated using measurements gathered during the operational phase of a project and can provide a means for adjusting the AOR over time as needed to reflect real world conditions.

Alternative Approaches 3.2: Artificial Penetration Identification

Identify all shallow and deep artificial penetrations (including active and abandoned wells) in the AOR. Provide: a description of each well's type, construction, date drilled, location, depth, record of plugging and/or completion, and any additional information the Director may require.

Comments 3.2

Question: Penetrations of what? The focus should be evaluation of penetrations of primary and secondary containment systems and other penetrations identified by the risk assessment.

Workgroup Recommendation 3.2

Provide information on the AOR including:

- Maps and cross sections
- A description of each artificial penetration of the confining zone, including active and abandoned wells, in the AOR. The description shall include all relevant available information on the well or penetration type, construction, date drilled, location, depth, record of plugging and/ or completion, and any additional information the Director may require.

Recommendation Rationale 3.2

As with other recommendations, the workgroup believed that while a standard set of information was needed, the Alternative Approaches did not include sufficient flexibility for the regulatory authority to require additional information as needed. Consequently, the recommendation added a provision for a program Director to require information beyond the listing.

Alternative Approaches 3.3: Corrective Action Identification

Review all available data on all abandoned wells in the AOR, determine if they have been plugged in a manner that prevents the movement of CO_2 or associated fluids based on reliable, recent plugging records, and identify those that need corrective action.

Comments 3.3

Question: What types of abandoned wells? Does this include private, public, industrial, agricultural, geothermal well, etc.? Again, the focus should be evaluation of penetrations of primary and secondary containment systems and other penetrations identified by the risk assessment.

Workgroup Recommendation 3.3

Review all available data on all abandoned wells in the AOR, assess if they have been plugged in a manner that prevents the movement of fluid containing any contaminant into a USDW, if the presence of that contaminant may cause a violation of any primary drinking water regulation under 40 CFR part 142 or may otherwise adversely affect the health of persons.

Recommendation Rationale 3.3

The proposed language was too vague with respect to fluid migration. The workgroup applied the standards of 40 CFR 144.12(a) to provide the appropriate context for this provision. The issue of remedial action is dealt with in Recommendation 3.4.

Alternative Approaches 3.4: Corrective Action

Remediate those wells in the AOR that pose the greatest risk to USDWs using corrosion resistant cements and other appropriate corrective action methods, **OR**

Remediate those wells in the AOR for which recent cementing data with a high degree of certainty do not exist, using corrosion resistant state-of-the-art cements, cements (e.g., latex-epoxy blend cements), and other appropriate corrective actions methods.

Comments 3.4

1. Again, we need to clarify what types of wells would require corrective action? Question: Should we necessarily require corrective action of a well plugged with bentonite, or other naturally-corrosion resistant earthen plugging materials?
2. Remediation of "leaking" abandoned wells requires certain types of electric logs to identify the leak flow path characteristics such as its location and size to select the proper sealing method and material. In some cases cement is used and others require chemical sealants that penetrate and seal matrix permeability.

Workgroup Recommendation 3.4

Remediate those artificial penetrations in the AOR, as necessary, to prevent the movement of fluid containing any contaminant into a USDW, if the presence of that contaminant may cause a violation of any primary drinking water regulation under 40 CFR part 142 or may otherwise adversely affect the health of persons.

Recommendation Rationale 3.4

The proposed language used a subjective standard, "greatest risk" that was both impractical and open to overly broad interpretation. To resolve this issue, the language of 40 CFR 144.12(a) was applied to provide consistent and appropriate context to the fluid migration question.

Further the Alternative Approaches dealt only with wells. Other artificial penetrations such as mine shafts were not addressed. Consequently, the workgroup changed "wells" to "artificial penetrations" to account for all anthropogenically derived openings. Finally, the workgroup felt that establishing a standard for the materials used to remediate wells at this early stage of regulatory development was unwise and could have unforeseen negative consequences.

4. Well Construction

Alternative Approaches 4.1: Well Construction and Fluid Movement

The well must be cased and cemented to prevent movement of fluids into or between USDWs, **OR**

Surface casing drilled below the USDW shall be set 100 feet below the lowest USDW and cemented to the surface.

Comments 4.1

The depth of surface casing below the USDW should be the discretion of the permitting agency.

Workgroup Recommendation 4.1

The well must be cased and cemented to prevent the movement of fluid containing any contaminant into a USDW, if the presence of that contaminant may cause a violation of any primary drinking water regulation under 40 CFR part 142 or may otherwise adversely affect the health of persons. The long-string casing shall be cemented above the top of the injection zone and confining zone. Appropriate logs and other tests shall be conducted during the drilling and construction of new injection wells. A descriptive report interpreting the results of such logs and tests shall be prepared by a knowledgeable log analyst and submitted to the Director.

Recommendation Rationale 4.1

The language of 40 CFR 144.12(a) was used to provide the appropriate context to the standard of fluid migration. However, the workgroup felt that a specific cementation standard for the cementing of the long string was appropriate provided it did not specify a depth but, rather, called for the cementation of long string to above the confining zone~~s~~ along with the submission of appropriate, professionally interpreted, logs to demonstrate the adequacy of cementation. Further, with respect to the verification of cementation called for in Alternative Approaches 4.2 the workgroup believed that establishing the use of specific logs such as a CBL or CET was not a good approach because geophysical logging technology is constantly changing. Therefore, it was believed that specifying "appropriate logs" was a more reasonable standard as this would allow the regulatory authority to accept logs that it believed were effective.

