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The Class V Underground Injection Control Study

Volume 15

Experimental Technology Wells

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EXPERIMENTAL TECHNOLOGY WELLS

The U.S. Environmental Protection Agency (USEPA) conducted a study of Class V underground injection wells to develop background information the Agency can use to evaluate the risk that these wells pose to underground sources of drinking water (USDWs) and to determine whether additional federal regulation is warranted. The final report for this study, which is called the Class V Underground Injection Control (UIC) Study, consists of 23 volumes and five supporting appendices. Volume 1 provides an overview of the study methods, the USEPA UIC Program, and general findings. Volumes 2 through 23 present information summaries for each of the 23 categories of wells that were studied (Volume 21 covers 2 well categories). This volume, which is Volume 15, covers Class V experimental technology wells.

1. SUMMARY

Experimental technology injection wells have been reported in seven states and are used to test new or unproven technologies. Experimental "tracer study" wells, which inject chemical tracers for the purpose of studying ground water and hydrogeologic parameters, comprise the vast majority of wells classified as experimental wells for the purpose of this study. Experimental technologies also have been recently applied in Class V wells associated with Aquifer Thermal Energy Storage (ATES) systems, which store thermal energy by injecting heated and/or cooled water into an aquifer. The existence of experimental wells varies widely from state to state because, in some instances, different definitions of "experimental well" are used by different states. The definitions used by the states may not necessarily correspond to the USEPA definition of experimental well that was included the Class V study questionnaire.

<u>**Experimental Tracer Study Wells**</u>

Many different types of substances are injected into experimental tracer study wells. Examples of these substances include organic dyes, inert gases, short half-life radionuclides, rare earth metals, and inorganic or organic compounds. Only one experimental well was reported for which injectate did not meet the primary maximum contaminant levels (MCLs), secondary MCLs, and health advisory levels (HALs), this being the tracer study well at the Naturita, Colorado site, where contaminated native ground water was used as a tracer carrier. The injectate for this tracer well exceeded MCLs for sulfates and chloride, and contained arsenic and molybdenum at levels greater than HALs.

The injection zone characteristics for experimental technology injection wells vary widely depending upon the purpose of the well. Wells used for tracer studies may inject into contaminated aquifers, sometimes including aquifers that serve as drinking water supplies.

No contamination incidents were reported for experimental tracer study wells. In addition, experimental tracer study wells are not vulnerable to illicit discharges because injectate quality is controlled by the conditions of the experiment being conducted. Tracer study wells generally release tracers in small quantities.

According to the state and USEPA Regional survey conducted for this study, six states have a total of 396 documented experimental tracer study wells: South Carolina, Colorado, Nevada, Idaho, Texas, and Washington. More than 97 percent of the documented tracer study wells exist in South Carolina (207 wells or 52%) and Nevada (179 wells or 45%). Most of the tracer study wells in South Carolina and Nevada are being operated at U.S. Department of Energy facilities. The States of Massachusetts, Florida, and Mississippi indicated that they may have experimental wells, but that they could not provide an estimate of how many actually exist. The Texas and Washington UIC programs identified five and two experimental wells operating in their states, respectively, but did not provide any information concerning the types of wells (they may in fact be something other than tracer study wells). The Illinois UIC program reported two experimental wells that are most likely no longer operating. Survey responses from the other states indicated that they had no experimental wells.

The experimental technology wells in South Carolina, Nevada, and Washington are individually permitted by the state. Idaho authorizes shallow injection wells (<18 feet deep) by rule, provided that inventory information is supplied and use of the well does not result in contamination of a USDW. Deep injection wells (>18 feet deep) in Idaho must obtain an individual permit. Experimental wells in Texas and Colorado are permitted by rule, but the wells in Colorado must have a construction permit.

ATES System Wells

Heated or cooled process water, which may originate from native ground water, surface water, or potable water, are injected into aquifers for ATES systems. Experimental ATES wells inject water into the same aquifer from which it was withdrawn. While no contamination incidents were reported for ATES system wells, several reports mentioned that the concentration of constituents in ground water receiving fluids from some ATES wells were higher than background levels. Experimental ATES system wells are not vulnerable to illicit discharges because injectate quality is controlled by the conditions of the process operation. In particular, experimental ATES systems inject treated water for which injectate quality must be controlled. No UIC programs reported any operating ATES system wells in the survey responses. ATES systems, however, were recently operated in Minnesota and New York, and are in operation in several European countries.

2. INTRODUCTION

Under the existing UIC Program regulations in 40 CFR 146.5(e), Class V injection wells include "injection wells used in experimental technologies." Experimental technology is defined in 40 CFR 146.3 as "a technology which has not been proven feasible under the conditions in which it is being tested." As part of this study, USEPA conducted a survey of state and USEPA Regional staff who administer Class V UIC programs in order to collect information on experimental technology wells. Unfortunately, the UIC program personnel who identified "experimental wells" in their survey responses did not use the same criteria to classify these types of wells, and in some cases, did not apply the definition of experimental well that appeared on the survey questionnaire itself. The questionnaire defined "experimental well" as follows:

> *DEFINITION*: Experimental wells are used to test new technologies. Wells will not be classified as experimental if the technology can be considered under an established well subclass. For example, a well used for bioremediation will be classified as an aquifer remediation well.

Despite this intended definition, the survey respondents classified many different types of wells as experimental. For example, certain state UIC programs included injection wells used for dye tracer studies in the experimental well category while other programs did not identify tracer study wells as experimental wells. Tracer study wells are used to <u>conduct</u> experiments (e.g., characterization of aquifers); however, the tracer study well technology itself is generally not considered an experimental technology, and would therefore not fit the USEPA definition of an experimental well. Other survey respondents included "experimental" solution mining, aquifer remediation, food processing, or aquifer storage and recovery injection wells in the experimental well category. However, these wells are not true experimental wells under the USEPA experimental well definition, either because they are not intended to test new injection technologies or because they fit within another established well subclass. For the purposes of this volume, wells that were identified by UIC programs as "experimental wells" were recategorized if another Class V sub-category appeared to be more appropriate. In other words, wells that USEPA believes are better classified under one of the other Class V well types -- even if considered experimental by the survey respondents -- are not discussed in this volume, but are discussed in the volume for the appropriate well type.

To be more specific, the following sections identify the different kinds of wells classified as experimental by the survey respondents and describe where and how they are covered the Class V Study.

Tracer Study Wells

Some UIC Programs identified tracer study wells as experimental wells since these wells injected ground water tracers (also called tracer tests). Other programs, however, did not identify these wells as experimental wells. A ground water tracer is "matter or energy carried by ground water which will give information concerning the direction of movement and/or velocity of the water and potential contaminants which might be transported by the water.... Tracers can also help with the determination of hydraulic conductivity, porosity, dispersivity, chemical distribution coefficients, and other hydrogeologic parameters" (Davis, et. al., 1986 as cited in Holmbeck-Pelham, 1998). While tracers may exist in the subsurface due to natural or anthropogenic reasons, in the context of this discussion the only tracers that are relevant are those deliberately introduced through injection wells.

Tracer study wells may not be considered experimental wells under the USEPA definition, as these wells are not intended to test new injection technologies. However, tracer study wells do not fit neatly into any other well category discussed in this report. Therefore, tracer study wells are discussed in Section 3 of this volume.

Aquifer Thermal Energy Storage Wells

An aquifer thermal energy storage (ATES) system stores thermal energy by injecting heated and/or cooled water into an aquifer. This energy can then be used at a later time. ATES system injectate (whether heated or cooled) generally is returned to the same aquifer from which it was previously withdrawn; however, in some cases, the injectate may have come from a different aquifer or from surface water. The heated or cooled water stored in the aquifer can be reused (for heating or cooling) by pumping the water to the surface.

Although no active ATES systems were identified in the survey, experimental ATES systems were recently operated in Minnesota and New York (Marseille and Wicke, 1992; Hoyer, et. al., 1994). ATES system wells are considered experimental injection wells because they are designed to test new injection technologies. These systems are discussed in Section 4 of this volume.

Solution Mining Wells

The Arizona and Colorado UIC programs identified injection wells as experimental wells since these wells tested innovative solution mining technologies. Solution mining involves injecting a fluid (e.g., sulfuric acid or sodium bicarbonate) into an underground mineral formation through an injection well, and then extracting the mineral-laden fluid through a recovery well for further processing to recover the mineral of interest. In the past, solution mining wells operated for experimental purposes have been rule authorized as Class V injection wells, while solution mining wells operated for commercial purposes may be permitted as Class III injection wells.

Although these wells have been handled this way in the past, USEPA now believes such wells are more appropriately classified as Class III solution mining wells. In fact, the only remaining solution mining well that was initially regulated as a Class V experimental well has been, or is in the process of being, permitted as a Class III well. In the future, all such wells will also be permitted as Class III wells. Therefore, these wells are not considered in this Class V Study. Volume 12 covers other solution mining wells that qualify as Class V wells.

Experimental Aquifer Remediation Injection Wells

Several UIC programs identified innovative aquifer remediation technologies as experimental wells. For example, the survey respondents identified the following experimental aquifer remediation technologies:

- Chlorine for remediation of aquifer bacterial contamination;
- Ethanol for remediation of aquifer nitrate contamination;
- Calcium polysulfide for remediation of aquifer hexavalent chromium contamination;

- Ground water to prevent migration of contaminants in aquifers; and
- Gas-phase or aqueous-phase nutrients for studies of experimental ground water *in situ* bioremediation systems.

For this study, aquifer remediation wells identified as "experimental" by survey respondents are not considered experimental because they do not test new injection technologies. Instead, they are covered along with other aquifer remediation wells in Volume 16 of this report.

Aquifer Storage and Recovery Injection Wells

The Tennessee UIC Program identified one injection well as an experimental well. This well is used by a municipal water company for drinking water storage. Aquifer storage and recovery wells are used to emplace and then retrieve drinking water from an aquifer. Typically, ground water (or surface water) is treated to drinking water standards and is injected back into an aquifer. The treated water is then retrieved during times of high water usage for distribution to customers.

The Tennessee UIC Program indicated that this injection well was permitted as an experimental well because, although aquifer storage and retrieval system technology has been demonstrated in other states, this is the first such system to be constructed in Tennessee. However, USEPA believes this well is the same as other such wells throughout the nation, and therefore covers it along with other aquifer storage and recovery wells in Volume 21 of this study.

Food Processing Wells

The West Virginia UIC Program reported that one experimental injection well is operating within the state. This well, which is located at a goat cheese factory, consists of a drain field that contains wood chips. The state reported that this well was classified as an experimental well because it did not fit into any other state program category. However, USEPA considers this to be a food processing well and covers it along with other such wells in Volume 6 of this report.

3. EXPERIMENTAL TRACER STUDY WELLS

This section provides the following information on experimental tracer study wells: (1) prevalence; (2) injectate characteristics and well operating practices; (3) potential and documented impacts on USDWs; (4) practices for effectively installing, operating, and removing tracer study wells; and (5) federal, state, and local programs governing the installation, operation, and removal of this well type.

3.1 Prevalence of Wells

For this study, data on the number of tracer study wells were collected through a survey of state and USEPA Regional UIC programs. The survey methods are summarized in Section 4 of Volume 1 of the Class V Study. Table 1 lists the number of experimental tracer study wells in each state by USEPA Region, as determined from the survey using the categorizations described above in Section 2. The table includes the documented and estimated number of tracer study wells in each state, along with the source and basis for any estimate, when noted by the survey respondents. If a state is not listed in Table 1, it means that the UIC program responsible for that state indicated that no tracer study wells are currently operating in the state. As described above, wells that were originally identified by UIC programs as "experimental" were reclassified if the wells were better addressed under another established injection well category. Table 1 does not include these particular wells.

As shown in Table 1, a total of 396 documented Class V experimental tracer study wells have been identified. None of the UIC programs reported "estimated" numbers for experimental tracer study wells. However, Florida, Massachusetts, and Mississippi reported that the true inventory of experimental wells is "unknown." The Texas and Washington UIC programs provided no information on the nature or purpose of the experimental wells existing in their states.

There may be considerable temporal variation in the tracer study well inventory data because, unlike some of the other Class V injection well categories, tracer study wells have a limited operating life. Operating permits or rule authorizations for tracer study wells generally expire at the conclusion of the experiment being conducted (e.g., when a tracer study for aquifer characterization is concluded). The duration of operating permits and rule authorizations for tracer study wells reported in the survey responses ranged in duration from two months to 10 years. Therefore, the numbers reported in Table 1 may be considered only as a "snapshot" of the tracer study well inventory.

