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The Class V Underground Injection Control Study

Volume 10

Mining, Sand, or Other Backfill Wells

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MINING, SAND, OR OTHER BACKFILL 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 10, covers Class V mining, sand, or other backfill wells.

1. SUMMARY

Mine backfill wells are used in many mining regions throughout the country to inject a mixture of water and sand, mill tailings, or other materials (e.g., coal combustion ash, coal cleaning wastes, acid mine drainage (AMD) treatment sludge, flue gas desulfurization sludge) into mined out portions of underground mines. On occasion, injection (in low porosity grout form) also occurs into the rubble disposal areas at surface mining sites. Mine shafts and pipelines in an underground mine, as well as more “conventional” drilled wells, used to place slurries and solids in underground mines are considered mine backfill. Such wells may be used to provide subsidence control (the most common purpose), enhanced ventilation control, fire control, reduced surface disposal of mine waste, enhanced recovery of minerals, mitigation of AMD, and improved safety.

The physical characteristics and chemical composition of the materials that are injected into backfill wells vary widely depending on the source of the backfill material, the method of injection, and any additives (e.g., cement) that may be included. Data from leaching tests (e.g., USEPA Method 1311 Toxicity Characteristic Leaching Procedure (TCLP)) of backfill materials indicate that concentrations of antimony, arsenic, barium, beryllium, boron, cadmium, chromium, lead, mercury, molybdenum, nickel, selenium, thallium, sulfate, and zinc frequently exceed primary maximum contaminant levels (MCLs) or health advisory levels (HALs). Concentrations of aluminum, copper, iron, manganese, total dissolved solids (TDS), and sulfate, as well as the pH, frequently exceed secondary MCLs.

At sites where water is present in the injection zone (the previously mined ore body), the mine water may already exceed MCLs or HALs prior to injection either as a result of mining activity or natural conditions. At such sites, one objective of injection often is to improve the already poor quality of the mine water by reducing the availability of oxygen in the mine workings and/or neutralizing AMD. In other areas, water from coal beds may be used to supply domestic wells.

No incidents of contamination of a USDW have been identified that are directly attributable to injection into mine backfill wells. Although ground water contamination is not uncommon at mining sites, it is generally difficult to identify the specific causes. The chance that backfill injection will contribute to ground water contamination is highly dependent onsite conditions, including mine mineralogy, site hydrogeology, backfill characteristics, and injection practices. Some studies of the effects of backfill injection on mine water quality show that concentrations of some cations and anions can increase in mine water following injection, whereas concentrations of trace metals generally are relatively unaffected or decline over time. Other studies (at other sites) show an increase in selected metal concentrations.

The vulnerability of mine backfill wells to receiving spills or illicit discharges also depends on site-specific conditions and practices. For example, if coal ash is hauled to a mine site, slurried with water, and then injected, the likelihood of contamination of the injected material resulting from a spill or illicit discharge is relatively low. On the other hand, if mill tailings are collected in a tailings pond along with site runoff and other facility wastes prior to injection, then the likelihood of contamination of the backfill material by spills would be higher.

According to the state and USEPA Regional survey conducted for this study, there are approximately 5,000 documented mine backfill wells and more than 7,800 wells estimated to exist in the United States A total of 17 states report having mine backfill wells. More than 90 percent of the documented wells reported are in four states: Ohio (3,570), Idaho (575); West Virginia (401), and North Dakota (200). In truth, there may be more due to the broad scope of this well type and the fact that some state inventories may count these wells as subsidence control wells while others did not. Also, the number of active wells at any given time varies widely due to their generally short life span, most often a few days or less. The number of mine backfill wells has the potential to grow in the future due to the growing movement to decrease surface disposal and control ground subsidence.

State regulations pertaining to mine backfill wells vary significantly in their scope and stringency. Some states impose few restrictions while others require permitting, or impose requirements by contract rather than regulation. Some of these approaches include permit by rule (e.g., West Virginia, Idaho, North Dakota), general or area permits (e.g., Wyoming), and individual permits (e.g., Ohio). In addition, federal requirements for planning and approval of mining activities include mine backfill activities. These requirements apply in states that have not obtained primacy under the Surface Mining Control and Reclamation Act and to activities on federal and Native American tribal lands.

2. INTRODUCTION

Under the existing UIC regulations, Class V injection wells include “sand backfill and other backfill wells used to inject a mixture of water and sand, mill tailings or other solids into mined out portions of subsurface mines whether what is injected is a radioactive waste or not” (40 CFR 146.5(e)(8)). Piping systems within mine shafts and workings, as well as more “conventional” drilled wells, used to place slurries/solids in underground mines are considered mine backfill wells under the USEPA’s UIC regulations. Similarly, mine shafts are considered backfill wells if backfill is injected into the shaft.

Backfill injection is extremely diverse. Although subsidence control is a common objective of backfilling, injection can be performed for a wide range of reasons, as noted above. The types of materials that are injected are similarly diverse, and include materials (and various mixtures of materials) resulting from coal mining and combustion, primary and precious metal mining, uranium mining, and non-metal mining. The environmental settings in which the mines are located and injection occurs are similarly diverse. This volume only provides an overview and a general categorization of mine backfilling activities.

3. PREVALENCE OF WELLS

For this study, data on the number of Class V mining, sand, or other backfill 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 numbers of Class V mining, sand, or other backfill wells in each state, as determined from this survey. The table includes the documented number and estimated number of 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 in its survey response that it did not have any Class V mining, sand, or other backfill wells.

In 1998, a total of approximately 5,000 mine backfill wells were reported nationwide, all of which are reported to be in 17 states. As indicated in Table 1, several states estimated that the actual number of mine backfill wells is greater than the number reflected in their documented inventory. In addition, some states did not provide inventory information, although it is likely that wells exist in some of these states. Thus, the actual number of operating mine backfill wells in 1998 is estimated to be at least 7,800. The fact that they often exist for a relatively short operating time (in some cases, a few days or less) complicates development of a precise count of mine backfill wells in use during a given year, as exemplified by the information provided by Pennsylvania, Texas, Illinois, and West Virginia and summarized in Table 1.