Alternative Approaches 4.2: Long String Cementing (See 4.1)

The long-string casing may be cemented above the top of the injection zone with verification by CBL or CET, **OR**

The long-string casing and cement shall run the entire length of the well.

Comments 4.2

1. Suggested alternative: The long string casing must be cemented between the top of the injection interval and at least 500 ft. above the secondary containment unit. The integrity and location of the cement must be verified using the best available technology capable of radially evaluating cement quality, identifying the location of channels or contaminated cement, and validating the casing-cement and cement-formation bonds through primary and secondary confining zones.
2. Some states suggest Class I hazardous well construction standards as a model. Others commented that this would be too prescriptive.

Workgroup Recommendation 4.2

Recommendation incorporated into 4.1

Recommendation Rationale 4.2

See recommendation 4.1

Alternative Approaches 4.3: Casing and Cement

Casing, tubing, and drill pipe should be adequate to withstand the corrosive nature of the injected CO2 and any impurities at the anticipated pressure, temperature and other operational conditions and meet API standards, **OR**

Casing, tubing, and drill pipe should be adequate to withstand the corrosive nature of the injected CO2 and any impurities at the anticipated pressure, temperature and other operational conditions and be state-of-the-art and meet API standards.

Comments 4.3

1. Suggested alternative: When wet CO2 exposure conditions exist, use corrosion and stress resistant cements in zones where cement-CO2 contact is likely or cement integrity is critical (e.g. cement zones through primary and secondary containment systems)."
2. Rules do not address well conversions.
3. Most reviewers do not want "state-of-the-art" to appear in the rules as a descriptive, as it tends to lead to litigation.
4. Remove "drill pipe" as it is not present in the well during CO2 injection operations.

Workgroup Recommendation 4.3

The casing and cement used in the construction of each newly drilled well shall be designed for the operating life expectancy of the well. In determining and specifying casing and cementing requirements, the following factors shall be considered:
(1) Depth to the injection zone;
(2) Depth to the bottom of all USDWs;
(3) Injection pressure, external pressure, internal pressure, and axial loading;
(4) Hole size;
(5) Size and grade of all casing strings (wall thickness, diameter, nominal weight, length, joint specification, and construction material);
(6) Characteristics of injection fluid (chemical content, corrosiveness, and density);
(7) Lithology of injection and confining intervals; and
(8)Type or grade of cement
(9) Planned well operations and operation results on casing/cement.

The tubing and packer, and annular fluid shall be designed for the expected service. In determining and specifying requirements for tubing, packer, or alternatives the following factors shall be considered:
(i) Depth of setting and temperature at setting depth;
(ii) Characteristics of injection and annular fluid (chemical content, corrosiveness, and density);
(iii) Injection pressure;
(iv) Annular pressure;
(v) Rate, temperature, composition, and volume of injected fluid; and
(vi) Size, weight, and grade of casing.

Recommendation Rationale 4.3

The workgroup felt that the general standards listed in the Alternative Approaches should be expanded to incorporate the particular factors that affect the use of casing, tubing, packers and cement. The language recommended is consistent with similar requirements for Class I and Class II wells under the UIC regulations.

Alternative Approaches 4.4: Tubing and Packer

Inject through tubing and packer that is set at a depth opposite a cemented interval of the long string casing and set no more than 50 feet above the uppermost perforation or open hole for the CO_2 storage reservoir.

Comments 4.4

1. The 50' standard is unnecessarily proscriptive. Indiana suggested 200' as a standard.
2. There is no reason, to require injection through perforations. In Ohio, as elsewhere, it is advantageous to develop Class I HaZ operations as open-hole completions.
3. The packer depth and end of tubing should be set high enough to permit logging assessment in the casing adjacent to the caprock(s) below the tubing.

Workgroup Recommendation 4.4

Inject through tubing and packer that is set opposite a cemented interval of the long string casing above the uppermost perforation or open hole for the injection zone at a depth acceptable to the Director.

Recommendation Rationale 4.4

The Alternative Approaches to establish a specific setting depth for packers above the uppermost perforations or open hole intervals was impractical in field application. In some cases the ability to set a packer within 50 feet above these intervals cannot be physically accomplished. The key is that wherever the packer is set it occurs within cemented long string casing and at a depth that is acceptable to the permitting authority. This provides the needed flexibility to establish a setting depth based on field conditions.

Alternative Approaches 4.5: Cement (See 4.3)

Use API standard cements recommended by technical support documents, **OR**

Use corrosion-resistant cement that can withstand extended contact with injected CO_2 and associated impurities, e.g., phosphate-based non-Portland cements.

Comments 4.5

Comments are variable – no consensus. The results of additional sidewall core research (beyond Sacroc) is not public information yet. This remains a topic of considerable state concern. Comments range from: "For any new CO_2 injection well, it makes sense to require CO_2 and stress resistant materials, including cements," particularly adjacent to zones that will be exposed to hydrated-CO_2 (through the upper confining zone.) However, Portland cements and cement-additive blends may also be adequate for cementing depending on conditions. It may be too proscriptive to rule out a major category of well cements. Since proper cement placement is more important than cement composition requirements, use the best cementing practices published in API RP 65 to ensure CO_2 zone isolation. Until standards are published for CO_2 resistant cement, use cementing company recommendations for the type of cement needed to resist the actual CO_2 conditions present in the well. These recommendations should be supported by lab test data tested under the well's specific downhole conditions including temperature, pressure, pH, stress loads, etc.