Of the 396 operating Class V experimental tracer study wells, 179 are in Nevada and 207 are in South Carolina. These two states account for more than 97 percent of the documented experimental wells in the U.S. All of the experimental tracer study wells reported by the Nevada UIC program are associated with the proposed Yucca Mountain High Level Radioactive Waste Repository Site Characterization Project (YMSCP) operated by the U.S. Department of Energy (DOE). Some of these 179 wells at the Yucca Mountain site have reportedly been plugged and abandoned. In addition, nearly all of the experimental wells documented in South Carolina are tracer study wells or aquifer remediation injection wells associated with environmental remediation projects at the DOE Savannah River Site. The survey questionnaire for South Carolina did not identify how many of the wells are tracer study wells and how many are aquifer remediation wells. Because no additional information is available concerning the purpose of the experimental wells reported by the South Carolina UIC program, all of South Carolina's wells are included in the tracer study well inventory.

Table 1. Inventory of Experimental Tracer Study Wells in the U.S.

State	Documented Number of Wells	Estimated Number of Wells	
		Number	Source of Estimate and Methodology
USEPA Region 1			
MA	0	Unknown	NA
USEPA Region 2 -- None			
USEPA Region 3 - None			
USEPA Region 4			
FL	0	Unknown	NA
MS	0	Unknown	NA
SC	207	207	Permit Program Data.
USEPA Region 5			
IL	0	NR	Permit Program Data. Two experimental wells reported to be used to inject compressed air are believed no longer to be operating.
USEPA Region 6			
TX	5	NR	Permit Program Data. The Texas UIC program reported 5 experimental wells in the state, but provided no information concerning the purpose of the wells.
USEPA Region 7 -- None			
USEPA Region 8			
CO	2	NA	Permit Program Data.
USEPA Region 9			
NV	179	179	Permit Program Data.
USEPA Region 10			
ID	1	1	IDWR Injection Well Permit Application No. 63-W-47, October 26, 1990, provided by Ms. Jane Talllman, Idaho Department of Water Resources.
WA	2	NR	Permit Program Data. The Washington UIC program reported 2 experimental wells in the state, but provided no information concerning the purpose of the wells.
All USEPA Regions			
All States	396	> 396	Total estimated number counts the documented number when the estimate is unknown or NR.

NA Not available
NR Although USEPA Regional or state officials reported the presence of the well type, the estimated number of wells was not reported.
Unknown Questionnaire completed, but number of wells is unknown

Two state UIC programs -- Colorado and Idaho -- reported one or two operational Class V experimental tracer study wells. Altogether, these programs comprise less than 1 percent of the documented tracer study wells in the nation.

The Colorado UIC Program reported two operational experimental tracer study wells. One well is being operated at an experimental mining operation in Idaho Springs, Colorado. The Colorado UIC program also reported three "experimental" aquifer remediation wells and one "experimental" solution mining well that have been recategorized for the purpose of this study, as described in Section 2.

The Idaho UIC Program reported that one experimental well is being operated in Eagle Island State Park by Boise State University (as part of a university graduate student research project). This project involves the construction of both a tracer injection well and monitoring wells used to study ground water contaminant migration in shallow aquifers.

3.2 Injectate Characteristics and Injection Practices

The following sections describe the injectate characteristics and injection practices for experimental tracer study wells.

3.2.1 Injectate Characteristics

Tracers used for injection well experiments may include organic dyes, rare earth metals, and other organic and inorganic compounds (e.g., rare earth metals, Rhodamine WT dye, chloride, bromide, and organic solutes) (Holmbeck-Pelham, 1998). Short half-life radioisotopes may also be used as long as the likelihood of contaminating drinking water is extremely low, or the site is already contaminated with radionuclides. For some tracer study wells, only general information is available concerning injectate characteristics. For these wells, examples of tracers and injectate data are presented below.

- **Boise State University Department of Geology.** The permit issued by the Idaho Department of Water Resources for the injection well tracer study limits the injectate to heated ground water derived from the same aquifer from a nearby well (IDWR, 1990). The project description in the permit application indicates that tracer solutions of chloride and bromide ions would be used in the tracer test (BSU, 1990). However, neither the permit application nor the permit for the injection well included any concentration data for the tracer solutions or identified the specific chloride and bromide ion compounds used in the tracer well tests.

- **Bureau of Mines Stope Leaching Project Tracer Study.** The U.S. Department of the Interior, Bureau of Mines (BOM) submitted an application in 1992 for authorization to inject potable water and sodium chloride (NaCl) tracer into a man-made fractured crystalline rock mass at the Colorado School of Mines (CSM) Experimental Mine Facility in Idaho Springs, Colorado. In all three tests, the injectate (potable water provided by the Idaho Springs Municipal Water Department) was mixed with a NaCl tracer. The concentration of NaCl in the injectate was 7,000 ppm, 3,000 ppm, and 6,000 ppm during the three tests.

- **Naturita Uranium Site Tracer Study.** In 1998, the United States Geological Survey (USGS) applied for approval to conduct a small-scale tracer study of an aquifer in Colorado contaminated with uranium, vanadium, sodium chloride, sodium bicarbonate, sulfuric acid, and ammonium sulfate. The USGS applied for approval to conduct five tracer tests at the Naturita site. Each test would inject native ground water with 1,000 ppm potassium bromide (ppm as bromide) into the aquifer. The native ground water used as a tracer carrier is contaminated with uranium, chloride, and sulfates at levels greater than drinking water maximum MCLs, and with molybdenum and arsenic at levels greater than HALs. Concentrations of strontium in the native ground water are also elevated above background concentrations. Native ground water (i.e., tracer carrier) quality data are summarized in Table 2 (USGS, 1999).

- **Yucca Mountain Site Characterization Project (YMSCP).** Although many other chemicals are being used (e.g., helium, lithium bromide, synthetic colloids, and short half-life radionuclides), the most commonly injected tracer for YMSCP tracer study wells is sulfur hexafluoride gas. Tracers approved by the Nevada UIC program for the Yucca Mountain project are shown in Table 3. Not all of these tracers have been used.

  During 1996 and 1997, the YMSCP injected sulfur hexafluoride to conduct tracer and ventilation testing at the site (USDOE, 1996). Additionally, lithium bromide was mixed with water and was used as a tracer to tag construction, dust control, and drilling water. Other tracers used in testing at the YMSCP include sodium iodide, pentafluorobenzoic acid (PFBA), and fluorescent microspheres.

3.2.2 Well Characteristics and Operating Practices

Examples of well characteristics and operating practices for tracer study wells are presented below.

Bureau of Mines Stope Leaching Project Tracer Study

The BOM conducted three tracer tests at the stope leaching research project. The research project involved the control of fluids released into a simulated stope filled with fractured rock.[1] The fractured rock was formed by blasting the in-place rock mass and by creating associated fracture patterns in the surrounding bedrock. While some fluid introduced into the formation is lost in the fractures, the remaining fluid is collected and recycled back into the formation for the duration of the tracer study (BOM, 1993).

[1] A stope is an excavation in the form of steps made by the mining of ore from steeply inclined or vertical veins.

Table 2. Summary of Native Ground Water (Tracer Carrier) Analyses at the Naturita Site 1989 -1994 (USGS, 1998)

Parameter	Background Ground Water Quality (mg/l)	Onsite Ground Water Quality (mg/l)	MCL (mg/l)	HAL (mg/l)
Aluminum	<0.09	<0.10	0.05-0.2 (S)	--
Ammonium	<0.10	0.26	--	--
Antimony	<0.003	<0.003	0.006	0.003 (NC)
Arsenic	<0.01	0.03	0.05	0.002 (C)
Barium	<0.1	<0.1	2.0	2.0 (NC)
Boron	<0.1	0.2	--	0.6 (NC)
Bromide	<0.1	0.4	--	--
Cadmium	<0.001	<0.001	0.005	0.005 (NC)
Calcium	155	243	--	--
Chloride	8.2	546	250.0 (S)	--
Chromium (total)	<0.01	<0.01	0.1	0.1 (NC)
Cobalt	<0.05	<0.05	--	--
Copper	<0.02	<0.02	1.3	--
Cyanide	<0.01	<0.01	0.2	0.2 (NC)
Fluoride	0.3	1.4	4.0	--
Iron	<0.03	<0.05	0.3	--
Lead (at tap)	<0.01	<0.01	0.015	--
Magnesium	<0.01	5.1	--	--
Mercury (inorganic)	<0.0002	<0.0002	0.002	0.002 (NC)
Molybdenum	<0.01	0.29	--	0.04 (NC)
Nickel	<0.04	<0.04	0.1	0.1 (NC)
Nitrate (as N)	1.7	2.7	10.0	--
Phosphate	<0.1	0.4	--	--
Potassium	1.9	41	--	--
Selenium	<0.005	0.01	0.05	--
Silica	<0.005	0.01	--	--
Silver	<0.01	<0.01	0.1 (S)	0.1 (NC)
Sodium	48	997	--	--
Strontium	1.2	5.5	--	17.0 (NC)

Table 2. Summary of Native Ground Water (Tracer Carrier) Analyses at the Naturita Site 1989 -1994 (USGS, 1998) (Continued)

Parameter	Background Ground Water Quality (mg/l)	Onsite Ground Water Quality (mg/l)	MCL (mg/l)	HAL (mg/l)
Sulfate	348	1200	500.0	--
Sulfide	<0.1	<0.1	--	--
Thallium	<0.01	<0.01	0.002	0.0005 (NC)
Tin	<0.005	<0.005	--	--
Uranium	0.012	2.2	0.02	–
Vanadium	<0.01	6.4	--	--
Zinc	0.057	<0.005	5.0 (S)	2.0 (NC)

-- means no MCL or health advisory level specified
(S) means the reported value is a secondary MCL (no notation means the value is a primary MCL)
(NC) means the reported health advisory level is for non-cancer effects
(C) means the reported health advisory level is for a 10^{-4} cancer risk

Table 3. Nevada UIC-Approved Tracers for Yucca Mountain Site Characterization Project, Yucca Mountain, Nevada

NV UIC Approved Tracers for the Yucca Mountain Project
Pyridone
Sodium Chloride
Lithium Bromide
Fluorescent Microspheres
Polystyrene Spheres
Sulfur Hexafluoride (SF6) - gaseous tracer
Nitrogen
“SUVA” Cold-MP (tetra-fluorethane) (gas)
2,4,6- Trifluorobenzoic Acid
2,4,5- Trifluorobenzoic Acid
2,3,4- Trifluorobenzoic Acid
2,3,6- Trifluorobenzoic Acid
2,3,4,5- Tetrafluorobenzoic Acid
2,3,4,6- Tetrafluorobenzoic Acid
3,4,5-Trifluorobenzoic Acid
2,3- Difluorobenzoic Acid
2,4- Difluorobenzoic Acid
2,5- Difluorobenzoic Acid
2,6- Difluorobenzoic Acid
3,4- Difluorobenzoic Acid
3,5- Difluorobenzoic Acid
Pentafluorobenzoic Acid

NV UIC Approved Tracers per 1996 Modification
Sodium Tungstate Dihydrate
Sodium Molybdate Dihydrate
Sodium Fluoride
Fluorescein, sodium derivative
Potassium Fluoride
Magnesium Fluoride
Magnesium Iodide
Helium
Neon
Krypton
Xenon
Argon
Sodium Iodide
Sodium Bromide
Potassium Iodide
Potassium Bromide

Three tracer tests were conducted in a stope filled with fractured rock, into which tracer fluid was injected. This research project involved the filling of the stope with tracer fluid, which subsequently flowed into the fractured rock. The Situation Statement for the project approved the use of cementious grout and superplasticizer for the control of water flow in the rock fractures. A USEPA Region 8 toxicologist indicated that these grouting materials are toxicologically insignificant (BOM, 1993). After the tracer tests were initiated, the BOM requested and obtained approval to use alternative grouting materials, including "Hey'di Special System" and "Hey'di K-11" waterproofing grouts (USEPA Region 8, 1993a; BOM, 1993a).

The first tracer test was conducted by injecting approximately 4,000 gallons of potable water with 7,000 ppm of NaCl tracer into the man-made fracture formation (stope). The injectate flowed through the stope and exited through a bulkhead, and then flowed through a pipe to a sump. Samples were taken from the pipe before the water reached the sump. The NaCl tracer was detected in fluids at a concentration ranging between 1,000 and 1,500 ppm NaCl. Approximately 3,000 gallons of tracer fluid were lost through fractures adjacent to the bulkhead. Almost all of the lost fluid was recovered in the sump and was transported to the Idaho Springs Municipal Waste Water Treatment Plant for disposal. On three different occasions, the stope was flushed with 4,000 gallons of potable water without any tracer to dilute the tracer in the fractures and to test the grouting measures used to seal the leaking fractures. This first tracer test resulted in considerable fluid loss through the fractures. As a result, the leaking fractures were surface grouted both inside and outside the stope with Portland cement grout and Hey'di waterproofing grouts (BOM, 1993a; BOM 1993b).

The second tracer test was conducted using a total of 8,000 gallons of potable water with 3,000 ppm of NaCl tracer. The water samples used for this test were obtained from the same locations as were the samples in the first tracer test and were analyzed for certain constituents (BOM, 1993b).