4. BACKFILL CHARACTERISTICS AND INJECTION PRACTICES

4.1 Injectate Characteristics

A wide assortment of materials are used for backfilling of underground mines. These materials may include waste rock, mining and ore beneficiation wastes (e.g., mill tailings, coal cleaning wastes), coal combustion ash and flue gas desulfurization (FGD) sludge resulting from coal combustion, or sludge from AMD treatment operations. Mill tailings have been reported to be the most commonly used mine backfill materials, because they are inexpensive and abundant (Underground Injection Council Research Foundation, 1988).

Table 1. Inventory of Mine Backfill Wells in the U.S.*

State	Documented Number of Wells	Estimated Number of Wells	
		Number	Source of Estimate and Methodology[1]
USEPA Region 1 -- None			
USEPA Region 2 -- None			
USEPA Region 3			
MD	6	6	N/A
PA	NR	NR	Injection for subsidence control is common, but no wells were reported to be active at the time of the survey. A total of 1,123 wells are planned as part of four projects awaiting approval. PA only includes wells used for subsidence control in the "backfill injection" category.
VA	NR	NR	USEPA Region reports that backfill wells exist in VA, but the number of wells is not documented by the Region and was not available from the state.
WV	401	<401	Best professional judgement. Most backfill wells are used for fire control and are closed when the fire is extinguished, so state staff believe that most of these wells have been closed. Backfill wells used for subsidence control (73) are also included in the inventory.
USEPA Region 4			
AL	22	22	N/A
KY	NR	NR	State staff report that backfill wells exist in KY, but none are documented.
TN	2	2	N/A
USEPA Region 5			
IL	19	17	2 of the 19 wells may not have commenced operations. UIC inventory shows 34 wells, but state personnel believe many have been closed and abandoned.
IN	98 (UIC) 83 (Region) 2 (DNR)	NR	Combination of state and regional information: state does not routinely distinguish mine backfill wells from some other categories of Class V wells. The 1997 UIC inventory is a compilation from the region and an 1988 EEI study. DNR believes that at least 2 wells are not included in the region's inventory.
OH	3,570	6,400	Best professional judgement, based on knowledge of areas containing mines and installation frequency of backfilling wells.
USEPA Region 6			
TX	61	61	Although 61 wells are in the UIC inventory, all of these wells may be closed.

Table 1. Inventory of Mine Backfill Wells in the U.S. (continued)

State	Documented Number of Wells	Estimated Number of Wells	
		Number	Source of Estimate and Methodology[1]
USEPA Region 7			
KS	48	48	N/A
MO	15	15	N/A
USEPA Region 8			
CO	2	NR	N/A
MT	NR	NR	USEPA Region 8 Montana Operations Office staff believe that backfill wells may exist in MT. However, neither the USEPA Region nor the state has inventory data on such wells.
ND	200	200	N/A
SD	1	1	N/A
UT	0	2	State database shows that 2 wells are under construction, but have never been completed due to economic factors.
WY	20	>20	Best professional judgement. The documented 20 wells do not include subsidence prevention wells. No information was available for subsidence prevention wells.
USEPA Region 9			
CA	17	17	State personnel did not provide estimate but indicated that they suspect that more than the documented number of wells exist.
USEPA Region 10			
AK	1	>1	N/A
ID	575	575	N/A
All USEPA Regions			
All States	5,060	>7,890	Total estimated number counts the documented number when the estimate is NR.

[1] Unless otherwise noted, the best professional judgement is that of the state or USEPA Regional staff completing the survey questionnaire.

N/A	Not available.
NR	Although regional, state and/or territorial personnel reported the presence of the well type, the number of wells was not reported, or the questionnaire was not returned.

* Backfill wells regulated by states primarily under other UIC categories are not included. For example, Kansas applies Class III requirements (in addition to Class V requirements) to wells used to backfill solution-mined salt caverns.

Backfill materials may also contain cementing agents and other additives, such as cement. These agents normally are added to increase the suitability of the material for providing structural support. The use of a particular backfill material depends on its availability, cost, and properties after placement (Karfakis, 1996). Backfill material needs to be physically, hydrologically, chemically, and mineralogically stable, especially when subsidence control is one of the objectives of backfilling. To provide long-term stability, fill material must resist infiltration and conductance of ground water, because water migration can weaken backfills by promoting chemical reactions. Further, low permeability reduces the potential for contaminants to leach into ground water (Jude, 1995).

The characteristics of the backfill materials most commonly injected into underground mines are discussed below. The information presented is not an exhaustive compilation given the wide range of materials and practices. Examples of site-specific operations are provided in Section 4.3.

4.1.1 Mill Tailings

Mill tailings typically consist of a finely ground mixture of processed ore, disaggregated host rock, and traces of the solutions used (if any) in ore beneficiation operations.[1] In some backfill applications, mill tailings (with or without size classification) are slurried with water and injected into underground mines in what is often referred to as a "hydraulic sandfill" or "sand backfill" operation (see Section 4.3) (Levens, 1993; Sutter Gold Mining Company, 1998; Scheetz Mining Company, 1999).[2] In other applications, mill tailings are mixed with cement or other pozzolanic material[3] to form a pumpable material with relative low (10 to 25 percent) moisture content this is often referred to as paste backfill. When mixed with cement or a similar additive, the resulting backfill may also be referred to as cemented sandfill. The fine solid particles may consist of naturally occurring metamorphic and igneous clay-sized to sand-sized material and metamorphic rock fragments (Brackebusch, 1994).

Available data on the chemical composition of mill tailings sandfill slurry or backfill paste injected into mines are limited. Leachate data for mill tailings, however, are available and are included. Table 2 provides information on tailings used as backfill at several facilities. As shown, these materials may contain significant quantities of iron and trace metals.