Workgroup Recommendation 4.5

Recommendation incorporated into 4.3

Recommendation Rationale 4.5

See recommendation 4.3

5. Operation

Alternative Approaches 5.1: Injection Pressure

Injection should be conducted such that the pressure during injection does not initiate new fractures or propagate existing fractures in the confining zone adjacent to the USDWs. Higher operating pressures may be allowed if approved by the permitting authority, **OR**

Injection should be conducted such that pressure in the injection zone does not exceed 90 percent of fracture pressure in any portion of the area defined by the anticipated pressure front. Injection may not initiate new fractures, propagate new fractures in the injection zone, or cause fluid movement into USDWs, **OR**

Injection should be conducted such that pressure in the injection zone does not exceed 90 percent of the fracture pressure in any portion of the area defined by the anticipated pressure front, or the capillary entry pressure at any point in the lower most portion of the primary confinement system. Injection may not initiate new fractures, propagate new fractures, or cause fluid movement into USDWs.

Comments 5.1

1. We can think of no circumstances where it would be appropriate to inject at pressures capable of initiating or propagating fractures in the confining zone.
2. Permitting agencies should determine the appropriate safety factor.

Workgroup Recommendation 5.1

Injection should be conducted such that the pressure during injection and storage does not initiate new transecting or transmissive fractures or propagate existing fractures in the confining zone, exceed the seal competence of the confining zone, or cause transecting faults that are not transmissive to become transmissive.

Recommendation Rationale 5.1

The workgroup accepted the basic premise of the Proposal regarding fracturing of the confining zones. The workgroup believed there should also be a focus on the risk of exceeding the competence of the seal of the confining zone that otherwise non-transmissive faults could become transmissive, which can occur at pressures lower than those that would cause new fractures. However, the workgroup strongly disagreed with the idea that operating pressures above fracture pressure should be allowed by the permitting authority. Except for well treatment, pressures should be limited to below formation fracture or parting pressure. Allowing injection pressures above this could compromise the integrity of the confining zones; which would be unacceptable. The recommendation does not deal with the issue of thermal fracturing; which is a probably consequence of injecting supercritical CO_2 into formations where the temperature is well above that of the injectate. However, since there is probably no way to prevent this, it was felt it could not be addressed under this recommendation.

Alternative Approaches 5.2: Injection Depth

Injection must be to a sufficient depth (i.e., at least 800 meters below the surface) so that the CO_2 remains in a supercritical state to avoid mechanical integrity concerns associated with phase change.

Comments 5.2

This could preclude injection into depleted reservoirs.

Workgroup Recommendation 5.2

Delete requirement because there is no reason to limit injection of CO_2 to the supercritical phase and doing so could limit injection to saline aquifers that would otherwise be usable for geosequestration.

Recommendation Rationale 5.2

The workgroup felt very strongly that this Possible Approach could cause significant problems for CO_2 geosequestration into shallow depleted oil and gas reservoirs and coal beds and was not necessary to the successful sequestration of CO_2.

Alternative Approaches 5.3: Operational Monitoring

Monitor injection pressure, flow rate, injected volumes, and pressure on the annulus as specified by the permitting authority, **OR**

Throughout injection, continuously monitor injection pressure, flow rate, injected volumes, and pressure on the annulus between the tubing and the long string casing, **OR**

Throughout injection, continuously monitor, using state-of the-art digital monitoring equipment injection pressure, flow rate, injected volumes, and pressure on the annulus between the tubing and the long string casing.

Comments 5.3

None

Workgroup Recommendation 5.3

Throughout injection, continuously monitor, without precluding the use of digital monitoring, the injection pressure, flow rate, injected volumes, and pressure on the annulus between the tubing and the long string casing.

Recommendation Rationale 5.3

The use of digital monitoring equipment does not necessarily meet the definition of "continuous monitoring". However, it was felt that such equipment was not only acceptable but was, in many ways, superior to typical analog means of measuring such as continuous charts. It should also be noted that the monitoring of annular pressure is an alternate means of demonstrating mechanical integrity of the casing, tubing and packer without conducting standard annulus pressure tests on a periodic basis. The importance of this is captured by the comment related to the potential negative impacts of the SAPT on casing/ cement integrity discussed in topic 6.1 below.

Alternative Approaches 5.4: Automatic Shutoff Equipment

Equip with down-hole safety shutoff valves that engage if any operating parameters are exceeded.

Comments 5.4

None

Workgroup Recommendation 5.4

Equip injection wells with safety shutoff equipment that engages if any operating parameters are exceeded.

Recommendation Rationale 5.4

Originally, the workgroup was in favor of leaving the proposed language as is. However, upon further reflection, it was felt that limiting the equipment used to shut in injection to downhole valves was too restrictive and would have prevented the use of other, effective means of halting injection. Consequently, the recommendation was constructed to be more generic.

Alternative Approaches 5.5: Odorants or Tracers

Add an odorant or a tracer to the injected CO2 to facilitate early detection of leaks or movement outside of the intended injection zone.

Comments 5.5

1. The idea may merit further discussion, or research to assess practicality;
2. Could create unintended subsurface contamination problems

Workgroup Recommendation 5.5

The use of tracers is not recommended except under specific risk based site by site conditions.

Recommendation Rationale 5.5

1. The idea may merit further discussion, or research to assess practicality but has not been sufficiently studied to develop regulatory language allowing or requiring the process.
2. Could create unintended subsurface contamination problem.
3. Due to the possibility of false positive results the use of tracers is not recommended until further research can be conducted.

Alternative Approaches 5.6: Corrosion Monitoring Plan

Develop a corrosion monitoring and prevention plan for all wells and surface facilities.