The third tracer test and a constant head test were completed in September 1994. Water samples were taken during this test at the same locations as during the first and second tests. A total of 8,114 gallons of potable water with 6,000 ppm NaCl tracer was injected into the stope. After the test's conclusion, in May 1994, a total of 3,603 gallons of fluid were recovered in the sump. The stope was subsequently flushed with 8,185 gallons of potable water without tracer. Over a period of about four months, USEPA Region 8 approved the reuse of the tracer solutions in drilling operations, and required that the concentration of the tracer solution be diluted to no greater than 1,000 ppm NaCl prior to reuse (USEPA Region 8, 1994).

USEPA limited the concentration of the sodium chloride tracer to no more than 7,000 ppm and required that BOM analyze fluid samples from the system sump for several constituents. Analyses were required prior to the beginning of the tracer test, two months after the beginning of the tracer test, and quarterly, thereafter. Ten samples were taken during the first tracer test, and analytical results are shown in Table 4 (these data are representative of the injectate and ground water).

Table 4. Analytical Data for Recovered Injectate - BOM Stope Leaching Project

	Sample Number											MCL (mg/l)
Parameter	**10-1**	**10-2**	**10-3**	**10-4**	**10-5**	**10-6**	**10-7**	**10-8**	**10-9**	**10-10**	**1-1**	
Arsenic	<0.005	<0.005	0.005	0.005	0.005	<0.005	0.005	0.006	<0.005	<0.005	<0.005	0.05
Cadmium	0.005	<0.005	0.019	0.016	0.016	0.009	0.014	0.017	0.017	0.016	<0.005	0.005
Copper	0.18	0.046	0.53	0.52	0.40	0.16	0.49	0.52	0.51	0.53	0.005	1.3
Lead	0.010	0.006	0.035	0.030	0.040	0.085	0.034	0.042	0.026	0.030	<0.005	0.015
Mercury	0.0011	0.0002	0.0026	0.0012	0.0008	0.0010	0.0006	0.0006	0.0005	0.0029	<0.0001	0.002
Zinc	0.72	0.28	3.3	3.4	3.9	2.7	3.7	3.6	3.5	3.6	1.2	5.0 (S)
Silver	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0002	0.1 (S)
Gross Alpha (pCi/L)	90 +/- 25	23 +/- 13	320 +/- 40	300 +/- 50	280 +/- 40	130 +/- 30	340 +/- 50	340 +/- 50	360 +/- 50	290 +/- 40	19 +/- 20	15.0
Gross Beta (pCi/L)	64 +/- 15	25 +/- 10	170 +/- 20	160 +/- 20	140 +/- 20	81 +/- 17	170 +/- 20	180 +/- 20	160 +/- 20	170 +/- 20	30 +/- 31	--
	Sample Number											
Parameter	**2-1**	**2-2**	**1-1**									
Fluoride	0.5	1.1	<0.5									4.0
Sulfate (SO4)	470	780	450									500.0

-- means no discharge limit, MCL, or health advisory level specified
(S) means the reported value is a secondary MCL (no notation means the value is a primary MCL)

USGS Naturita Uranium Site Tracer Study

Each of the five proposed tests at this site, introduced in Section 3.2.1, would inject 50 gallons of native ground water with 1,000 ppm potassium bromide tracer into the aquifer. Monitoring would be conducted at two existing monitoring wells and 12 newly installed wells at the site. The USGS reported that injection and monitoring wells would be installed approximately 150 yards from the San Miguel River. The river recharges the alluvial aquifer during high water season, while the aquifer discharges to the river during the low water season. Unconfined ground water occurs in the alluvial aquifer at depths ranging from zero to 18 feet below ground surface (USGS, 1998). The USGS predicted that the tracer tests would result in elevated concentrations of potassium (K+) and bromine (Br-). Local ground water concentrations of K+ would increase from approximately 40 mg/l to 540 mg/l, and local concentrations of Br- would increase from less than 5 mg/l to 1,000 mg/l. Bromide concentrations in the aquifer would be comparable in magnitude to concentrations of sodium and sulfate in the aquifer, prior to any dispersion (USGS, 1998). The USGS did not provide any information concerning well characteristics or operating data for the experimental well operation.

Boise State University Department of Geology

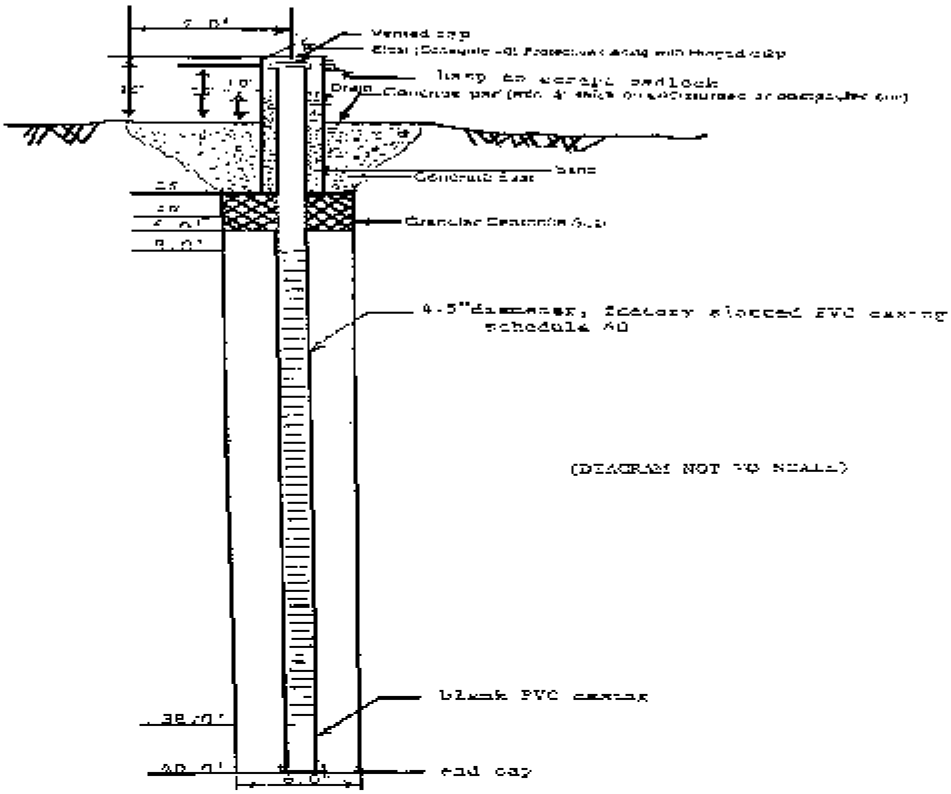
A diagram of the injection well in use at the Boise State University (BSU) tracer study site is shown in Figure 1. The well has a 4.5 inch diameter Schedule 40 PVC casing slotted from 8 feet deep to 38 feet deep, with a vented cap and a concrete and granular bentonite seal to 6 feet deep. The well is 6 inches in diameter. In the permit application for the proposed injection well, BSU requested exemption from a requirement to install 18 feet of steel surface casing (BSU, 1990).

Heated ground water containing chloride or bromide ions (i.e., the tracers) is injected into this well. The ground water containing the injected tracer solution is withdrawn from the aquifer through monitoring wells to determine the flow characteristics of the aquifer. The permit issued by the Idaho Department of Water Resources limits the flow of injectate into the injection well to no more than 10 gallons per minute on a weekly average, and limits the source of the injectate to heated ground water taken from a water production well located in the same aquifer zone as the injection well.

Yucca Mountain Site Characterization Project

The YMSCP is studying the hydrological and geological properties of rock formations around Yucca Mountain. Three wells are injecting tracers to study hydrological characteristics of the saturated zone. Three more wells may be constructed, if necessary. Other injection wells and boreholes are injecting approved tracers to tag the drilling water or air. The tracers will allow project managers to identify water or air from ground water and gas sources other than the water or air being injected into the well (Land, 1997).

Figure 1. Schematic Diagram of Tracer Study Injection Well, Boise State University Department of Geology



Source: BSU, 1990

During 1996, YMSCP researchers injected 4.6 ft^3 of sulfur hexafluoride to conduct tracer and ventilation testing at the site (USDOE, 1996). Additionally, 30,465 ounces of lithium bromide were mixed with 9,374,000 gallons of water. The mixture was used to tag construction, dust control, and drilling water. Other tracers used for this test include sodium iodide, pentafluorobenzoic acid (PFBA), and fluorescent microspheres.

During 1997, YMSCP scientists continued using sulfur hexafluoride as a tracer in drilling and testing activities at the site (USDOE, 1997a). The total annual amount of this tracer used in operations, drilling activities, and testing activities is approximately 215,000, 38, and 215,000 ft^3, respectively.

During 1997, researchers also performed tests using several different tracers, including helium, lithium bromide, and various dyes. Tables 5 and 6 show the amounts and concentrations of selected dyes and tracers used in research at the site in 1997. In order to tag construction, dust control, and drilling water, researchers also used approximately 1.4 ft^3 of helium in eight tracer tests and 15,000 ounces of lithium bromide (diluted in over 4.6 million gallons of water). Table 7 provides a side-by-side comparison of analytical results characterizing ground water collected from a tracer test injection well and a drinking water well at the Yucca Mountain site. Figure 2 shows a schematic diagram of an injection well used for multi-strata tracer studies.

Table 5. 1997 Dye Usage, Yucca Mountain Site Characterization Project, Yucca Mountain, Nevada

Dye	Amount Used (liters)	Average Concentration (mg/l)
FD&C Blue #1	2.3522	8,750
No. 8006 FD&C Yellow #6	0.13	9,200
FD&C Red #40	2.2493	8,250
Sulfo rhodamine b	2.5718	1,830
Lissamine FF	0.118	1,900

Source: USDOE, 1997a

Table 6: 1997 Tracer Injection Analysis, Yucca Mountain Site Characterization Project, Yucca Mountain, Nevada

Tracer	Amount Injected (kg)	Peak Concentration (mg/l)	Mass Recovered (kg)	Percent Recovered
LiBr (Lithium ion)	14.6 (Li)	0.56	9.5 (Li)	65
LiBr (Bromide ion)	165.1 (Br)	9.4	115 (Br)	69
PFBA	12.12	0.83	10.24	84
Fluorescent Microspheres	0.0085	2.0 million/L	0.0013	15
2,6-DFBA	11.3505	0.251	8.0	70
Pyridone	3.018	0.0437	0.038	1.9

Source: USDOE, 1997b

Table 7. 1997 Semi-annual Ground Water Sampling Results, Yucca Mountain Site Characterization Project, Nevada

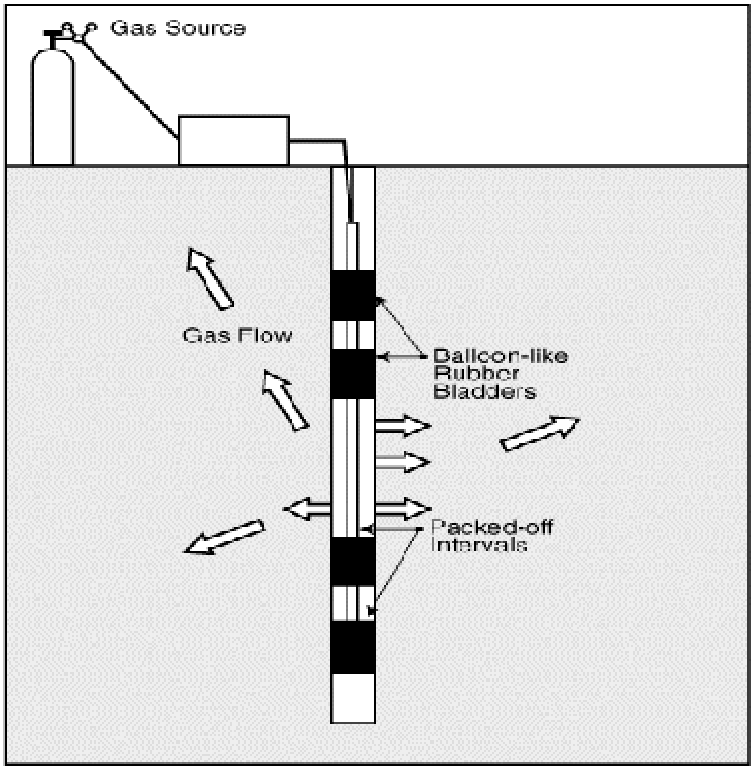
Constituent	Concentration mg/l (except as noted)	
	Tracer Testing Injection Well	Drinking Water Well
Total Dissolved Solids	241	241
Electrical Conductivity (Fmo/cm)	294	270
Calcium	13	13
Magnesium	0.34	2.0
Sodium	56	44
Potassium	2.0	5.6
Sulfate	17	16
Chloride	7.6	7.5
Nitrate	1.3	2.0
Bicarbonate	100	100
Carbonate	ND	ND
Fluoride	1.7	1.6
Arsenic	ND	ND
Iron	ND	ND
Manganese	ND	ND
Copper	ND	ND
Zinc	ND	ND
Barium	ND	ND
Boron	0.14	0.14
pH (units)	8.04	7.62
Cadmium	ND	ND
Chromium	ND	ND
Lead	ND	ND
Mercury	ND	ND
Molybdenum	NR	ND
Nickel	NR	ND

Table 7. 1997 Semi-annual Ground Water Sampling Results, Yucca Mountain Site Characterization Project, Nevada (Continued)

Constituent	Concentration mg/l (except as noted)	
	Tracer Testing Injection Well	Drinking Water Well
Selenium	ND	ND
Silver	ND	ND
Tungsten	ND	ND
Gross Alpha (pCi/L)	2.1±1.8	2.7±1.5
Gross Beta (pCi/L)	0.7±2.1	4.5±2.2
Silica	41	35
Lithium	0.06	0.043
Strontium	0.043	0.049
Bromide	ND	ND
Iodide	ND	ND
Pentafluorobenzoic Acid	ND	ND
2,6-Difluorobenzoic Acid	ND	ND
Fluorescent Microspheres	ND	ND
Pyridone	ND	ND

NR - Not Reported ND - Not Detected
Source: USDOE, 1997b

Figure 2. Schematic Diagram of Pneumatic Packed Tracer Injection Well for Geologic Strata Tracer Studies at Yucca Mountain Site



(Source: http://www.ymp.gov/about/science/e_sci/pneuma.htm) USDOE, No date.