The chemical characteristics of tailings used for backfill are determined primarily by the characteristics of the ore body and host rock and to a lesser extent the extraction processes used. Thus, in many cases the chemical characteristics of the mill tailings injected into underground

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[1] The particle size of mill tailings depends primarily on the beneficiation and processing techniques employed.

[2] These terms may also be used to refer to materials other than mill tailings, such as materials used in backfilling of underground coal mines.

[3] Material that reacts at ambient temperature with moisture to form a slow-hardening cement.

Table 2. Chemical Characteristics of Selected Metal Mine Tailings Backfill

	Pb-Zn Mine Tailings (ppm)*			Zn Mine (ppm)**	
Constituent	(1)	(2)	(3)	(4)	(5)
Aluminum	19,000	15,000	14,000		
Arsenic	<300	500	1,500		
Barium	200	80	44		
Cadmium	16	8	13	6.00	<0.006
Calcium	2,300	3,300	3,700		
Chromium	90	80	100		
Cobalt	10	20	30		
Copper	210	250	620	33.0	<0.05
Iron	53,000	57,000	54,000		
Lead	1,800	1,500	1,500	9.96	<0.04
Manganese	5,600	5,000	1,600		
Magnesium	1,900	2,400	1,400		
Mercury				<0.05	<0.0002
Molybdenum	<50	<50	<50		
Nickel	200	330	240		
Potassium	5,500	5,800	5,100		
Silicon	334,000	348,000	358,000		
Sodium	400	600	500		
Zinc	4,300	2,500	5,800	1,100	0.654

(1) Cemented tailings backfill collected from a test stope.
(2) Uncemented tailings backfill collected from a stope about 10 years after placement.
(3) Uncemented tailings backfill collected from new tailings.
(4) Sample of solids from tailings impoundment.
(5) Sample of water from tailings impoundment.
* Source: Levens, 1996
** Source: ASARCO, 1998

mines are similar to the ore body before it was mined even though the physical characteristics (i.e., particle size) have changed. As shown in Table 3a, a variety of leaching tests have been performed to evaluate the potential effect of the change in physical characteristics on the release of metals from backfilled mill tailings at a lead and zinc mine. For the constituents analyzed, concentrations frequently exceeded the primary drinking water standards (MCLs) or HALs in both of the acidic leaching tests. When leaching tests were performed using deionized water, only lead concentrations exceeded a health-based standard. The type of leaching test used varies depending on the conditions anticipated in the mine. Laboratory leaching data from gold mines that also backfill tailings as part of mining operations are shown in Table 3b. (Information on mine water analyses from backfilled stopes and other field monitoring of leachate quality is discussion in Section 5.) As shown, concentrations of arsenic, barium, chromium, lead, and nickel exceed MCLs in USEPA

Table 3a. Chemical Characteristics of Leachates from Selected Mill Tailings

	Drinking Water Standard		Health Advisory Level		Pb-Zn Mine Tailings Leachate Concentrations (mg/l)								
					HCl/HNO_3*			Deionized water**			H_2SO_4***		
Constituent	mg/l	Primary or Secondary	mg/l	Cancer or Noncancer	(1)	(2)	(3)	(4)	(5)	(6)	(4)	(5)	(6)
Aluminum	0.05 to 0.2	S	--		2.1	2.0	1.9	0.2	2.2	0.2	54.0	0.44	80.1
Arsenic	0.05	P	0.002	C	1.2	6.0	10.4	--	--	--	--	--	--
Barium	2	P	2	N	0.3	0.03	0.02	0.17	0.08	0.06	0.01	0.003	ND
Boron	--		0.6	N	--	0.84	0.51	--	--	--	--	--	--
Cadmium	0.005	P	0.005	N	0.17	0.21	0.34	--	--	--	0.01	0.32	1.8
Calcium	--		--		23.0	35.4	38.8	54.2	96.1	183	640	716	623
Chromium	0.1	P	0.1	N	--	0.40	0.25	--	--	--	--	--	--
Cobalt	--		--		--	0.13	0.17	--	--	--	--	--	--
Copper	1.3	P	--		0.69	0.56	0.69	0.04	0.09	ND	0.10	0.07	0.68
Iron	0.3	S	--		306	312	186	0.2	0.2	0.1	6.6	6.8	97.6
Lead	0.015	P	--		32.0	21.6	27.8	0.06	ND	0.02	0.90	1.6	3.9
Manganese	0.05	S	--		32.4	29.4	9.5	ND	0.1	ND	52.8	65.3	64.8
Magnesium	--		--		11.2	12.4	6.4	--	--	--	95.2	125	110
Nickel	0.1	P	0.1	N	--	0.16	0.21	--	--	--	--	--	--
Potassium	--		--		0.9	0.9	0.8	7.3	15.5	26.6	3.9	1.4	3.0
Silicon	--		–		2.2	2.2	1.7	6.6	6.7	8.5	14.6	34.7	157
Silver	0.1	S	0.1	N	0.04	0.02	0.03	--	--	--	--	--	--
Sodium	--		--		0.52	0.12	0.41	7.9	14.7	14.0	8.0	8.7	9.4
Sulfur	--		--		7.8	37	86	--	--	--	--	--	--
Sulfate	250	S	--		--	--	--	86.1	130	366	1,807	2,050	3,622
Zinc	2/5	P/S	2	N	21.9	14.9	35.4	0.06	ND	0.05	0.97	33.7	336

ND = Not detected.
* Overnight shaking of 1 g of backfill with mixture of HCl (2 cm^3), HNO_3 (4 cm^3), and 20 cm^3 water with filtering prior to analysis.
** Washing with deionized water for 7 days.
*** Washing with H_2SO_4 for 227 days.
(1) Cemented tailings backfill collected from a test stope.
(2) Uncemented tailings backfill collected from a stope about 10 years after placement.
(3) Uncemented tailings backfill collected from new tailings.
(4) Same tailings material as (1) with cement added in the laboratory.
(5) Same tailings material as (2) with cement added in the laboratory.
(6) Same tailings material as (3) with cement added in the laboratory.