Comments 5.6

None

Workgroup Recommendation 5.6

Submit a corrosion monitoring and prevention plan for wells acceptable to the Director

Recommendation Rationale 5.6

The workgroup felt that preparation of a plan was not sufficient. Submission of the plan to the regulatory authority was necessary. Further, it was felt that surface facilities do not fall within the authority of the UIC program.

6. Mechanical Integrity Testing

Alternative Approaches 6.1: Mechanical Integrity Demonstration

GS wells must be monitored in a manner that protects USDWs from endangerment, **OR**

Demonstrate internal mechanical integrity, i.e., that there is no significant leak in the casing, tubing or packer (using a pressure test) at a frequency specified by the permitting authority, **OR**

Demonstrate internal mechanical integrity, i.e., that there is no significant leak in the casing, tubing or packer (using a pressure test) at least once per year. Use the best available technology to test for corrosion of the internal well casing, e.g., electrical resistivity logs to detect pitting and other casing problems, and televiewers to assess the integrity of the casing, **OR**

Demonstrate internal mechanical integrity, i.e., that there is no significant leak in the casing, tubing or packer (using a pressure test) at least once every six months. Use the best available technology to test for corrosion of the internal well casing, e.g., electrical resistivity logs to detect pitting and other casing problems, and televiewers to assess the integrity of the casing.

Comments 6.1

1. Do not use "state-of-the-art" or "best available technology"s a descriptor in the regulations.
2. Some states favor continuous monitoring vs. periodic pressure tests. Therefore, Option 1 would allow permitting agencies to prescribe more protective requirements.
3. It may be advisable to prevent applied pressure from traditional mechanical integrity tests. Consider language that would permit monitoring by other means.

Workgroup Recommendation 6.1

Demonstrate mechanical integrity using a method and at a frequency acceptable to the Director.

A well has mechanical integrity it there is no significant leak in the casing, tubing and packer and there is no significant fluid movement into a USDW through vertical channels adjacent to the injection wellbore.

Recommendation Rationale 6.1

The workgroup felt that a two part demonstration of casing, tubing and packer integrity coupled with a demonstration of no significant fluid movement comprised and essential standard. However, the workgroup also discounted the notion that the method to use for demonstration Part I should, in all cases, be the SAPT. A recent study by SPE indicated that potential casing/ cement integrity issues could result from such tests. Consequently, while the term "pressure test" was removed in this recommendation, an alternate method of determining casing, tubing and packer integrity was proposed under recommendation 5.3 above.

Alternative Approaches 6.2: Fluid Movement Testing (See 6.1)

Conduct a radioactive tracer survey of the bottom-hole cement using a CO_2 -soluble isotope at least once every six months.

Comments 6.2

Too proscriptive. Allow permitting agency to determine frequency or trigger events. There may be other tools that would provide necessary data.

Workgroup Recommendation 6.2

Recommendation incorporated into 6.1

Recommendation Rationale 6.2

Although the scope of this recommendation was included in 6.1 the specific test called for in the Alternative Approaches was not noted. Instead, the workgroup referred the selection of test methods and frequencies to the discretion of the regulatory authority. This is consistent of numerous state UIC programs; which allow the selection of test methods to be set by regulation with provisions for other tests acceptable to the Director.

Alternative Approaches 6.3: External Mechanical Integrity (See 6.1)

Demonstrate external mechanical integrity, i.e., there is no significant fluid movement into a USDW through vertical channels adjacent to the injection well bore (using temperature or noise logs) at least once every six months.

Comments 6.3

Too prescriptive. Allow permitting agency to determine frequency or trigger events.

Workgroup Recommendation 6.3

Recommendation incorporated into 6.1

Recommendation Rationale 6.3

Although incorporated into recommendation 6.1, the frequency of text and the method used to conduct tests should be left to the discretion of the regulatory authority.

Alternative Approaches 6.4: Pressure Falloff Testing (See 7.4)

Conduct a pressure fall-off test at least once every six months.

Comments 6.4

Too prescriptive. Allow permitting agency to determine frequency or trigger events.
If the intent is to determine the change in skin damage or other property, it should be stated that way. Note that pressure fall-off may not be the preferred test method. Assuming the intent is to monitor the injection performance, the comment below is offered.

Workgroup Recommendation 6.4

Recommendation moved to 7.4

Recommendation Rationale 6.4

See workgroup Recommendation 7.4

7. Measurement, Monitoring and Verification

Alternative Approaches 7.1: Baseline Determination

Conduct baseline geochemical monitoring within the injection and confining systems before injection commences.

Comments 7.1

If there is a secondary containment system, it would make more sense to monitor it vs. a confining system.

Workgroup Recommendation 7.1

Conduct baseline geochemical analysis within the injection and confining zone before injection commences.

Recommendation Rationale 7.1

The workgroup believes the EPA Proposed language is appropriate for the purpose of the regulation.

Alternative Approaches 7.2: Injection Fluid Monitoring

Monitor the nature of injected fluids at a frequency sufficient to yield data representative of their characteristics, **OR**

Monitor the nature of injected fluids at a frequency sufficient to yield data representative of their characteristics and to demonstrate their compatibility with the well materials.

Comments 7.2

1. Injectate tests should also be triggered by fuel-source or process changes that could reasonably be expected to change the concentration of specified impurities.
2. Permit could specify range of allowable impurities (e.g. H_2S) based upon approved well construction practices.

Workgroup Recommendation 7.2

Monitor the nature of injected fluids at a frequency sufficient to yield data representative of their characteristics and to demonstrate their compatibility with the well materials.