3.3 Potential and Documented Damage to USDWs

The chemical quality of fluids released into experimental tracer study wells is not necessarily the best indicator of the potential damage that these wells can have on USDWs. The risk associated with experimental wells is largely a function of the receiving ground water and aquifer characteristics as well as the objective of the experimental project.

In some cases, tracer study wells intentionally introduce a tracer into the ground water at a specific concentration and location, knowingly exceeding drinking water standards. This being the case, a direct comparison of injectate quality to drinking water standards is useful, but does not tell the whole story about the potential for experimental wells to endanger USDWs. It is also necessary to consider the potential effects of experimental well operations by evaluating ground water monitoring data for these well systems. In general, operators of experimental injection wells are required to collect ground water quality data from monitoring wells situated in the vicinity of the injection well. Monitoring is required to determine whether the experimental well operation is having the desired effect and to determine whether the operation is having any effects beyond its zone of operation (e.g., the tracer is migrating beyond the aquifer formation).

Section 3.3.1 identifies the injectate constituents likely to exceed drinking water standards and reviews the properties of these constituents that most influence risk (e.g., toxicity, persistence, and mobility in ground water). Section 3.3.2 then summarizes available ground water monitoring results and other information on observed impacts associated with experimental well operations.

Numerous boreholes intersecting many different geologic strata or levels have been drilled for tracer studies at the Yucca Mountain Site. Tracer study injection wells use inflatable rubber bladders to separate the different geologic segments ("packing them off"). These balloon-like devices allow DOE to study if and how gases move through the various strata. Tracer gases are injected into these boreholes and the circulating gas pressure, found in each strata, is then measured to determine how much gas can be recovered back from the rock.

3.3.1 Injectate Constituent Properties

The primary constituent properties of concern when assessing the potential for Class V wells to adversely affect USDWs are toxicity, persistence, and mobility. The toxicity of a constituent is the potential of that contaminant to cause adverse health effects if consumed by humans. Appendix D to the Class V Study provides information on the health effects associated with contaminants found above drinking water standards or health advisory limits in the injectate of experimental wells and other Class V wells. As discussed in Section 3.2.1, the contaminants that have been observed above MCLs and/or HALs in experimental well injectate are chloride, strontium, sulfates, uranium, molybdenum, and arsenic.

Persistence is the ability of a chemical to remain unchanged in composition, chemical state, and physical state over time. Appendix E presents published half-lives of common constituents in fluids released in experimental wells and other Class V wells. All of the values reported in Appendix E are for ground water. Caution is advised in interpreting these values because ambient conditions have a significant impact on the persistence of both inorganic and organic compounds. Appendix E also provides a discussion of mobility of certain constituents found in the injectate of experimental wells and other Class V wells.

3.3.2 Observed Impacts

Ground water monitoring data are not available for all of the experimental injection wells for which injectate data and other permit data were reported. Potential effects on ground water quality identified in the survey conducted for this study include:

- Migration of tracers from the study zone into drinking water aquifers; and
- Migration of contaminants (e.g., uranium, strontium) from reinjection of native contaminated ground water.

The experimental tracer study well at the Naturita, Colorado site was the only well that did not meet primary MCLs, secondary MCLs, and HALs. The injectate for this tracer well exceeded MCLs for sulfates and chloride, and contained arsenic and molybdenum at levels greater than HALs. However, in this case, the injectate was not being injected into an aquifer of drinking water quality. In particular, the natural concentrations of strontium and uranium in the receiving aquifer were higher than normal background levels.

None of the state UIC programs documented any incidents of USDW contamination (i.e., exceedance of drinking water standards) from the operation of experimental tracer study wells.

The majority of experimental tracer study wells reported by state and USEPA Regional UIC programs are used to inject tracers (e.g., organic dyes, noble gases, short half-life radionuclides) into ground water. These tracers are used to determine the characteristics of the ground water. In tracer study well experiments, these compounds are injected in low concentrations. Therefore, negative ground water impacts are unlikely. As discussed in Attachment A, state UIC programs generally require that tracer wells be permitted and operated so as not to affect ground water quality. Given this requirement, no incidents of USDW contamination have been reported from the operation of experimental technology wells.

3.4 Best Management Practices

Best management practices (BMPs) for experimental tracer study wells are similar to the best management practices for aquifer remediation wells (see Volume 16), and include proper site characteristics, design, construction, maintenance, operation, monitoring, and closure. BMPs for tracer study wells are primarily related to the concentration and characteristics of the tracer. In general, tracers are injected in low concentrations with either potable or native ground water. Ideal tracers do not affect the flow regime or experience significant chemical, biological, or physical reactions during the test(s) (Holmbeck-Pelham, 1998). Tracer injectate concentrations can be minimized by using tracers of unique isotopic signatures. These signatures can allow the researcher to distinguish between natural and introduced compounds. In some cases, environmentally benign tracer compounds such as sodium and potassium salts can be used as tracers. However, for other applications, tracers with more unique signatures are required. While stable and radioactive isotopes fit this description, their use can raise concerns about residual radioactivity. This radioactivity can be minimized by using radioactive isotopes that have short half-lives.

Another potential concern for tracer study wells is the use of existing ground water as a tracer carrier. Many tracer studies are conducted at aquifer remediation sites where ground water is already contaminated with metals, organic compounds, or other constituents. The use of contaminated ground water as a tracer carrier could potentially spread this contamination to other areas, if the tracer wells and monitoring wells are not sited properly. However, the nature of the tracer study or the lack of potable water may require the use contaminated ground water. Therefore, careful siting of both the injection and monitoring wells will preclude any spreading of contamination. The potential for contamination can also be reduced by minimizing the concentration and quantity of the injectate required for the tracer study.

3.5 Current Regulatory Requirements

Several federal, state, and local programs exist that either directly manage or regulate experimental wells, or impact them indirectly through broad based water pollution prevention initiatives.

3.5.1 Federal Programs

On the federal level, management and regulation of Class V experimental wells fall primarily under the UIC program authorized by the Safe Drinking Water Act (SDWA), as discussed below. Some states and localities have used these authorities, as well as their own authorities, to extend the controls in their areas to address endemic concerns associated with experimental wells. Because more than 97 percent of the documented experimental wells are owned or operated by DOE, applicable DOE environmental control programs are also summarized below.

SDWA

Class V wells are regulated under the authority of Part C of SDWA. Congress enacted the SDWA to ensure protection of the quality of drinking water in the United States, and Part C specifically mandates the regulation of underground injection of fluids through wells. USEPA has promulgated a series of UIC regulations under this authority. USEPA directly implements these regulations for Class V wells in 19 states or territories (Alaska, American Samoa, Arizona, California, Colorado, Hawaii, Indiana, Iowa, Kentucky, Michigan, Minnesota, Montana, New York, Pennsylvania, South Dakota, Tennessee, Virginia, Virgin Islands, and Washington, DC). USEPA also directly implements all Class V UIC programs on Tribal lands. In all other states, which are called Primacy States, state agencies implement the Class V UIC program, with primary enforcement responsibility.

Experimental wells currently are not subject to any specific regulations tailored just for them, but rather are subject to the UIC regulations that exist for all Class V wells. Under 40 CFR 144.12(a), owners or operators of all injection wells, including experimental wells, are prohibited from engaging in any injection activity that allows the movement of fluids containing any contaminant into USDWs, "if the presence of that contaminant may cause a violation of any primary drinking water regulation . . . or may otherwise adversely affect the health of persons."

Owners or operators of Class V wells are required to submit basic inventory information under 40 CFR 144.26. When the owner or operator submits inventory information and is operating the well such that a USDW is not endangered, the operation of the Class V well is authorized by rule. Moreover, under section 144.27, USEPA may require owners or operators of any Class V well, in USEPA-administered programs, to submit additional information deemed necessary to protect USDWs. Owners or operators who fail to submit the information required under sections 144.26 and 144.27 are prohibited from using their wells.

Sections 144.12(c) and (d) prescribe mandatory and discretionary actions to be taken by the UIC Program Director if a Class V well is not in compliance with section 144.12(a). Specifically, the Director must choose between requiring the injector to apply for an individual permit, ordering such action as closure of the well to prevent endangerment, or taking an enforcement action. Because experimental wells (like other kinds of Class V wells) are authorized by rule, they do not have to obtain a permit unless required to do so by the UIC Program Director under 40 CFR 144.25. Authorization by rule terminates upon the effective date of a permit issued or upon proper closure of the well.

Separate from the UIC program, the SDWA Amendments of 1996 establish a requirement for source water assessments. USEPA published guidance describing how the states should carry out a source water assessment program within the state's boundaries. The final guidance, entitled *Source Water Assessment and Programs Guidance* (USEPA 816-R-97-009), was released in August 1997.

States must conduct source water assessments which are comprised of three steps. First, a state must delineate the boundaries of the assessment areas in the state from which one or more public drinking water systems receive supplies of drinking water. In delineating these areas, states must use "all reasonably available hydrogeologic information on the sources of the supply of drinking water in the state and the water flow, recharge, and discharge and any other reliable information as the state deems necessary to adequately determine such areas." Second, the state must identify contaminants of concern, and for those contaminants, the state must inventory significant potential sources of contamination in delineated source water protection areas. Class V wells, including experimental wells, should be considered as part of this source inventory, if present in a given area. Third, the state must "determine the susceptibility of the public water systems in the delineated area to such contaminants." States should complete all of these steps by May 2003 according to the final guidance.[2]

DOE Environmental Control Programs

Approximately 99 percent of the experimental injection wells reported in the UIC survey questionnaires are experimental tracer study wells being operated at DOE facilities as part of the its ongoing aquifer remediation programs. A representative of the DOE Office of Science and Technology familiar with the aquifer remediation program at the DOE Oak Ridge Reservation in Oak Ridge, Tennessee indicated that she did not believe that the Department has established any standardized procedures for the construction and operation of tracer study wells (Phillips, 1999). A representative of the USEPA National Risk Management Research Laboratory who has worked with DOE on development of experimental tracer study techniques for aquifer characterization indicated that experimental tracer study wells operated by DOE are not subject to standardized design procedures but are designed on a site-specific basis (Parker, 1999).

DOE is subject to federal and state environmental regulations concerning the design and operation of injection wells, including federal and state UIC regulations. DOE also has a system of Directives (DOE Orders) that have been developed by the Department to implement environmental protection programs. DOE Order 5400.5, Radiation Protection of the Public and the Environment, establishes standards and requirements for operations of DOE and DOE contractors with respect to protection of members of the public and the environment against undue risk from radiation. DOE Order 5400.1, General Environmental

[2] May 2003 is the deadline including an 18-month extension.

Protection Program, establishes environmental protection program requirements, authorities, and responsibilities for DOE operations for assuring compliance with applicable federal, state, and local environmental protection laws and regulations, executive orders, and internal department policies. Under these and related DOE Orders, DOE is required to obtain operating permits for tracer study wells operated at their facilities in states with UIC permit programs, and is required to comply with ground water protection standards and other environmental regulations related to construction and operation of underground injection wells.

3.5.2 State and Local Programs

Six states -- Colorado, Idaho, Nevada, South Carolina, Texas, and Washington -- have documented Class V experimental wells. Two of these states, Nevada and South Carolina, have more than 97 percent of the current documented well inventory. In addition, Illinois staff report that two experimental wells have been recorded but are most likely no longer operating at this time.

In Colorado, USEPA Region 8 directly implements the Class V UIC program. For the BOM Stope Leaching Project Tracer Study and the USGS Naturita Uranium Site Tracer Study conducted in that state, USEPA Region 8 staff indicate that individual UIC permits were not required but that both projects were rule authorized and subject to the general program requirements described above in Section 3.5.1. USEPA Region 8 staff also indicate that, for the Naturita project, the rule authorization was valid for three years from the date of issuance and the results of the tracer test had to be reported to USEPA. Both projects were also required to comply with Colorado Department of Public Health and Environment Regulations (USEPA Region 8, 1993).