Source: Levens, 1993; 1996

Table 3b. Chemical Characteristics of Laboratory Leachates from Tailings Backfill in Underground Gold Mines (concentrations in mg/l)

Constituent	Units	Drinking Water Standards		Health Advisory Levels		(1)	(2)	(3)	(4)
Aluminum	mg/l	0.05-0.2	S	--		--	--	--	--
Antimony	mg/l	0.006	P	0.003	N	--	--	--	<0.00976
Arsenic	mg/l	0.05	P	0.002	C	0.030	0.025	0.06	0.0244
Barium	mg/l	2	P	2	N	0.623	1.15	8.2	0.0415
Beryllium	mg/l	0.004	P	0.0008	C	--	--	--	<0.0021
Cadmium	mg/l	0.005	P	0.005	N	<0.001	0.0012	0.0011	<0.00275
Chromium	mg/l	0.1	P	0.1	N	0.004	0.30	0.25	<0.0033
Cobalt	mg/l	–		–		--	--	--	<0.0025
Copper	mg/l	1.3	P	--		--	--	--	<0.0030
Gold	mg/l	--		--		--	--	--	
Iron	mg/l	0.3	S	--		--	--	--	
Lead	mg/l	0.015	P	--		0.001	0.030	0.007	<0.00505
Mercury	mg/l	0.002	P	0.002	N	0.0009	0.0003	0.0002	<0.00004
Molybdenum	mg/l	–		0.04	N	--	--	--	<0.0043
Nickel	mg/l	0.1	P	0.1	N	--	0.25	0.10	<0.00415
Selenium	mg/l	0.05	P	--		<0.005	0.002	0.002	<0.0108
Silver	mg/l	0.1	S	0.1	N	<0.001	0.0021	0.0022	<0.0030
Thallium	mg/l	0.002	P	0.0005	N	--	--	--	<0.0118
Vanadium	mg/l	--		--		--	--	--	<0.0052
Zinc	mg/l	5	S	2	N	--	0.030	0.33	<0.00525

(1) TCLP extraction analysis of sand backfill from Homestake Mine
(2) EP extraction analysis of backfill tailings from Homestake Mine open cut and fill stope 20 years after backfill
(3) EP extraction analysis of backfill tailings from Homestake Mine stope 2 years after backfill
(4) Underground fill material from Sutter Gold Mine

Source: Scheetz, 1999; Righettini, 1999

Method 1310 Extraction Procedure (EP) leachate from sand backfill but not in TCLP leachate (USEPA Method 1311).

Backfilling of tailings also occurs in association with non-metal mining activities. For example, backfilling of tailings occurs at a soda ash and caustic production facility in Wyoming. Available data on chemical characteristics of the injected tailings slurry indicate that pH and presumably the dissolved solids content exceed secondary MCLs of 6.5 to 8.5 for pH and 500 mg/l for total dissolved solids, as shown below (Tg Soda Ash, 1997).

Parameter	No. of Samples	Minimum	Maximum	Average	Mean
pH	207	9.84	12.49	10.51	10.48
% Solids	207	0.00	29.58	14.66	15.16

4.1.2 Coal Combustion Ash

Coal combustion ash and cement (when needed) are mixed (mass ratio on the order of 9:1) and slurried with water to produce a high-volume, low-strength fluid material that is used to fill mined-out sections of underground mines. Gradual hardening of the slurry after injection will occur without bleeding (Vlasak, 1993). In addition, this material can be used in related mine applications such as construction of packwalls and filling of abandoned entries (Jude, 1995).

Coal combustion ash characteristics depend primarily on the characteristics of the coal burned and the type of combustion technology utilized. For example, fly ash from conventional pulverized coal combustion (PCFA) is a powder-like substance typically collected from flue gas exhaust ducts using electrostatic precipitators or fabric filter units. PCFA derived from burning subbituminous coal and lignite produced in the Western U.S. typically has a calcium oxide content greater than 10 percent (on a weight basis), making it a self-hardening and pozzolanic material when in the presence of water. PCFA derived from bituminous or anthracite coal produced in the Eastern U.S., on the other hand, generally has a much lower calcium oxide content and, thus, requires the addition of either cement or lime and water to achieve hardening properties (Jude, 1995).

Another type of fly ash results from fluidized bed combustion (FBC). This type of fly ash is derived from crushed coal and limestone burned in a “bed” of ash particles suspended upward by blowing air in the combustion chamber. FBC ash is made up of larger particles composed mainly of coal mineral matter, calcium sulfate and unreacted lime that result from the sulfation and calcination of the limestone (Jude, 1995).

Available data on the chemical composition of coal combustion ash slurries injected into mines are limited. Data on coal ash (prior to slurrying and/or mixing with other materials) and leachate data for coal ash are available and are included for reference, although the leachate characteristics of mixtures of ash and cement or other materials may differ. Tables 4a through 4e summarize information from selected studies that provide information on the chemical characteristics of coal combustion ash. As shown, trace metal composition varies over a wide range for each type of material (e.g., bottom ash) and among types of materials. Table 4d further illustrates the variability by type of material and type of coal based on data from a power plant in Kentucky. Table 4e provides a comparison of the metal content of ash from a Pennsylvania facility to soil.