Recommendation Rationale 7.2

The workgroup believed the nature of the fluids should not only be periodically monitored, but should also be evaluated for continued compatibility with the well materials. Consequently, the workgroup agreed with the language of the second Alternative Approaches for 7.2

Alternative Approaches 7.3: Geochemical Monitoring

Monitor geochemical changes within the primary and secondary confining systems using a network of state-of-the-art monitoring wells (i.e., that are constructed of corrosion-resistant materials) whose number and location are sufficient to monitor geochemical changes.

Comments 7.3

1. Commenter's expressed mixed emotions about this as a regulatory requirement. It boreholes present the highest-risk for out-of-zone migration, why require deep monitoring wells. Deep monitor wells may be useful in calibrating/validating models early in our learning curve, but may be overkill if required for all geo-sequestration projects regardless of size. Permitting agencies need site-specific flexibility. We should learn from demo-projects to determine the value and necessity of monitoring schemes.
2. Avoid the term "state-of-the-art."
3. Mirror the requirements of 40 CFR 146.13 (D)(1) that authorizes agencies to require monitoring plans that are based on site-specific risk analysis.
4. If permits are subject to periodic review or renewal, monitoring plans could be phased in and subject to periodic re-assessment.
5. Must distinguish between monitoring for wellbore leakage and determining the extent and direction of the plume. Seismic is considered the best option to determine the extent and direction of the plume when the conditions are appropriate for imaging.
6. Monitor wells are of limited use in determining the extent and direction of the plume.
7. Could the monitoring be done in the injection wells by logs or sensors if access is available to the casing above the injection zone?

Workgroup Recommendation 7.3

Monitor geochemical changes of the confining zone using a network of monitoring that could be conducted from injection or observation wells, that are constructed consistent with the requirements of recommendation 4.3 and whose number and location are sufficient to monitor geochemical changes.

Recommendation Rationale 7.3

The use of the term state-of-the-art is open to too much interpretation and could automatically call for products and services that while, state-of-the-art, are not yet commercially available and may not have been proven over time in the field. Consequently, the workgroup removed the term state-of-the-art both in this recommendation and wherever it appeared in any Alternative Approaches. Rather than specify corrosion resistant materials, the workgroup instead recommended construction based on the well construction criteria specified in Recommendation 4.3.

Alternative Approaches 7.4: Plume Monitoring

Track the subsurface extent of the CO_2 plume using geophysical techniques and/or down-hole CO_2 detection tools, **OR**

Track the subsurface extent of the CO_2 plume using geophysical techniques (e.g., seismic, electrical, gravity, or electromagnetic surveys) or use of down-hole CO_2 detection tools.

Comments 7.4

Comments generally favored the less-proscriptive option, but some states haven't seen enough information on MMV monitoring methods to be convinced that they are necessary or reliable?

Workgroup Recommendation 7.4

Conduct monitoring to evaluate the injection zone performance using methods and frequencies acceptable to the Director.

Recommendation Rationale 7.4

The recommendation proposed by the workgroup is based not on a measurement standard but, rather, on a performance standard linked to comparisons of modeling and actual plume migration. It does not foreclose any potential means of monitoring but also does not call for a specific monitoring methodology. Rather, it embraces the idea that there may be multiple methods of conducting evaluations of the reservoir performance.

Alternative Approaches 7.5: Monitoring Plan

Develop and implement a plan for surface air monitoring and/or soil gas monitoring to detect leakage of CO_2 in the vicinity of the injection well, **OR**

Develop and implement a plan for surface air monitoring and/or soil gas monitoring to detect leakage of CO_2 in an area that reflects the surface "footprint" of the CO_2 plume, **OR**

Develop and implement a plan for surface air monitoring and/or soil gas monitoring to detect leakage of CO_2 in an area that reflects the surface "footprint" of the CO_2 plume, at all artificial penetrations within the AOR, and at other sensitive areas, e.g., in buildings and man-made surface structures that are intended for human occupancy.

Comments 7.5

1. Commenter's dislike all three options.
2. Unless a tracer or odorant was added to the injected CO_2 , how one can determine if the detected CO_2 was from leakage or from other ambient sources. Local atmospheric CO_2 fluctuates depending on time of day (e.g., presence or absence of sunlight to promote photosynthesis; number of vehicles emitting exhaust nearby, etc.)
3. Has air monitoring proven valuable at sites such at Weyburn? What lessons have been learned to date at research sites?
4. Required air and soil-gas monitoring appears to outside scope of SDWA.
5. None of the Alternative Approaches mention monitoring of groundwater.

Workgroup Recommendation 7.5

Develop and implement a plan for monitoring chemical and physical changes of USDWs within the AOR caused by leaking CO_2 or movement of fluids related to CO_2 injection.

Recommendation Rationale 7.5

There were several key elements considered by the workgroup in developing this recommendation including:

1. The authority of the SDWA to call for air and soil monitoring
2. The need to monitor not only for CO_2 leakage but for fluids related to CO_2 injection including displaced brines
3. The need to define a reasonable boundary for monitoring
4. The need to tie the monitoring program into demonstrated changes to the character of USDW's rather than broad/ generalized USDW monitoring

Alternative Approaches 7.6: Modeling and Reporting

Report annually on the characteristics of injection fluids, injection pressure, flow rate, volume and annular pressure, and on the results of MITs, and ground water and atmospheric/soil gas monitoring, **OR**

Report quarterly on the characteristics of injection fluids, injection pressure, flow rate, volume and annular pressure, and on the results of MITs, and ground water and atmospheric/soil gas monitoring, **OR**

Report monthly on the characteristics of injection fluids, injection pressure, flow rate, volume and annular pressure, and on the results of MITs, and ground water and atmospheric/soil gas monitoring.