The other states listed above have primacy for the Class V UIC program and have established a range of requirements for their programs. Specifically:

- Idaho authorizes shallow injection wells (<18 feet deep) by rule, provided that inventory information is supplied and use of the well does not result in contamination of a USDW. Deep injection wells (>18 feet deep) must obtain an individual permit. Both shallow and deep wells must satisfy operating requirements to ensure that no violation of the state's water quality standards for ground water occurs.

- Illinois has established rules for its Class V UIC program that are intended to be identical in substance to USEPA's rules in 40 CFR Part 144. The state applies inventory requirements and uses a permit-by-rule approach to ensure non-endangerment of USDWs. The state may require an individual permit to ensure no violation of drinking water requirements.

- Nevada requires experimental wells to obtain individual permits, based on detailed information about the facility.

- South Carolina requires experimental wells to obtain individual permits, based on detailed information about the facility. South Carolina's operating requirements for experimental wells are identical to the requirements for Class II and III injection wells. Monitoring requirements are the same as those for Class III wells.

- Texas authorizes Class V wells, including experimental wells, by rule. The state applies mandatory requirements and uses a permit-by-rule approach to ensure non-endangerment of USDWs. In addition, the state applies specific construction standards for Class V wells.

- Washington individually permits experimental wells.

4. EXPERIMENTAL ATES SYSTEM WELLS

An aquifer thermal energy storage (ATES) system stores thermal energy by injecting heated and/or cooled water into an aquifer for use at a later time. ATES system injectate (whether heated or cooled) generally is returned to the same aquifer from which it was previously withdrawn; however, in some cases, the injectate may have come from a different aquifer or from surface water. The heated or cooled water stored in the aquifer can be reused (for heating or cooling) by pumping the water to the surface. Although no operating ATES systems were identified in the survey responses as currently being active, experimental ATES systems were recently operated in Minnesota and New York (Marseille and Wicke, 1992, Hoyer, et. al., 1994). ATES systems are considered to be experimental injection wells because they are intended to test new injection technologies. These systems are therefore discussed in this volume of the report, and are not discussed in other report volumes.

4.1 Prevalence of Wells

No UIC program reported any operating ATES system wells. ATES system wells, however, were recently operated in New York and Minnesota.

There may be considerable temporal variation in the experimental well inventory data because, unlike some of the other Class V injection well categories, experimental wells have a limited operating life. Operating permits or rule authorizations for experimental wells generally expire at the conclusion of the experiment being conducted (e.g., when an experimental injection technology is demonstrated as either viable or not viable). Therefore, ATES system wells may be operated in the future, although none were reported to be operating at present.

4.2 Injectate Characteristics and Injection Practices

Although no ATES system wells are currently known to be operating, their injectate characteristics and injection practices are described here because they have been used recently and may be used again in the future. Because injectate data for ATES system wells were not available, Section 4.2.1 presents general characteristics of ATES system injectate. Section 4.2.2 presents ATES system injection practices.

4.2.1 Injectate Characteristics

Injectate data for experimental ATES systems were not available, and therefore only a general discussion of injectate characteristics is included in this section. Injectate for ATES systems is commonly heated water, or in some cases cooled water, that is being returned to the same aquifer from which it was withdrawn. In some cases, the water that is injected may come from a different aquifer or from a surface water source. In addition, cleaning agents may be injected into ATES system wells during well operation and maintenance activities to prevent plugging of the well due to scaling or other causes. The Minnesota Franconia-Ironton-Galesville Experimental ATES System provides an illustrative example of this type of well. Based on the review of the literature, an ATES system was operated in a confined aquifer system in St. Paul, Minnesota, referred to as the Franconia-Ironton-Galesville (F-I-G) aquifer (Hoyer, et. al., 1994). The injectate was ground water that had been heated and softened.

4.2.2 Well Characteristics and Operating Practices

ATES injection wells are used to store thermal energy to supply process cooling, space cooling, space heating, and ventilation air preheating; they may be used with or without heat pumps. Waste or by-product energy, ambient air, and renewable energy (e.g., solar energy) are often used as energy sources for ATES systems (Morofsky, 1997).

An ATES system is composed of one or more pairs of fairly conventional water supply wells drilled into an aquifer (Hall and Raymond, 1992). The well spacing is chosen to minimize interference and thermal short-circuiting during operation, which is normally seasonal. ATES systems are designed to maximize the amount of cold or heat stored in each cycle of ground water withdrawal and injection (Mirza, 1994). During the operation, ground water is withdrawn from one well, heated or chilled in a heat exchanger, and then returned for storage in the same aquifer through a second well. The stored thermal energy is recovered when the second well is pumped and the hot or cold water is again circulated through a heat exchanger and then returned to the aquifer through the first well. Different system types may be selected based on local geology, geography, climate conditions, and general applications. ATES systems have been classified into four main types:

1. Storage of warm water;
2. Storage combined with process cooling;
3. Storage for combined space cooling and heating; and
4. High-temperature ATES systems.

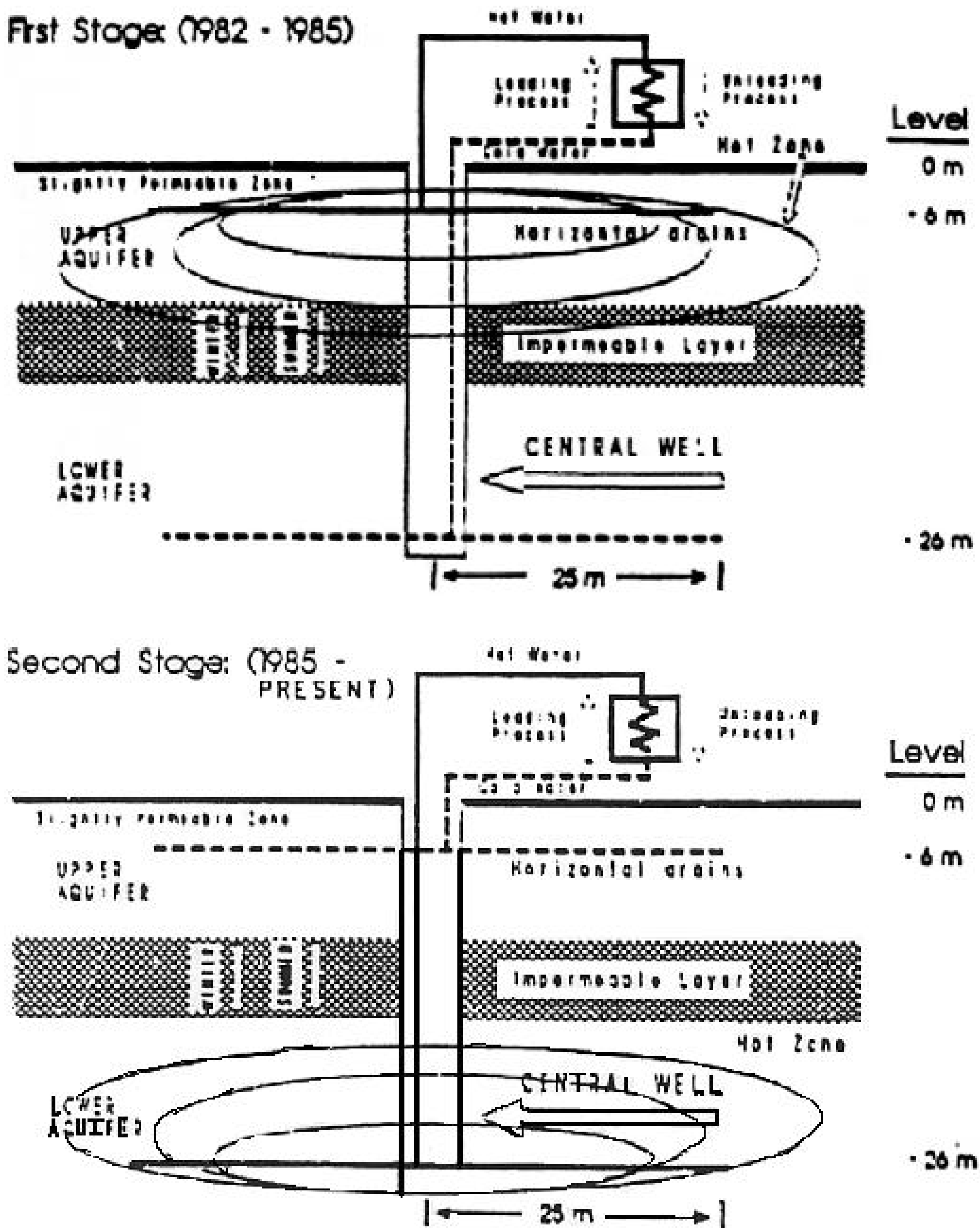
For the first type, in the summer, warm surface water is pumped through a heat exchanger to heat ground water that is pumped from a cool part of the aquifer. The heated water is then stored in a warm part of the aquifer; in the winter, the water is withdrawn and used as a source of energy to a heat pump system. The second and third types are similar and used for industrial process cooling and space heating and cooling. The third type, however, differs in that the systems are designed for optimal space cooling while space heating is complemented by the use of heat pumps. Typical users of ATES systems are commercial building owners and district heating networks (Andersson and Sellberg, 1992). Approximately 83% of 55 systems reviewed (from Canada, Germany, The Netherlands, and Sweden) were for commercial building applications, 13% for process cooling, and 4% for residential applications (Chant and Morofsky, 1992, Hall and Raymond, 1992).

ATES systems can potentially be used for seasonal and short-term energy storage at temperatures ranging from 2^{o}C to more than 100^{o}C. In Sweden, several low-temperature systems (<25^{o}C) have operated since before 1990. These systems also generally involve the use of heat pumps in combination with the seasonal storage (Andersson and Sellberg, 1992). Many systems have storage temperatures in the range of 12 to 40^{o}C, while there are fewer -- one study found only six -- high-temperature systems (greater than 85^{o}C). In 1992, high temperature systems were considered experimental (Jenne, et. al., 1992). One experimental high-temperature system was constructed to study scaling caused by over saturation (Andersson and Sellberg, 1992).

Potentially suitable aquifers for ATES systems are widely available throughout the U.S. The capacity of an aquifer limits the flow rate of an ATES system. The effective porosity of the aquifer affects the volume of aquifer required to store a volume of heated or chilled water. This consequently affects the size of an ATES well field required to store a specified quantity of energy (Hall and Raymond, 1992). Maximum flow rates range from 30 to 1,000 m^3/hour (Andersson and Sellberg, 1992). ATES system wells may be operated in either confined or unconfined aquifers. Operation in a confined aquifer would inhibit heated water from migrating out of the formation.

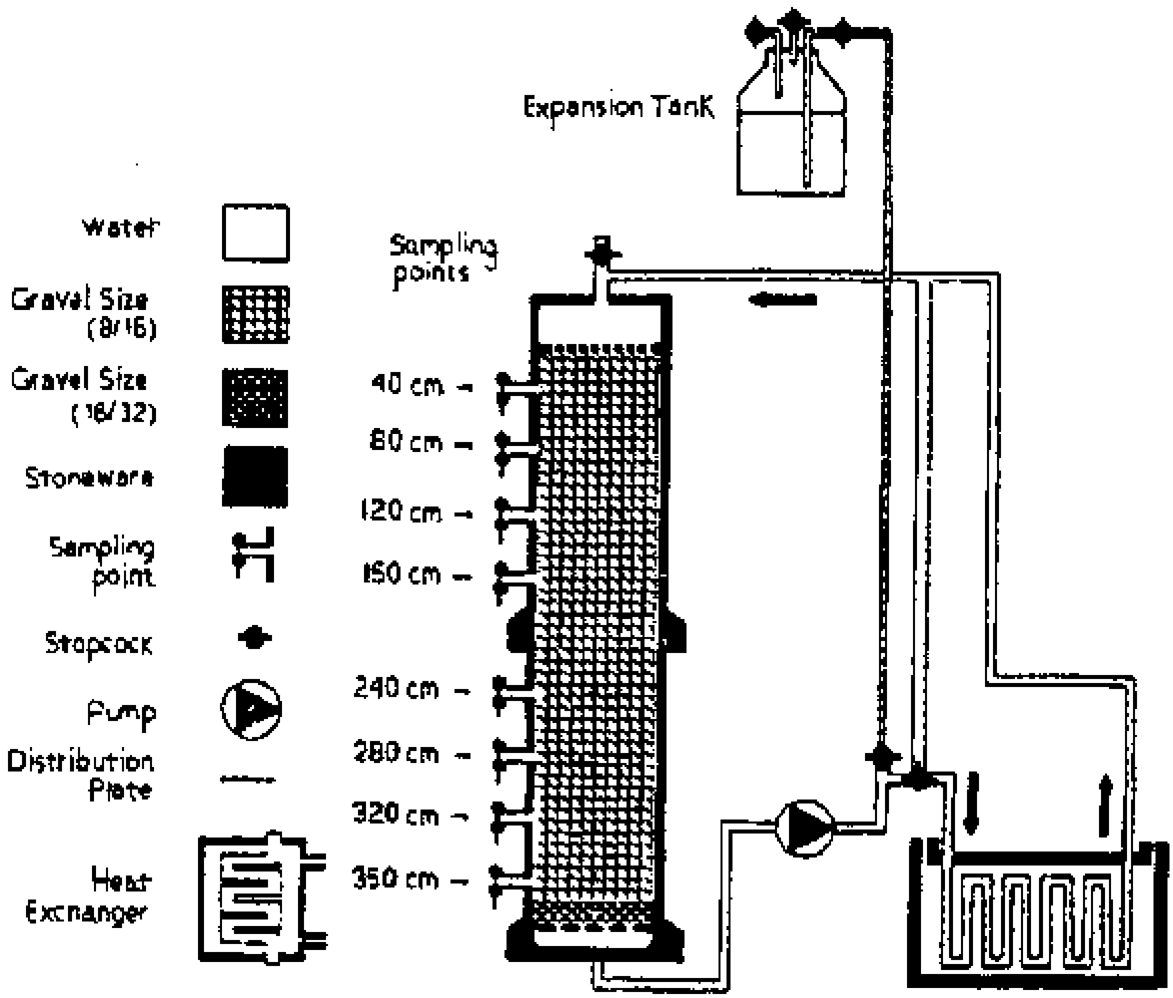
The configuration of ATES systems also varies widely depending upon the application. Although information on ATES systems in the U.S. is limited, information characterizing these systems in Europe is believed to be representative of systems in the U.S. For example, in Switzerland, one experimental ATES system has a large diameter central well (2.2 meters), from which two networks of six horizontal drains (0.2-meter diameter, 25-meter length) were driven into the soil at the level of two sandy aquifers (depths of 7 and 24 meters). The storage volume is 100,000 m^3 with a flow rate of 5-20 m^3/hour (Jollien, et. al., 1992). This system is illustrated in Figure 3. Schematic diagrams of three other experimental ATES systems, recently operated in Europe, are included in Figures 4 through 6.