Table 4a. Coal Combustion Ash Characteristics from Selected Studies

Data Source	Analyte	Number of Samples	Number of Non-Detected Values	Concentration (ppm)			
				Mean	Minimum	Maximum	Median
Mechanical Hopper Ash (a)	Arsenic	n/a	n/a	n/a	3.3	160	25.2
	Barium	n/a	n/a	n/a	52	1152	872
	Boron	n/a	n/a	n/a	205	714	258
	Cadmium	n/a	n/a	n/a	0.40	14.3	4.27
	Chromium	n/a	n/a	n/a	83.3	305	172
	Cobalt	n/a	n/a	n/a	6.22	76.9	48.3
	Copper	n/a	n/a	n/a	42.0	326	130
	Fluorine	n/a	n/a	n/a	2.50	83.3	41.8
	Lead	n/a	n/a	n/a	5.2	101	13.0
	Manganese	n/a	n/a	n/a	123	430	191
	Mercury	n/a	n/a	n/a	0.008	3.00	0.073
	Selenium	n/a	n/a	n/a	0.13	11.8	5.52
	Silver	n/a	n/a	n/a	0.08	4.0	0.70
	Strontium	n/a	n/a	n/a	396	2430	931
	Vanadium	n/a	n/a	n/a	100	377	251
	Zinc	n/a	n/a	n/a	56.7	215	155
Fine Fly Ash (b)	Arsenic	n/a	n/a	n/a	2.3	279	56.7
	Barium	n/a	n/a	n/a	110	5400	991
	Boron	n/a	n/a	n/a	10.0	1300	371
	Cadmium	n/a	n/a	n/a	0.10	18.0	1.60
	Chromium	n/a	n/a	n/a	3.6	437	136
	Cobalt	n/a	n/a	n/a	4.90	79.0	35.9
	Copper	n/a	n/a	n/a	33.0	349	116
	Fluorine	n/a	n/a	n/a	0.40	320	29.0
	Lead	n/a	n/a	n/a	3.10	252	66.5
	Manganese	n/a	n/a	n/a	24.5	750	250
	Mercury	n/a	n/a	n/a	0.005	2.50	0.10
	Selenium	n/a	n/a	n/a	0.60	19.0	9.97
	Silver	n/a	n/a	n/a	0.04	8.0	0.501
	Strontium	n/a	n/a	n/a	30.0	3855	775
	Vanadium	n/a	n/a	n/a	11.9	570	248
	Zinc	n/a	n/a	n/a	14.0	2300	210
1993 Data (c)	Antimony	46	35	10.5	0.2	205	4.6
	Arsenic	81	3	76.4	0.0003	391.0	43.4
	Barium	74	3	1589	0.02	10850	806.5
	Beryllium	12	0	201.8	0.200	2105	5.0
	Boron	27	0	469.5	2.98	2050	311
	Cadmium	66	41	6.1	0.0100	76.0	3.4
	Chromium	83	8	129	0.19	651	90
	Copper	78	1	123	0.20	655	112
	Lead	76	2	67.0	0.02	273	56.8
	Mercury	27	7	4.3	0.013	49.5	0.1
	Nickel	71	0	117.5	0.1	1270	77.6
	Selenium	81	16	8.7	0.0003	49.5	7.7
	Silver	62	42	3.7	0.01	49.5	3.2
	Thallium	11	4	19.2	0.15	85.0	9.0
	Vanadium	61	5	397	43.5	5015	252
	Zinc	79	0	286.5	0.28	2200	148

Source: USEPA, 1993b

(a) Mechanical hopper fly ash data from Tetra Tech’s 1983 Study and presented in the 1988 RTC.
(b) Fine fly ash data from Tetra Tech’s 1983 Study and presented in the 1988 RTC.
(c) Statistics calculated assuming that values below the detection are equal to ½ the detection limit.

Table 4b. Coal Combustion Ash Characteristics from Pennsylvania Facilities

		Concentration (ppm)			
Elements	No. of Values	Minimum	Maximum	Mean	Median
Major Elements					
Aluminum	199	12	156000	24661	19160
Calcium	23	3	400000	59114	6200
Iron	200	8	130000	20872	13663
Magnesium	25	.5	3840	1501	1140
Manganese	191	.07	2980	153	70
Sulfate	189	4	10500	770	447
Trace Elements					
Antimony	80	.01	142	35.6	28.5
Arsenic	195	.03	22320	271.24	17.05
Barium	109	.16	2960	303.5	194
Boron	144	.016	3995	160	40
Cadmium	91	.02	30	3.3	1.42
Chromium	201	.05	360	46.4	34
Cobalt	21	4.32	82.6	21.96	15
Copper	194	.04	474	48.09	32.5
Lead	179	.04	225	37.1	27.3
Mercury	134	.0003	5.44	.56	.4
Molybdenum	103	.23	108	20.4	16
Nickel	190	.015	753	44.8	22
Selenium	138	.0022	7540	63	3.4
Silver	73	.015	22	3.7	1.2
Zinc	199	.05	841	61.5	26

Total number of values in solids data set = 242.

Source: Kim, 1997

Table 4c. Summary of Fluidized Bed Combustion Ash Composition (concentrations in ppm)