Comments 7.6

1. Views on reporting frequency differ significantly.
2. We also need to consider how agencies will store, maintain and evaluate environmentally monitoring reports and make information available upon public request. This could be complicated by projects that span state, or national boundaries, with differing monitoring and reporting requirements, as well as differing data management systems/capabilities.
3. Again the reporting of air or soil monitoring appears to be outside the scope of the SDWA.

Workgroup Recommendation 7.6

Report annually, or at a frequency acceptable to the Director, the characteristics and cumulative volumes (annual and total) of injected fluids, injection pressures, injection rates, annular pressures for each injection well, the results of any mechanical integrity tests conducted during this time period, available site integrity monitoring results, the extent of the injected CO_2 and the pressure front based on current data.

Update site operations as appropriate and site modeling results annually, or at a frequency acceptable to the Director, to reflect current data. Compare the updated results to the previous results. Identify and explain to the Director any discrepancies between the updated results and the previous results.

Rationale 7.6

The workgroup agreed that periodic reporting was necessary to proper regulation of geosequestration. However, the workgroup also recommended that the frequency of reporting be left to the discretion of the regulatory authority. The workgroup also deleted the reference to atmospheric/ soil monitoring as being outside the scope of the SDWA UIC program. Additionally, the workgroup believed periodic verification of modeling to evaluate performance was an important part of monitoring.

Workgroup Recommendation 7.7 (Moved from Post Closure Recommendation 8.6)

Conduct post-closure monitoring, and associated modeling, for a period sufficient to demonstrate to the Director that fluid movement will not endanger USDWs.

Recommendation Rationale 7.7

The workgroup determined that the most important elements of this recommendation revolved around:

1. The endangerment of USDW's rather than a strict fluid movement standard; and
2. That the demonstration on non-endangerment be designed to show that endangerment will not occur now or in the future as a result of geosequestration

8. Well Closure

Alternative Approaches 8.1: Plugging Preparation

Flush the well with a buffer fluid.

Comments 8.1

None

Workgroup Recommendation 8.1

Flush the well with a buffer fluid.

Recommendation Rationale 8.1

The workgroup concurred with the alternative approach language.

Alternative Approaches 8.2: Well Stabilization

Ensure that the well is in a state of static equilibrium with mud equalized prior to placement of the plugs.

Comments 8.2

Precludes other options such as mechanical bridges (bridge plugs) to ensure state equilibrium.

Workgroup Recommendation 8.2

Ensure that the well is in a state of static equilibrium prior to the placement of the final plug.

Recommendation Rationale 8.2

The essential modification to the considered alternative language recommended by the workgroup was that static equilibrium need only be required prior to the placement of the final plug. Since the placement of packers, CIBP's and cement bridges are plugging methods that are at least as effective as mud, requiring the well be placed in a state of static equilibrium using mud prior to any plugging would preclude the use of other very effective plugging methods.

Alternative Approaches 8.3: Plugging Methods and Materials

Plug the well with cement in a manner that will not allow the movement of fluids either into or between USDWs (or as required by the permitting authority), **OR**

Plug the well with cement in a manner that will not allow the movement of fluids either into or between USDWs. The cement used should be compatible with the injected CO2 and any associated impurities.

Comments 8.3

Until API standards are published for CO2 resistant cement, use cementing company recommendations for the type of cement needed to resist the actual CO2 conditions present in the well. These recommendations should be supported by lab test data tested under the well's specific downhole conditions including temperature, pressure, pH, stress loads, etc.

Workgroup Recommendation 8.3

Plug the well with cement in a manner that will prevent the movement of fluid containing any contaminant into a USDW, if the presence of that contaminant may cause a violation of any primary drinking water regulation under 40 CFR part 142 or may otherwise adversely affect the health of persons. The cement used should be compatible with the injected fluids.

Recommendation Rationale 8.3

The workgroup recommended that the language of 40 CFR 142 was the appropriate standard for demonstrating fluid movement. This is consistent with the other recommendation made by the workgroup on the topic of fluid movement.

Alternative Approaches 8.4: Plug Placement and Testing

Place cement plugs by either: the balance method, dump bailer method, two-plug method, or an alternative approved method. Each plug used shall be appropriately tagged and tested for seal and stability.

Comments 8.4

Alternative: Place cement plugs by an approved method. Each plug used shall be appropriately tagged and/or tested for seal and stability.

Workgroup Recommendation 8.4

Place and test cement plugs by a method acceptable to the Director.

Recommendation Rationale 8.4

The workgroup believed that simplifying this recommendation to take into account a multitude of plugging methods and testing regimes acceptable to the regulatory authority was a better way to require the placement and verification of plugs.

Alternative Approaches 8.5: Pre-plugging Mechanical Integrity Demonstration

Perform MIT to ensure the integrity of that portion of the long string casing and cement that will be left in the ground after closure.

Comments 8.5

1. Unclear whether this is referring to an internal or external test, or both.
2. Internal MIT may be unnecessary if the injection string is cemented to surface or the well has been continuously monitored or subject to frequent pressure tests.
3. New technology and field studies indicate that internal MIT pressures may exceed the tensile strength and fatigue limitations of many cement compostions and cause the cement sealing and structural integrity to fail the external MIT. This caution was published in API RP 90 and recommends an analysis of the cement properties to determine the maximum MIT pressure that can be used without damaging cement integrity.

Workgroup Recommendation 8.5

Ensure the internal and external integrity of that portion of the long string casing and cement that will be left in the ground after closure.

Recommendation Rationale 8.5

The workgroup recommendation is very similar to the Alternative Approaches. The only difference is that the workgroup recommendation leaves open the possibility that a demonstration other than a standard MIT could be used to make a demonstration of casing and cement integrity.