Figure 3. Schematic Diagram of Dorigny, Switzerland ATES System



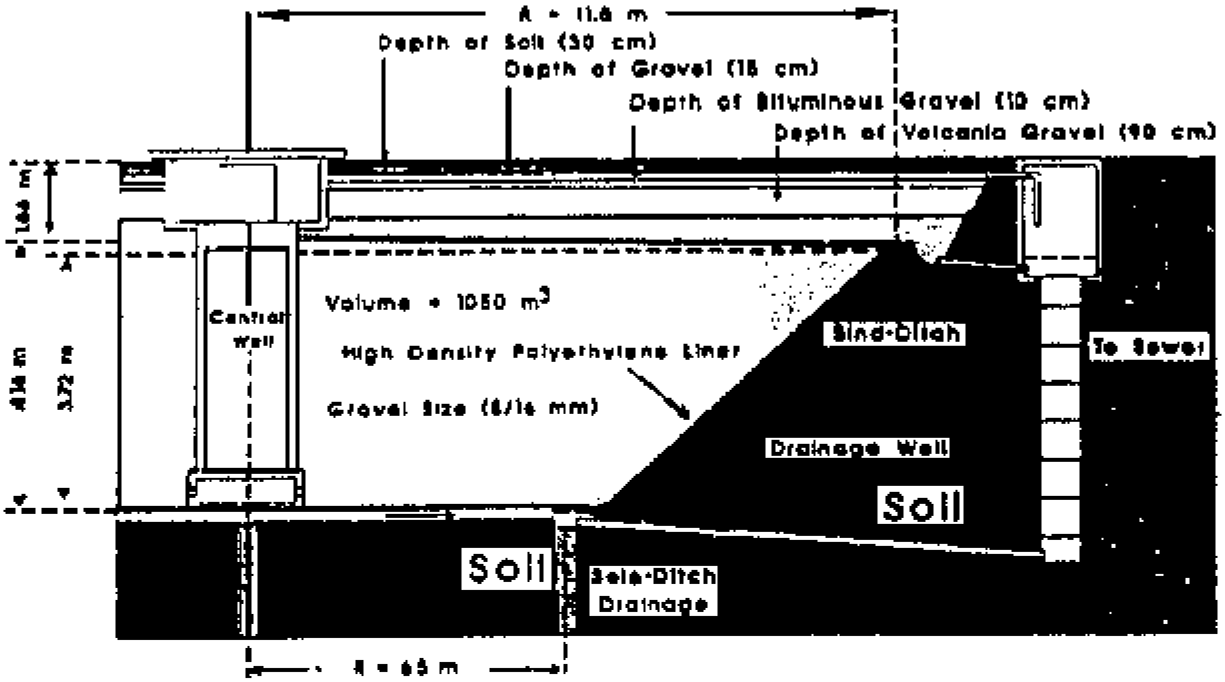
Source: Jollien, et. al., 1992

Figure 4. Schematic Diagram of Stuttgart, Germany ATES System



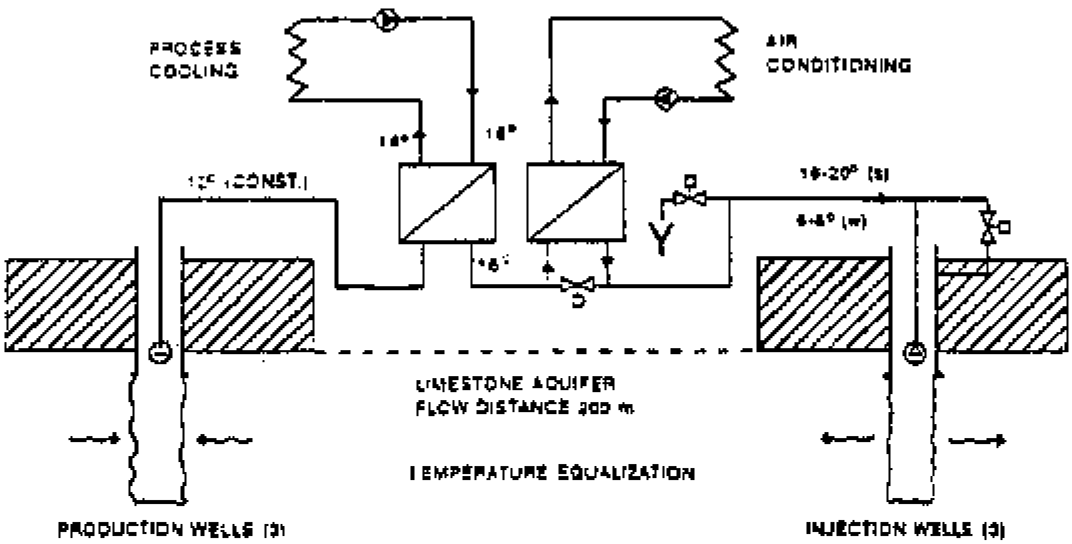
Source: Adinolfi and Ruck, 1992

Figure 5. Schematic Diagram of Impounded ATES System at University of Stuttgart, Germany



Source: Adinolfi and Ruck, 1992

Figure 6. Schematic Diagram of Combined Process ATES System, Malmö, Sweden



Source: Andersson and Selberg, 1992

Separately, in New York, an experimental ATES system (which is believed to no longer be operating) consisted of six wells, each 55 meters in depth, with a 0.305-meter diameter steel bushing fitted with a 15.2-meter long screen, of 0.2-meter diameter. The screen is surrounded by a 0.46-meter diameter fine gravel envelope that extends 6.1 meters above the screen for a total height of 21.3 meters. The casing above the gravel pack is enclosed in cement grout. The well pump is within the casing above the screen and within the water table at a sufficient distance to allow for draw down. The 25-millimeter clearance around the pump on all sides of the well casing allows for recharge. The wells are located in glacial outwash sand and gravel sediments (manetto gravel). The ground water table is 12.2 meters below surface grade (Marseille and Wilke, 1992).

Finally, in Minnesota, one recent field-test facility of an ATES project was conducted in the Franconia-Ironton-Galesville (F-I-G) confined aquifer in St. Paul, Minnesota. Researchers assessed the feasibility of designing, constructing, and operating the ATES system in a confined aquifer at temperatures as high as 150°C. The storage and source wells were spaced 225 meters apart (Hoyer, et. al., 1994).

4.3 Potential and Documented Damage to USDWs

The chemical quality of fluids released into ATES system wells is not necessarily the best indicator of the potential for these wells to threaten USDWs, because the risk associated with experimental wells is largely a function of the receiving ground water and aquifer characteristics as well as the objective of the experimental project. For example, injection of heated and softened ground water into the experimental ATES facility located in Minnesota lowered ground water temperature, raised ground water pH, and resulted in the mobilization of silica into the ground water from the native quartz deposits in the receiving formation. Although data are not available for other metals, it is possible that changes to the chemistry of the ground water resulting from injection of heated and softened water or other treated water could mobilize toxic metals (e.g., chromium, arsenic) if they are also present in the formation.

This being the case, a direct comparison of injectate quality to drinking water standards is useful, but does not tell the whole story about the potential for experimental wells to endanger USDWs. It is also necessary to consider the potential effects of ATES system well operations by evaluating ground water monitoring data for these systems. In general, operators of experimental injection wells are required to collect ground water quality data from monitoring wells situated in the vicinity of the injection well. Monitoring is required to determine whether the experimental well operation is having the desired effect and to determine whether the operation is having any effects beyond its zone of operation (e.g., is heated water injected into an ATES system aquifer formation migrating beyond the formation).

Section 4.3.1 identifies the injectate constituents likely to exceed drinking water standards. Section 4.3.2 then summarizes available ground water monitoring results and other information on observed impacts associated with experimental well operations.

4.3.1 <u>Injectate Constituent Properties</u>

The constituents that may exceed MCLs and HALs in ATES system well injectate include chlorine, arsenic, and chromium. Biological constituents (represented by total coliforms) may also be present in some ATES system wells. In addition, although not present in the injectate itself, ground water monitoring data for experimental injection wells indicate that trihalomethanes may be created in the aquifer through chemical or physical reaction between the injectate and the ground water or receiving formation.

Appendix D to the Class V Study describes the critical or adverse toxicological effects noted in the studies that served as the basis for the MCLs or HALs for these constituents. Appendix E to the study presents data on the persistence and mobility of these and other constituents in ground water.

4.3.2 Observed Impacts

Ground water monitoring data are not available for ATES system experimental injection wells. However, several potential effects on ground water quality were identified as a result of the survey conducted for this study, including production of trihalomethanes in ground water from injection of treated (chlorinated) water into aquifers; and mobilization of minerals from receiving formations into ground water from injection into aquifers.

Although experimental ATES system well operations were not reported to result in contamination of a USDW to concentrations greater than drinking water standards, elevated concentrations in ground water above background concentrations resulting from physical or chemical reaction of the injectate with the ground water or ground water formation were notable for some experimental injection wells. Potential impacts that may result directly from injectate characteristics or from physical or chemical reactions are discussed further in Section 4.4.2.

Injectate used for ATES systems (e.g., water used for heating or cooling systems) may not meet primary and secondary drinking water standards. Operation of ATES systems may also result in changes in ground water temperature and geochemistry, and water treatment chemicals used in these operations may migrate outside the ATES system aquifer. Literature sources indicate that the experimental ATES system formerly operated in Minnesota affected the characteristics of the underlying aquifer.

In general, ATES operations induce geochemical changes to native waters through the introduction of non-native waters or heat (Holm, et. al., 1987). Some of the geochemical changes that occur include precipitation-dissolution reactions, ion exchange, and mixing. All of these types of reactions may occur to different extents and at different times during ATES operation. In the case of the experimental F-I-G aquifer ATES system in St. Paul, Minnesota, the ATES operations caused the character of the geochemistry of the native ground water to change from a calcium-magnesium-bicarbonate water system near saturation with calcite, aragonite and dolomite, to a sodium-bicarbonate water system. The ATES system testing also caused changes in ground water pH, alkalinity, dissolved silica, and most major ion concentrations. Ground water sampling data from the ATES operations on the F-I-G aquifer indicate that the ATES system raised the native water temperature; slightly lowered the pH; and slightly increased the concentration of chloride, fluoride, and silica above background levels (Hoyer, et. al., 1994).

In addition to the direct effects of geochemical and heat changes (within the aquifer and its close surroundings), there are other potential risks including (Andersson and Sellberg, 1992):

- Leakage of toxic substances like glycol, brine, etc.;
- Emission of CFC gases (see discussion below on methane);
- Growth of pathogenic bacteria; and
- Change of water composition in the aquifer due to chemical treatment.

Some aquifer systems have had high concentrations of dissolved gases such as methane while others have had no major chemical contamination (Chant and Morofsky, 1992). Reaction of methane with HCl used as a water treatment chemical could result in the production of CFCs. Scaling and clogging were cited as the biggest operational problem with ATES systems; the injection of HCl prevented scaling but increased corrosion and potential environmental impacts. The changes in aquifer chemistry included pH and hardness (over saturation for calcium carbonate) (Jollien, et. al., 1992).