Material Type	Constituent	Num.of Values	Minimum Value	25th Percentile	50th Percentile	75th Percentile	90th Percentile	95th Percentile	Maximum Value
Bed Ash	Aluminum	34	9.000	3825.00	10682.00	30446.00	56700.00	68800.00	104300.00
	Antimony	58	0.100	2.50	3.50	28.00	62.00	111.40	1775.00
	Arsenic	62	0.250	3.50	9.93	34.70	58.00	82.00	119.70
	Barium	68	0.050	7.00	62.15	172.00	274.00	316.10	453.00
	Beryllium	38	0.500	0.50	1.10	8.00	15.00	17.00	31.00
	Boron	52	0.050	1.50	3.15	22.74	41.38	118.00	304.00
	Cadmium	61	0.003	0.50	0.50	1.50	3.60	6.75	14.00
	Chromium	68	3.700	5.00	16.18	41.85	56.10	74.10	259.80
	Cobalt	47	0.125	1.40	3.90	14.00	37.90	51.40	128.40
	Copper	65	0.500	1.70	8.90	18.50	26.00	42.70	50.00
	Iron	33	6.200	9570.00	13010.00	15640.00	18534.00	21111.10	31500.00
	Lead	67	0.050	1.50	2.50	26.00	56.00	66.00	89.90
	Manganese	33	34.500	62.00	110.00	379.00	610.00	719.40	892.90
	Mercury	54	0.000	0.01	0.10	0.10	0.43	1.10	208.90
	Molybdenum	52	0.050	3.90	13.00	19.60	27.00	48.00	190.00
	Nickel	63	2.000	22.50	66.70	735.00	1000.00	1270.00	1440.00
	Potassium	41	1.300	100.00	150.00	240.00	1340.00	4700.00	11950.00
	Selenium	56	0.001	0.52	2.00	3.50	3.50	13.40	45.00
	Silver	55	0.005	0.50	0.50	1.00	5.00	7.00	338.00
	Thallium	29	0.250	2.50	3.50	5.00	20.00	25.00	50.00
	Vanadium	37	12.000	1150.00	3820.00	5700.00	7550.00	8700.00	10000.00
	Zinc	65	1.000	20.00	26.00	33.10	52.70	147.50	399.00
Fly Ash	Aluminum	42	20.000	23495.60	32835.65	53415.00	88900.00	105920.00	176300.00
	Antimony	66	0.100	2.86	3.50	36.00	63.55	151.70	1370.00
	Arsenic	73	0.100	3.50	17.00	39.22	93.70	115.00	176.00
	Barium	73	0.100	17.00	177.00	320.33	540.00	940.00	7700.00
	Beryllium	39	0.500	0.50	1.20	6.00	11.00	15.00	16.00
	Boron	60	0.050	1.50	6.98	50.00	101.95	606.00	2473.00
	Cadmium	72	0.003	0.50	0.60	2.10	4.00	7.00	13.00
	Chromium	76	0.500	6.05	29.50	56.45	77.60	104.00	211.10
	Cobalt	47	0.125	2.00	5.00	19.00	33.90	75.30	178.50
	Copper	71	0.500	2.00	28.10	47.00	73.35	73.35	99.00
	Iron	46	22.170	18620.00	26530.00	32722.00	50900.00	55962.00	81318.00
	Lead	75	0.500	1.50	17.50	44.80	65.00	73.00	129.50
	Manganese	42	0.100	86.00	126.40	196.70	470.00	661.60	57700.00
	Mercury	73	0.000	0.10	0.31	0.95	1.68	7.35	384.20
	Molybdenum	67	0.050	3.10	9.00	21.10	28.50	48.64	143.60
	Nickel	75	12.500	32.80	51.20	529.00	825.00	900.00	1270.00
	Potassium	44	1.125	150.00	214.50	3132.00	8332.49	11478.80	14680.00
	Selenium	69	0.001	2.05	3.50	5.40	23.00	39.00	166.00
	Silver	64	0.005	0.50	0.50	2.00	3.40	5.00	38.50
	Thallium	34	0.500	2.50	3.50	5.00	20.00	25.00	39.01
	Vanadium	39	36.333	160.00	2880.00	3840.00	4830.00	5430.00	10000.00
	Zinc	73	1.000	28.00	36.00	54.50	79.77	114.40	167.90
Combined Ash	Aluminum	48	1.090	14617.50	24585.00	32950.00	44300.00	64000.00	75850.00
	Antimony	45	0.003	0.50	10.00	26.00	43.87	51.70	142.00
	Arsenic	60	0.140	7.08	13.05	32.49	68.90	106.15	115.50
	Barium	57	0.100	120.00	180.00	253.00	457.70	650.00	690.00
	Beryllium	12	0.295	0.99	1.91	2.51	5.00	9.50	9.50
	Boron	45	0.904	14.40	21.10	31.95	45.00	49.00	1670.00
	Cadmium	50	0.000	0.25	0.69	1.34	3.49	5.00	7.00
	Chromium	58	8.000	19.30	34.50	47.30	53.70	56.00	1906.00
	Cobalt	30	1.200	2.84	4.60	8.00	9.80	12.54	18.70
	Copper	56	1.900	19.10	26.10	37.45	71.00	249.00	408.10
	Iron	48	850.000	8042.50	12765.00	18175.00	26600.00	28074.70	51600.00
	Lead	57	0.714	13.00	23.00	33.80	52.30	67.00	89.00
	Manganese	47	20.000	49.00	61.80	91.00	133.00	170.40	905.00
	Mercury	57	0.000	0.06	0.26	0.61	0.80	2.78	29.00
	Molybdenum	50	0.050	2.50	9.96	16.00	24.00	27.00	41.00
	Nickel	59	0.500	11.35	15.40	23.00	70.60	530.00	985.00
	Potassium	26	2.820	2950.00	4140.00	5400.00	6362.00	6600.00	9163.00
	Selenium	59	0.003	1.25	4.00	9.80	16.00	22.97	27.00
	Silver	48	0.005	0.35	0.75	1.70	2.45	5.00	21.80
	Thallium	8	0.180	1.88	5.19	18.55	25.00	25.00	25.00
	Vanadium	11	19.570	21.50	38.00	838.00	1700.00	5000.00	5000.00
	Zinc	57	6.100	14.40	19.90	26.00	48.10	257.00	90619.00

Source: Council of Industrial Boiler Owners (CIBO), 1997

Table 4d. Comparison of Coal and Ash Content for Selected Metals at a Kentucky Power Plant

	High-sulfur Unit				Low-sulfur Unit				
Element	Feed Coal Mean* (Whole Coal)	Feed Coal Mean* (Ash Basis)	Fly Ash Mean*	Bottom Ash Mean*	Feed Coal Mean* (Whole Coal)	Feed Coal Mean* (Ash Basis)	Fly Ash Mean* (Fine)	Fly Ash Mean* (Coarse)	Bottom Ash Mean*
As	12	120	170	11	3.3	37	91	54	54
Be	1.5	15	19	14	2.4	27	27	22	16
Cd	0.4	3.6	5.5	0.8	0.1	0.8	1	0.8	--
Co	4.6	45	59	49	11	120	150	97	61
Cr	15	150	170	150	19	210	230	190	200
Hg	0.07	0.69	0.39	0.02	0.03	0.31	0.02	0.02	0.24
Mn	25	250	270	330	14	150	230	210	480
Ni	18	170	220	210	17	190	220	160	140
Pb	11	110	150	46	11	120	170	100	380
Sb	0.9	8.7	13	3.5	0.7	7.9	15	8.9	10
Se	2.5	26	8.9	0.59	5.6	52	1.1	0.82	1.7
Th	2	20	22	21	2.9	32	31	30	29
U	1.6	16	19	14	1.4	16	21	15	10

* Notes:

All elements are in parts per million and are presented on the whole coal and as-determined basis for the feed coal, and on as-determined basis for the fly ash and bottom ash.