Alternative Approaches 8.6 Post Closure Monitoring

Conduct post-closure monitoring to confirm that CO2 movement is limited to intended zones, **OR**

Conduct post-closure monitoring including: pressure fall-off test; seismic monitoring, if appropriate; monitoring in and above the injection zone and the USDW to confirm that CO2 movement is limited to intended zones. Post-closure monitoring should be performed for a sufficient time frame to ensure that there is no threat to USDWs and human health, **OR**

Conduct post-closure monitoring including: pressure fall-off test; seismic monitoring, if appropriate; monitoring in and above the injection zone and the USDW to confirm that CO2 movement is limited to intended zones. Post-closure monitoring should be performed for a time period that is twice as long as the injection period or until there is a 95 percent pressure die-off.

Comments 8.6

None

Workgroup Recommendation 8.6

Recommendation moved to 7. 7

Recommendation Rationale 8.6

Recommendation moved to 7.7

9. Financial Responsibility

Alternative Approaches 9: Plugging and Post Closure Monitoring Assurance

Provide through a performance bond, or other appropriate means, the resources necessary plug the well,
OR

Demonstrate and maintain financial responsibility for closing the well and providing post-closure monitoring.

Comments 9

1. Neither option addresses financial resources necessary for remediation or corrective action.
2. There may be development of other government-backed mechanisms to support the post-closure monitoring, and remediation requirements.

Workgroup Recommendation 9

Demonstrate and maintain financial responsibility for closure of the well(s) and post-closure monitoring.

Recommendation Rationale 9

The principal difference between the Alternative Approaches and workgroup recommendation is the recognition that financial responsibility could apply to more than one well and thus the post-closure monitoring would not be limited to the well but could potentially be project based. The workgroup recognizes that there may be costs not covered by this recommendation but which may need to be addressed in any discussion of long term liability.

Appendix A

Additional Comments

In addition to the comments received from the states based on a questionnaire sent prior to the workgroup's deliberations, several organizations submitted comments on the proposed language and workgroup recommendations. These were not included in the comments under each topic because in most cases they were received after the workgroup had reached initial consensus on the recommendations. In some cases the comments were considered critical enough to re-open discussion and were dealt with as noted in the workgroup responses below. In other cases, they are listed here to ensure completeness.

1. American Water Works Association (Submitted through the American Public Power Association)

   Alternative Approaches 6.1: What exactly is meant by "monitored in a manner that protects USDWs from endangerment?" This is very vague and should include more detail. A reference should be provided to acceptable monitoring techniques or to a specific part of the regulation.

   Alternative Approaches 6.3: A definition needs to be provided as to what constitutes "significant fluid movement into a USDW." The drinking water community will probably have a different definition than those who are operating the sequestration process.

   Alternative Approaches 7.1: Need to provide clarification as to what is included in geochemical monitoring. We recommend that this include establishing baseline concentrations of compounds such as heavy metals, boron, and dissolved solids in the surrounding USDWs as well as the injection and confining systems. This will provide for the ability to observe if compounds from the confining systems are dissolving into solution due to changes in the surrounding aquifers. Monitoring should also apply to any redundant containment systems.

   Alternative Approaches 7.2: Monitoring should also be triggered by changes in operation of the well, such as pressure changes or process modifications. Also need to provide clarification on frequency requirements as this can be interpreted many different ways. We suggest including an acceptable range of monitoring frequencies and include provisions to modify the frequency based upon the results of the monitoring. For example, if the monitoring shows changes beyond what was expected, the frequency should increase to allow for a better understanding of the changes that are occurring.

   Alternative Approaches 7.3: Suggest also including monitoring of surrounding USDWs to look for potential changes due to CO2 migrations. Monitoring the confining layers can show leakage but we also want to be able to observe the changes in the aquifers.

   Alternative Approaches 7.5: Included in this section needs to be a requirement for establishing the baseline CO2 profile prior to injection. While this does change over time, it will give a general idea as to the existing conditions. Once CO2 injection has commenced, air monitoring should continue and should be focused around those areas that are pathways for CO2, such as artificial penetrations. This part of the regulation should also include provisions for monitoring of groundwater because it can be used in combination with the air monitoring to determine if leakage from the CO2 plume has occurred. If high levels of CO2 are observed in the air but not in the groundwater, it could be an indication that the CO2 is a natural occurrence and is not coming from the CO2 sequestration process.

   Alternative Approaches 7.6: There is not a specific section in the Alternative Approaches in the monitoring section that addresses the long-term monitoring of groundwater. A specific provision needs to be included in the regulation that addresses groundwater monitoring in the same way that Section 7.5 addresses atmospheric/soil gas monitoring.

This section should also require immediate reporting in the event of a process upset or sudden change or in the characteristics of any part of the sequestration process. This is required for other environmental systems and should also be included as part of the operation of a sequestration process.

Alternative Approaches 8.3: Both portions of this section should include the provision that the cement should be compatible with the injected CO2 and other impurities. This is extremely important in protecting the purity of the USDWs.

Alternative Approaches 8.6: All post-closure monitoring needs to include a provision for long-term monitoring of the surrounding USDWs. The monitoring requirements should reference the MMV section so consistent and comparable results are obtained. We support an open-ended monitoring requirement (the second part of this section) as it is possible that adverse effects could be observed past the time limits suggested at the end of this section (twice as long as injection period or 95% pressure die-off).