4.4 Best Management Practices

Research suggests certain characteristics are key to successful performance of ATES wells. This research generally defines successful performance in terms of energy storage and system operation, and not necessarily in terms of ground water quality. Best management practices begin with design of the system and continue through construction and installation, characterization of the aquifer, and operation and maintenance of the well.

Proper design of wells includes attention to the entire well field and its relationship to the storage aquifer. In addition, the water well design for the ATES facility requires that the energy management plan of the facility be known. Poor design and installation of a number of ATES wells has led to poor performance. Factors responsible for poor efficiency and specific yield include inadequate recognition of geochemical and biologically induced degradation with time and temperature changes, use of improper water well design, incorrect siting, insufficient quality control during well construction, and not understanding the demands placed on the well during its service. ATES operation requires wells and drains that are designed to withstand seasonal changes in flow direction, accommodate large changes in temperature on a cyclical basis, and operate with little maintenance.

Aquifer characterization, including site-specific investigations, is a critical step for well design. The characterization involves understanding the regional and local geology and hydrogeology, including analysis of all operating water wells within a 2 to 3 mile radius of the ATES facility. Test wells are screened and developed until the suspended solids in the discharge water are less than 1 ppm. A test well with more than 1 ppm of sediment during sustained pumping indicates either that it is not properly designed, installed or developed, or that the aquifer has features that have not been taken into consideration. Test drilling and pumping tests also yield water quality information and indicate whether or not dissolved gases may be present under the confining aquifer pressure. The presence of gases can later lead to problems in installation and pollution from gases escaping into formations intersected by the well bore. For well drilling, mud can invade the fine pores of the aquifer formation. Proper well development ensures that all the mud that has migrated into the aquifer formation is pulled back out of the aquifer zone immediately adjacent to the gravel pack. If not, wells will eventually clog within a few years after commissioning (Mirza, 1994).

The most significant problems affecting the operation of experimental ATES systems are caused by scaling, clogging, and corrosion. Microbes play a crucial role in these processes and are relevant to water quality (Seppaenen, 1994). However, most of the hydrochemically related clogging and corrosion problems in ATES systems can be predicted and prevented by proper design, construction, operation (including water treatment), and performing complete and careful pre-investigation. Scaling of heat exchangers and clogging of wells, gravel pack, and adjacent aquifer(s) caused by chemical precipitates has frequently occurred in ATES systems. The precipitation of carbonates has especially occurred in systems operating above 85^{o}C and iron and manganese oxides in systems operating below 40°C (Jenne, et. al., 1992). The content of phosphonates or dissolved organic matter in the ground water serves as natural inhibitors for growing carbonate crystals (Andersson and Sellberg, 1992). Conventional treatments for scaling utilize hydrochloric acid, sodium hydroxide, or ion exchange (with a large consumption of regeneration chemicals) (Koch and Ruck, 1992). To avoid problems associated with conventional water treatment, chemicals and processes are used to prevent scaling (i.e., mineral deposits inside pipes); the use of small amounts of carbon dioxide has been found to be a preferable treatment alternative (Koch and Ruck, 1992).

Clogging by iron bacteria slime is a potential risk mainly in low-temperature systems and in waters with an iron concentration of at least 1 mg/l. Major bacterial growth is also a risk with redox potential (Eh) values between 200 and 400 mV and pH values between 5.5-7.5. Corrosion usually occurs in slightly acidic water and with total dissolved solids greater than approximately 1,000 mg/l (Driscoll, 1986 as cited in Jenne, et. al., 1992).

At the ATES facility in St. Paul, Minnesota, the water injected into the aquifer was treated by an ion-exchange water softener to decrease calcium carbonate precipitation and scaling within the ATES system. Previous operation of the system with a calcium carbonate precipitator filter protected the aquifer and injection well from scaling and clogging problems, but scale build up required the heat exchangers to be shut down for eight hours at a time so that the filters could be replaced (Hoyer, et. al., 1994).

The principal technical problems with warm surface water storage systems has been biofouling of the surface water heat exchanger, clogging of injection wells, and clogging of recovery wells during production. The biofouling problem has been solved through use of a specially designed air bubble filter in front of the surface water open-hole inlet. Frequent cleaning with acid has been used to remove iron precipitation in the tubes and the heat exchanger. In one system, the source of the iron precipitation was considered to be from the mixing of lake water containing elevated iron with oxidized aquifer water (relatively free of iron). The oxidized water oxidized the iron rich water when mixed in one of the wells, which caused a delayed precipitation reaction to occur in tubes and fittings. This problem was proposed to be resolved with an in situ oxidation of the dissolved iron (Andersson and Sellberg, 1992).

ATES well operations are also frequently hindered by the presence of a specific bacteria species, *Legionella*. Factors to control the survival and propagation of *Legionella* include:

- Maintaining pH and alkalinity of the ground water below 5.5 or above 8.1 (tolerance range).
- Preventing scaling and corrosion (of cooling towers) with the addition of organic phosphorous compounds and corrosion inhibitors such as zinc and chromate.
- Adding commercially available biodispersants to ensure *Legionella* associated with biofilms are exposed to disinfectant and high alkalinity conditions.
- Reducing concentrations of metals, such as manganese and zinc, to levels that do not support the growth of *Legionella*. Low levels of certain metals (such as iron, zinc, and potassium) enhance growth of *Legionella*.
- Maintaining temperatures of water systems below 5°C or above 65°C. *Legionella* have been isolated at temperatures between 5.7 and 63°C.

- Selecting biocides detrimental to both *Legionella* and the specific microflora found in association with this microorganism.
- Keeping the environment aerobic. *Legionella* have been isolated at dissolved oxygen content between 0.3 to 9 mg/l (Hicks and Stewart, 1988 as cited in Seppaenen, 1994).
- Using treatment chemicals responsibly and only in the amounts and frequencies necessary to control bacterial growth, biofouling, and other system operating parameters.

4.5 Current Regulatory Requirements

4.5.1 Federal Programs

ATES system wells are covered by the UIC regulations discussed in Section 3.5.1 of this volume.

4.5.2 State and Local Programs

No UIC program reported any operating ATES wells. Therefore no state regulatory requirements currently apply.

ATTACHMENT A
STATE AND LOCAL PROGRAM DESCRIPTIONS

This attachment does not describe every state's program requirements; instead it focuses on the six states where experimental tracer study wells are known to exist: Colorado, Idaho, Nevada, South Carolina, Texas, and Washington. Altogether, these six states have a total of 396 documented experimental tracer study wells. The program in Illinois is also described because that state reports two experimental wells that are most likely no longer operating.

Colorado

Colorado is a Direct Implementation state. However, the state engineer issues permits to construct wells. The Water Well Construction Rules (2 Colorado Code 402-2) (CCR) apply to well construction contractors and drillers and to the construction of water wells, test holes, dewatering wells, monitoring and observation wells, and well plugging and sealing (abandonment). The rule specifies that excavations that do not penetrate through a confining layer between aquifers recognized by the state engineer may be designed, constructed, used, and plugged and sealed by authorized individuals, as specified in the rule, who are not a licensed well construction contractor. Wells constructed for sampling, measuring and test pumping for scientific, engineering, and regulatory purposes that do not penetrate a confining layer may be constructed by an authorized individual.

Idaho

Idaho is a Primacy state and has promulgated regulations for the underground injection control program in the Idaho Administrative Code (IDAPA), Title 3, Chapter 3. Deep injection wells are defined as more than 18 feet in vertical depth below the land surface (37.03.03.010.11 IDAPA). Wells are further classified, with Class V Subclass 5X25 defined as experimental technology wells (37.03.03.025.01.z IDAPA).

Permitting

Construction and use of shallow injection wells is authorized by rule, provided that inventory information is provided and use of the well does not result in unreasonable contamination of a drinking water source or cause a violation of water quality standards that would affect a beneficial use (37.03.025.03.d. IDAPA). Construction and use of Class V deep injection wells may be authorized by permit (37.03.03.025.03.c IDAPA). The regulations outline detailed specifications for the information that must be supplied in a permit application (37.03.03.035 IDAPA).

Operating Requirements

Standards for the quality of injected fluids and criteria for location and use are established for rule-authorized wells, as well as for wells requiring permits. The rules are based on the premise that if the injected fluids meet MCLs for drinking water for physical, chemical, and radiological contaminants at the wellhead, and if ground water produced from adjacent points of diversion for beneficial use meets the water quality standards found in Idaho's "Water Quality Standards and Wastewater Treatment Requirements," 16.01.02 IDAPA, administered by the Idaho Department of Health and Welfare, the aquifer will be protected from unreasonable contamination. The state may, when it is deemed necessary, require specific injection wells to be constructed and operated in compliance with additional requirements (37.03.03.050.01 IDAPA (Rule 50)). Rule-authorized wells "shall conform to the drinking water standards at the point of injection and not cause any water quality standards to be violated at the point of beneficial use" (37.03.03.050.04.d IDAPA).

Monitoring, recordkeeping, and reporting may be required if the state finds that the well may adversely affect a drinking water source or is injecting a contaminant that could have an unacceptable effect upon the quality of the ground waters of the state (37.03.03.055 IDAPA (Rule 55)). The permit for the BSU Department of Geology tracer study well also prohibits the injection well operation from degrading ground water or harming "beneficial uses" of ground water, and requires that Idaho water quality standards not be exceeded.

Plugging and Abandonment

The Idaho Department of Water Resources (IDWR) has prepared "General Guidelines for Abandonment of Injection Wells," which are not included in the regulatory requirements. IDWR expects to approve the final abandonment procedure for each well. The General Guidelines recommend the following:

- Pull casing, if possible. If casing is not pulled, cut casing a minimum of two feet below land surface;
- Measure the total depth of the well;
- Perforate the casing if is left in place. Neat cement with up to 5% bentonite can be pressure-grouted to fill the hole. As an alternative, when the casing is not pulled, coarse bentonite chips or pellets may be used to fill the hole. If the well extends into the aquifer, the chips or pellets must be run over a screen to prevent any dust from entering the hole. No dust is allowed to enter the bore hole because of the potential for bridging. Perforation of the casing is not required for this alternative;
- If well extends into the aquifer, a clean pit-run gravel or road mix may be used to fill bore up to ten feet below top of saturated zone or ten feet below the bottom of casing, whichever is deeper, and cement grout or bentonite clay used to surface. The use of gravel may not be allowed if the lithology is undetermined or unsuitable;
- Place a cement cap at top of the casing if it is not pulled, with a minimum of two feet of soil overlying filled hole/cap; and
- Abandonment of well must be witnessed by IDWR representative.

Financial Responsibility

No financial responsibility requirement exists for rule-authorized wells   Permitted wells are required by the permit rule to demonstrate financial responsibility through a performance bond or other appropriate means to abandon the injection well according to the conditions of the permit (37.03.03.35.03.e IDAPA).

Illinois

Illinois is a Primacy state. The Illinois Environmental Protection Agency (IUSEPA), Bureau of Land has promulgated rules establishing a Class V UIC program in 35 Illinois Administrative Code (IAC) 704 that are intended to be identical in substance to USEPA rules in 40 CFR 144.

Permitting

Any underground injection, except into a well authorized by permit or rule, is prohibited. The construction of any well required to have a permit is prohibited until the permit has been issued (704.12. IAC). Injection into Class V wells is authorized by rule until requirements under future regulations become applicable (704.146 IAC). Under the state's rules, basic information must be submitted, including the activities to be conducted, location of the facility, principal activities, operator information, list of other permits, topographic map of the facility, when required by the IUSEPA (702.123 IAC). Wells used in experimental technologies are required to submit the following information:

- Location of each well;
- Date of completion of each well;
- Identification and depth of the formation(s) into which each well is injecting;
- Depth of each well;
- Casing and cementing record, tubing size, and depth of packer;
- Nature of the injected fluids;
- Average and maximum injection pressure at the wellhead;
- Average and maximum injection rate;
- Date of last mechanical integrity test, if any (704.148(b) IAC).

Operating Requirements

Owners or operators of wells authorized by rule must submit inventory information (704.148 IAC). In addition, IUSEPA may require submission of other information deemed necessary by IUSEPA (704.149 IAC). This may include information about the performance of ground water monitoring, analysis of injected fluids, and description of the geologic strata through which and into which injection is taking place.

If at any time the IUSEPA learns that a Class V will may cause a violation of primary drinking water regulations under 40 CFR 142, it will require the injector to obtain an individual permit, issue a permit that requires the injector to take such action, including closure of the well, as may be necessary to prevent the violation, or take enforcement action. If a Class V well may be otherwise adversely affecting the health of persons, the IUSEPA may prescribed such actions as may be necessary to prevent the adverse effect.

Mechanical Integrity Testing

If the IUSEPA determines that a well lacks mechanical integrity, it may order immediate cessation of injection (704.142(f) IAC). However, the regulations do not establish a specific requirement for mechanical integrity testing for Class V wells A permit for a Class V well may include requirements for demonstration of mechanical integrity (704.190 IAC).