Leaders (--) indicate statistics could not be calculated owing to an insufficient number of analyses above the lower detection limit.

Source: Affolter, 1997.

Table 4e. Comparison of Ash and Soil Composition for Selected Elements at a Pennsylvania Power Plant

	Comparison of Ash to U.S. Soils			Comparison of Ash to Local Soils		
Constituents	Ash (mg/kg)*	Soil Average (ppmw)*	Soil Range (ppmw)*	Ash (mg/kg)*	Residential Soil (mg/kg)* (North)	Residential Soil (mg/kg)* (South)
Aluminum	24100	66000	700 - >100,000	24100	12,000	15,500
Antimony	25	0.67	<1 - 8.8	25	54	<20.0
Arsenic	24	7.2	<0.1 - 97	24	1.9	2.6
Barium	1142	580	10 - 5,000	1142	32	71
Boron	<10.0	34	<20 - 300	<10.0	<10.0	<10
Cadmium	<0.5	0.06	0.01 - 0.7	<0/5	<0.5	<0.5
Chromium	28	54	1.0 - 2,000	28	11	13
Cobalt	7	10	<3 - 70	7	23	25
Copper	23	25	<1 - 700	23	32	34
Iron	9590	25,000	100 - >100,000	9590	32,000	33,700
Lead	25	19	<5 - 70	25	27	18
Manganese	38	660	<1 - 7,000	38	1,020	400
Mercury	<0.02	0.089	<0.01 - 4.6	<0.02	<0.02	<0.02
Molybdenum	<10		<3 - 7	<10	<10.0	<10
Nickel	14	19	<5 - 700	14	39	47
Potassium	5000	23,000	50 - 70,000	5000	670	460
Selenium	2.4	0.39	<0.1 - 4.3	2.4	<0.5	<0.5
Silver	1			1	<1.0	<1.0
Zinc	13.8	60	<5 - 2,900	13.8	80	110

* Notes:

- Ash analysis from Northampton Generating Plant (July 1996).
- U.S. soil analysis data based on results from a survey performed by the USGS team on native soils across the United States.
- Local soil analysis data from a local survey performed by Hawk Mtn. Labs in early August 1996. Samples were taken near the housing development on the north side of the quarry and along Chestnut Street on the south side.

Source: Ramsey, 1999

Tables 5a, 5b, 5c and 5d provide similar data from laboratory leaching studies using EP, TCLP, and Synthetic Precipitation Leaching Procedure (SPLP) methods (USEPA Methods 1310, 1311, and 1312, respectively). As shown, the leachate concentrations vary depending on the study and leaching method used, but in general antimony, arsenic, beryllium, cadmium, lead, molybdenum, selenium, and thallium typically (at least 50 percent of the time) exceed MCLs or HALs. Leachate concentrations of barium, boron, chromium, copper, iron, mercury, nickel, silver, and zinc also exceed MCLs or HALs in some cases. Because laboratory leaching data are not always predictive of leachate chemistry in the field (Robl, 1999), data from field studies are discussed in Section 5.

Table 5a. Coal Combustion Ash Leachate Characteristics from Selected Studies

				Concentration (mg/l)*				Drinking Water Standard		Health Advisory Level	
Data Source	Analyte	Number of Samples	Number of Non-Detected Values	Mean	Minimum	Maximum	Median	mg/l	Primary or Secondary	mg/l	Cancer or Noncancer
Tetra Tech (a)	Arsenic	n/a	n/a	0.012	<0.004	1.46	n/a	0.05	P	0.002	C
	Barium	n/a	n/a	0.222	0.003	7.6	n/a	2	P	2	N
	Cadmium	n/a	n/a	0.0047	0.0001	1.4	n/a	0.005	P	0.005	N
	Chromium	n/a	n/a	0.036	0.001	0.68	n/a	0.1	P	0.1	N
	Lead	n/a	n/a	0.005	<0.0001	0.25	n/a	0.015	P	--	
	Mercury	n/a	n/a	0.00042	<0.0001	0.007	n/a	0.002	P	0.002	N
	Selenium	n/a	n/a	0.01	<0.0001	0.17	n/a	0.05	P	--	
	Silver	n/a	n/a	0.00064	<0.0001	0.20	n/a	0.10	S	0.1	N
ADL (b)	Arsenic	n/a	n/a	0.08	0.002	0.410	n/a	0.05	P	0.002	C
	Barium	n/a	n/a	0.34	0.1	0.7	n/a	2	P	2	N
	Cadmium	n/a	n/a	0.03	0.002	0.193	n/a	0.005	P	0.005	N
	ChromiumVI	n/a	n/a	0.16	0.008	0.930	n/a	0.1	P	--	
	Lead	n/a	n/a	0.01	0.003	0.036	n/a	0.015	P	--	
	Mercury	n/a	n/a	<0.002	<0.002	---	n/a	0.002	P	0.002	N
	Selenium	n/a	n/a	0.05	0.002	0.340	n/a	0.05	P	--	
	Silver	n/a	n/a	<0.001	<0.001	---	n/a	0.10	S	0.1	N
1993 Data (c)	Antimony	1	1	---	0.0495	0.0495	---	0.006	P	0.003	N
	Arsenic	76	19	0.393	0.001	16.4	0.038	0.05	P	0.002	C
	Barium	76	16	1.22	0.005	22.5	0.28	2	P	2	N
	Beryllium	5	3	0.0187	0.001	0.0495	0.002	0.004	P	0.0008	C
	Boron	8	0	4.01	0.126	17.1	0.955	---		0.6	N
	Cadmium	78	21	0.0342	0.0003	0.548	0.01	0.005	P	0.005	N
	ChromiumVI	78	25	0.249	0.001	8.37	0.0405	0.1	P	--	
	Copper	8	1	0.888	0.0036	6.3	0.17	1.3	P	--	
	Lead	77	39	0.0968	0.008	1.83	0.01	0.015	P	--	
	Mercury	74	67	0.0023	0.00004	0.0495	0.0007	0.002	P	0.002	N
	Nickel	7	1	4.54	0.0495	29.4	0.45	0.1	P	0.1	N
	Selenium	77	18	0.0698	0.0005	0.376	0.027	0.05	P	--	
	Silver	75	59	0.0161	0.0001	0.520	0.005	0.10	S	0.1	N
	Thallium	1	1	---	0.0495	0.0495	---	0.002	P	0.0005	N
	Vanadium	14	3	4.47	0.005	26.9	0.665	---		--	
	Zinc	16	1	10.82	0.009	111.0	0.372	5	S	2	N