Alternative Approaches 9.0: There are no provisions for remediation in the event that a CO2 leak occurs. If a USDW is contaminated either by CO2 or by the movement of a saline aquifer, the treatment costs could be extremely high and the affected utility should not bear these costs. The amount of the bond should include a portion to provide for treatment of the USDW due to contamination by the carbon sequestration process. The amount of the bond required for USDW remediation could be determined prior to the start of the project by modeling the processes that would be required of a water treatment plant to treat the contaminated USDW.

(Workgroup Response: The comments submitted by AWWA were specifically related to the Alternative Approaches rather than the workgroup recommendations. In some cases the issues raised by a comment were addressed in a workgroup recommendation and in some cases the comment was either outside the scope of the UIC program or was not intended to be addressed in the specific regulatory language Alternative Approaches; though it might be addressed in final regulatory elements).

2. Shell Exploration and Production Company

Comments 1.1, Item 5 - Throughout the document, references are made to primary and secondary confinement systems, and more generally, to "confinement system(s)". While the presence of a secondary confinement system might be an ideal situation, the absence of one should not condemn an otherwise suitable site. We suggest that this comment be expanded (or introductory text be added) to emphasize that the use of the term "confinement system(s)" throughout the Workgroup's document is not intended to imply that a secondary confinement system is necessary or required, but rather to accommodate one when it's present or is deemed necessary by the Director based on site-specific conditions.

(Workgroup Response: We all recognized that there are many sites where the thickness, areal extent and impermeability of a primary confining zone would likely be more than sufficient to qualify a site for use without the need for a secondary confining zone. However, the workgroup also felt that the definition of confining zone in the CFR sufficiently covered the issue of confinement by single and multiple zones and the addition of the term “secondary confinement” was not needed and could create confusion.

Workgroup Recommendation 3.1 - It's unclear whether the "CO_2 plume" in this recommendation refers to free phase CO_2 or includes CO_2 dissolved in the water. We suggest that clarifying language be added.

(Workgroup Response: In this context the term "CO_2 plume "was intended to describe the full travel distance of the plume from the injection site. Since the dissolved component of the plume would be within this boundary it is considered part of the plume).

Workgroup Recommendation 3.3 (first occurrence in black font) - Delete, since it is redundant to final Workgroup recommendation (in green font).

(Workgroup Response: Duplicative language in 3.3 was deleted.).

Workgroup Recommendation 4.2 - Current draft language is incomplete. We suggest deletion of existing text and insertion of "Recommendation incorporated into 4.1", since Workgroup Recommendation 4.1 appears to address this issue. Could consider adding language to call for verification of cement integrity and location using methods acceptable to the Director.

(Workgroup Response: Based on Shells comment to 4.2, the workgroup revisited the text and proposed to delete 4.2 and change 4.1 to read as follows: The well must be cased and cemented to prevent the movement of fluid containing any contaminant into a USDW, if the presence of that contaminant may cause a violation of any primary drinking water regulation under 40 CFR part 142 or may otherwise adversely affect the health of persons. The long-string casing shall be cemented above the top of the injection zone and confining zone. Appropriate logs and other tests shall be conducted during the drilling and construction of new injection wells. A descriptive report interpreting the results of such logs and tests shall be prepared by a knowledgeable log analyst and submitted to the Director.

Workgroup Recommendation 5.4 - We question the appropriateness of down-hole safety shutoff valves for this application, and recommend revised language to say "When appropriate, equip with safety shutoff devices that engage if defined operating parameters are exceeded."

(Workgroup Response: See response to 5.4 under Anadarko Petroleum below)

Workgroup Recommendation 7.1 - Revise to say "When necessary, conduct baseline geochemical analyses..." to account for the fact that some suitable sites will not require geochemical monitoring within the confinement system(s) as mineralogy & fluid compositions are inert.

(Workgroup Response: The purpose of these requirements was to allow for monitoring of zones within and above the confining zone for changes that would indicate leaks. Stable composition of mineralogy and fluid composition would actually help facilitate monitoring of these zones (when necessary) for changes that would indicate seal leaks.

Workgroup Recommendation 7.3 - Revise to say "When necessary, monitor geochemical changes of the confinement system(s) using...", to account for the fact that some suitable sites will not require geochemical monitoring within the confinement system(s) as mineralogy & fluid compositions are inert, and for consistent terminology regarding confinement system(s).

(Workgroup Response: See response to 7.1 above)

3. BP AE

Alternative Approaches 5.1 - we say we can think of no circumstances where it might be appropriate to inject at pressures capable of initiating fractures. I can think of one from our past waterflood experience: the permitting of thermal fracturing in a thermally cooled injection zone. This can be acceptable and useful, as long as the fracture is constrained to the grow horizontally in the inj interval. Since cooling may occur in CO2 injection, there is an injectivity enhancement associated with allowing controlled thermal fraccing. And in some situations it might be preferred to frac within the interval vs having to drill, complete and manage new incremental inj well(s). I can refer you to a couple of SPE papers on the subject.

(Workgroup Response: The purpose of Recommendation 5.1 was to deal with the issue of over pressuring of the injection zone; which could lead to fractures in the confining zone. The issue of thermal fracturing was discussed by the workgroup and while such fracturing should be discussed further, it was thought not to apply to this particular recommendation)

4. Anadarko Petroleum

The main issue APC has is Section 5.4 requiring down-hole safety shutoff valves. While versions of these valves are commonly used (mainly within the O&G industry for off-shore applications), there is no reason this type of flow shutoff device should be the only one allowed. There are many options (both surface and down-hole) that can achieve the desired safety results and control yet still allow for site-specific design.

(Workgroup Response: Recommendation 5.4 was modified to reflect the concerns expressed by this comment and those of Shell concerning this topic)