Nevada

Nevada is a Primacy state in which the Division of Environmental Protection (DEP) administers the UIC program. The statute specifically defines injection wells used in experimental technologies as Class V wells (445A.849.16 NRS).

Nevada Revised Statutes (NRS) §§ 445A.300 - 445A.730 and regulations under the Nevada Administrative Code (NAC) §§ 445A.810 - 445A.925 establish the state's basic underground injection control program. The injection of fluids through a well into any waters of the state, including underground waters, is prohibited without a permit issued by the DEP (445A.465 NRS), although the statute allows both general and individual permits (445A.475 NRS and 445A.480 NRS). Furthermore, injection of a fluid that degrades the physical, chemical, or biological quality of the aquifer into which it is injected is prohibited, unless the DEP exempts the aquifer and the federal USEPA does not disapprove the exemption within 45 days after notice of it (445A.850 NRS).

Regulations, particularly Chapter 445A NAC, "Underground Injection Control," define and elaborate these statutory requirements. First, they provide that any federal, state, county, or municipal law or regulation that provides greater protection to the public welfare, safety, health, and to the ground water prevails within the jurisdiction of that governmental entity over the Chapter 445A requirements (445A.843 NAC).

Permitting

The UIC regulations specify detailed information that must be provided in support of permit applications, including proposed well location, description of geology, construction plans, proposed operating data on rates and pressures of injection, analysis of injectate, analysis of fluid in the receiving formation, proposed injection procedures, and corrective action plan (445A.867 NAC). The DEP may modify the permit application information required for a Class V well.

Siting and Construction

The state specifies, among other siting requirements, that the well must be sited in such a way that it injects into a formation that is separated from any USDW by a confining zone that is free of known open faults or fractures within the area of review. It must be cased from the finished surface to the top of the zone for injection and cemented to prevent movement of fluids into or between USDWs (445A.908 NAC).

Operating Requirements

Monitoring frequency for injection pressure, pressure of the annular space, rate of flow, and volume of injected fluid is specified by the permit for Class V wells. Analysis of injected fluid must be conducted with sufficient frequency to yield representative data. Mechanical integrity testing is required once 5 years, by a specified method (445A.913.5 NAC and 445A.916 - 445A.920 NAC). For the YMSCP site, the concentration of injected chemicals "will not result in the injected water exceeding state or federal drinking water standards or in degradation of waters of the state" according to officials at Nevada's Bureau of Water Pollution Control (Land, 1997).

Plugging and Abandonment

A plugging and abandonment plan and cost estimate must be prepared for each well, and reviewed annually. Before abandonment, a well must be plugged with cement in a manner that will not allow the movement of fluids into or between USDWs (445A.923 NAC).

Financial Responsibility

Class V wells may be required to provide a bond in favor of the state either equal to the estimated cost of plugging and abandonment of each well or, if approved by DEP, a sum not less than $50,000 to cover all injection wells of the permit applicant in the state (445A.871 NAC). However, if adequate proof of financial responsibility is presented, the bonding requirements may be waived or reduced.

South Carolina

South Carolina is a Primacy state. The state's underground injection control program is implemented by the Department of Health and Environmental Control (DHEC). The UIC regulations, found in Chapter 61 of the state regulations (SCR), divide Class V wells into two groups, with experimental wells, defined as "injection wells used in experimental technologies," found in group (A) ((R61-87.10E.(1)(g)). The same requirements apply to experimental wells as are applied to other Class V(A) wells.

Permitting

Experimental wells, as Class V(A) wells, are prohibited except as authorized by permit (R61-87.10.E.(2)). The permit application must include a description of the activities to be conducted, the name, address, and location of the facility, the names and other information pertaining to the owner and operator, a description of the business, drawings of the surface and subsurface construction of the well, and proposed operating data, including average and maximum daily rate and volume of fluid to be injected, average and maximum injection pressure, and source and an analysis of the chemical, physical, biological, and radiological characteristics of the injected fluid (R61-87.13.G(2)). The movement of fluids containing wastes or contaminants into USDWs as a result of injection is prohibited if the waste or contaminant may cause a violation of any drinking water standard or otherwise adversely affect the health of persons (R61-87.5).

Siting and Construction

Siting and operating criteria and standards for Class V(A) wells require logs and tests, which will be specified by DHEC in the permit, to identify and describe USDWs and the injection formation. Construction standards are the same as those applied to drinking water wells.

Injection may not commence until construction is complete, the permittee has submitted notice of completion to DHEC, and DHEC has inspected the well and found it in compliance (R61-87.13U).

Operating Requirements

DHEC will establish maximum injection volumes and pressures and such other permit conditions as necessary to assure that fractures are not initiated in the confining zone adjacent to a USDW and to assure compliance with operating requirements (R61-87.13V). Operating requirements for Class V(A) wells are not distinguished in the state regulations from operating standards for Class II and III wells (R61-87.14). Injection pressure at the wellhead may not exceed a maximum calculated value to ensure that injection does not initiate new fracturing or propagate existing fractures in the confining zone adjacent to the USDW.

Monitoring requirements will be specified in the permit. Monitoring requirements for Class V(A) wells are the same as those for Class III wells, and may include installation of monitoring wells in the injection zone and adjacent zones as necessary to detect the dispersion and migration of injection fluids within and from the injection zone.   Monitoring of the fluid levels and water quality in the injection and monitor wells at specified intervals and submission of monitoring results will be specified in the permit. However, reporting of monitoring results to DHEC is required at least quarterly (R61-87.14.G and I(1)).

Mechanical Integrity

Prior to granting approval for operation, DHEC will require a satisfactory demonstration of mechanical integrity. Tests will be performed at least every 5 years (R61-87.14.G).

Plugging and Abandonment

A plugging and abandonment plan must be prepared and approved by DHEC (R61-87.12.B and .15).

Texas

Texas is a Primacy state. The Injection Well Act (Chapter 27 of the Texas Water Code) and Title 3 of the Natural Resources Code provide statutory authority for the underground injection control program. Regulations establishing the underground injection control program are found in Title 30, Chapter 331 of the Texas Administrative Code (TAC).

Permitting

Underground injection is prohibited, unless authorized by permit or rule. (331.7 TAC) By rule, injection into a Class V well is authorized , although the Texas Natural Resources Control Commission (TNRCC) may require the owner or operator of a well authorized by rule to apply for and obtain an injection well permit (331.9 TAC). No permit or authorization by rule is allowed where an injection well causes or allows the movement of fluid that would result in the pollution of a USDW. A permit or authorization by rule must include terms and conditions reasonably necessary to protect fresh water from pollution (331.5 TAC). Experimental wells are not specifically identified in the rules as Class V wells, but the category is not limited to the well types specified in the rules (331.11 (a)(4) TAC).

Siting and Construction

All Class V wells are required to be completed in accordance with explicit specifications in the rules, unless otherwise authorized by the TNRCC. These specifications are:

- A form provided either by the Water Well Drillers Board or the TNRCC must be completed.
- The annular space between the borehole and the casing must be filled from ground level to a depth of not less than 10 feet below the land surface or well head with cement slurry. Special requirements are imposed in areas of shallow unconfined ground water aquifers and in areas of confined ground water aquifers with artesian head.
- In all wells where plastic casing is used, a concrete slab or sealing block must be placed above the cement slurry around the well at the ground surface; and the rules include additional specifications concerning the slab.
- In wells where steel casing is used, a slab or block will be required above the cement slurry, except when a pitless adaptor is used, and the rules contain additional requirements concerning the adaptor.

- All wells must be completed so that aquifers or zones containing waters that differ significantly in chemical quality are not allowed to commingle through the borehole-casing annulus or the gravel pack and cause degradation of any aquifer zone.
- The well casing must be capped or completed in a manner that will prevent pollutants from entering the well.
- When undesirable water is encountered in a Class V well, the undesirable water must be sealed off and confined to the zone(s) of origin (331.132 TAC).

Operating Requirements

None specified. Chapter 331, Subpart H, " Standards for Class V Wells" addresses only construction and closure standards (331.131 to 331.133 TAC).

Mechanical Integrity Testing

Injection may be prohibited for Class V wells that lack mechanical integrity. The TNRCC may require a demonstration of mechanical integrity at any time if there is reason to believe mechanical integrity is lacking. The TNRCC may allow plugging of the well or require the permittee to perform additional construction, operation, monitoring, reporting, and corrective actions which are necessary to prevent the movement of fluid into or between a USDW caused by the lack of mechanical integrity. Injection may resume on written notification from the TNRCC that mechanical integrity has been demonstrated (331.4 TAC).

Plugging and Abandonment

Plugging and abandonment of a well authorized by rule is required to be accomplished in accordance with §331.46 TAC (331.9 TAC). In addition, closure standards specific to Class V wells provide that closure is to be accomplished by removing all of the removable casing and filling the entire well with cement to land surface. Alternatively, if the use of the well to be permanently discontinued, and if the well does not contain undesirable water, the well may be filled with fine sand, clay, or heavy mud followed by a cement plug extending from the land surface to a depth of not less than 10 feet. If the use of a well that does contain undesirable water
is to be permanently discontinued, either the zone(s) containing undesirable water or the fresh water zone(s) must be isolated with cement plugs and the remainder of the well bore filled with sand, clay, or heavy mud to form a base for a cement plug extending from the land surface to a depth of not less than 10 feet (331.133 TAC).

Financial Responsibility

Chapter 27 of the Texas Water Code, "Injection Wells," enacts financial responsibility requirements for persons to whom an injection well permit is issued. A performance bond or other form of financial security may be required to ensure that an abandoned well is properly plugged (§ 27.073). Detailed financial responsibility requirements also are contained in Chapter 331, Subchapter I of the state's UIC regulations (331.141 to 331.144 TAC). A permittee is required to secure and maintain a performance bond or other equivalent form of financial assurance or guarantee to ensure the closing, plugging, abandonment, and post-closure care of the injection operation. However, the requirement, unless incorporated into a permit, applies specifically only to Class I and Class III wells (331.142 TAC).

Washington

Washington is a Primacy state. Chapter 173-218 of the Washington Administrative Code (WAC) establishes the underground injection control program. Under the program, the policy of the Department of Ecology (WDOE) is to maintain the highest possible standards to prevent the injection of fluids that may endanger ground waters which are available for beneficial uses or which may contain fewer than 10,000 mg/l total dissolved solids (TDS). Consistent with that policy, new Class V injection wells that inject industrial, municipal, or commercial waste fluids into or above a USDW are prohibited (172-218-090(1) WAC), and existing wells that inject industrial, municipal, or commercial waste fluids into or above a USDW must obtain a permit to operate. All other Class V injection well owners and operators must notify the WDOE and supply required inventory information (172-218-090 (2) and (3) WAC).

Permitting

A permit must specify conditions necessary to prevent and control injection of fluids into the waters of the state, including all known, available, and reasonable methods of prevention, control, and treatment; applicable requirements in 40 CFR Parts 124, 144, 146; and any conditions necessary to preserve and protect a USDW. Any injection well that causes or allows the movement of fluid into a USDW that may result in a violation of any primary drinking water standard under 40 CFR Part 141 or that may otherwise adversely affect the beneficial use of a USDW is prohibited (173-218-100 WAC). The state's Waste Discharge Permit Program, which prohibits the discharge of pollutants into waters of the state (which include ground water) without a permit (Chapter 173-216 WAC) does not apply to the injection of fluids through wells which are regulated by the UIC control program (173-216-010 WAC).

Siting and Construction

The state's minimum standards for construction and maintenance of wells require notice before construction, reconstruction, or abandonment of a well, and submission of complete records describing construction or alteration of a well (173-160-050 and 173-160-055 WAC).

Wells are required to be planned and constructed to be adapted to the geologic and ground water conditions at the well site and designed to facilitate conservation of ground water (173-160-065 WAC).

The natural barriers to ground water movement between aquifers must be maintained, and aquifers or strata penetrated during drilling must be sealed to prevent impairment of water quality or cascading water. All sealing must be permanent and prevent movement of surface or ground water into the annular space. Sealing shall prevent the movement of ground water either upward or downward from zones that were cased off because of poor quality. When cement grout is use in sealing, it must be set in place 72 hours before additional drilling takes place, unless special additives are mixed with the grout that cause it to set in a shorter period of time. All grouting must be performed by tremmying the mixture from the bottom of the annular space to the surface in one continuous operation. The annual space to be grouted shall be a minimum four inches larger than the permanent casing. When casing diameter is reduced, a minimum of 8 feet of casing overlap is required and the bottom of the annular space between the casings shall be sealed with a watertight packer. The remainder of the annular space must be pressure grouted with bentonite or neat cement (173-160-075 WAC).

Operating Requirements

The water quality standards for ground waters establish an antidegradation policy. The injectate must meet the state ground water standards at the point of compliance (173-200-030 WAC).

Plugging and Abandonment

All wells not in use must be securely capped so that no contamination can enter the well (173-160-085 WAC).

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