* All data were obtained using the Extraction Procedure (EP) Toxicity leaching procedure.

(a) Data from Tetra Tech's 1983 Study and presented in the 1988 RTC. Tetra Tech's results are for coal ash in general.

(b) Data from Arthur D. Little's 1985 Study and presented in the 1988 RTC.

(c) Statistics calculated assuming that values below the detection are equal to ½ the detection limit

---: data not available

Source: USEPA, 1993b

Table 5b. Coal Combustion Ash Leachate Characteristics from Selected Studies

Constituent	Drinking Water Standard (mg/l)	Health Advisory Levels		Kincaid Station TCLP 10/18/94 (mg/l)	Coffen Station TCLP 8/22/97 (mg/l)	Kincaid (50%)/Coffen (50%) Fly Ash Leachate (mg/l)					
		mg/l	Cancer or Noncancer			TCLP 3/31/98	TCLP 4/30/98	TCLP 5/7/98	TCLP 8/20/98	TCLP 11/17/98	Deionized Water 4/30/98
Antimony	0.006 P	0.003	N	--	0.140	0.07	0.0332	0.03	0.06	0.09	--
Arsenic	0.05 P	0.002	C	0.40	0.075	0.049	0.0267	0.20	0.10	0.28	--
Barium	2 P	2	N	2	0.47	0.641	0.376	<1	<1	<1	--
Beryllium	0.004 P	0.0008	C	--	0.015	ND	ND	0.019	<0.0002	<0.0001	--
Boron	--	0.6	N	--	34.2	51.68	92.1	49	35	23	--
Cadmium	0.005 P	0.005	N	0.30	0.163	0.168	ND	0.21	0.0005	0.0052	--
Chloride	250 S	--		--	--	--	--	--	--	--	3.4
Chromium	0.1 P	0.1	N	1.4	0.083	0.166	0.39	0.31	0.023	0.043	--
Cobalt	--	--		--	0.11	ND	ND	0.11	0.007	0.004	--
Copper	1.3 P	--		--	0.43	ND	ND	0.67	0.023	0.028	--
Cyanide, total	0.2 P	0.2	N	--	--	--	--	--	--	--	0.011
Fluoride	4 P	--		--	--	--	--	--	--	--	8.1
Iron	0.3 S	--		--	0.17	ND	ND	10	0.02	0.09	--
Lead	0.015 P	--		0.4	0.04	ND	ND	0.07	<0.01	<0.06	--
Manganese	0.05 S	--		--	0.88	ND	ND	1.9	0.10	0.1	--
Mercury	0.002 P	0.002	N	<0.0002	ND	ND	ND	<0.0002	<0.0002	0.0022	--
Nickel	0.1 P	0.1	N	--	0.97	ND	ND	0.80	0.090	0.094	--
Selenium	0.05 P	--		0.046	0.011	0.451	0.869	0.05	0.29	0.3	--
Silver	0.1 S	0.1	N	<0.05	ND	ND	ND	<0.005	<0.005	0.012	--
Sulfate	500 P	--		--	ND	--	--	--	--	--	1210
Thallium	0.002 P	0.0005	N	--	0.021	ND	ND	<0.4	0.006	0.008	--
Zinc	5 S	2	N	--	3.21	0.045	0.177	3.1	<1	<1	--

Source: Crislip, 1999

Table 5c. Coal Combustion Ash Leachate Characteristics from Pennsylvania Facilities

Elements	Mean/Median Leachate Concentrations (in mg/l, by method)				Drinking Water Standard		Health Advisory Level	
	ASTM(4)*	EPTOX(10)*	SPLP(20)*	TCLP(200)*	mg/l	P/S*	mg/l	C/N*
Antimony	BDL	.15/.15	.13/.06	.28/.11	0.006	P	0.003	N
Arsenic	01/.008	.06/.02	.18/.09	.10/.03	0.05	P	0.002	C
Barium	.40/.20	.20/.24	.29/.22	.40/.30	2	P	2	N
Boron	BDL	1.09/1.02	2.1/.19	1.30/.50	--		0.6	N
Cadmium	.009/.009	.012/.004	.003/.003	.04/.02	0.005	P	0.005	N
Chromium	.22/.22	.11/.02	.05/.06	.14/.08	0.1	P	0.1	N
Cobalt	BDL	BDL	.01/.01	.22/.05	--		--	
Copper	.06/.05	.03/.01	.06/.04	.09/.05	1.3	P	--	
Lead	.02/.02	.02/.02	BDL	.17/.15	0.015	P	--	
Mercury	BDL	.001/.001	.001/.001	.01/.003	0.002	P	0.002	N
Molybdenum	.02/.02	.10/.08	.39/.09	.23/.19	--		0.04	N
Nickel	.06/.04	.17/.15	.09/.08	.15/.12	0.1	P	0.1	N
Selenium	.015/.015	.03/.05	.13/.11	.12/.05	0.05	P	--	
Silver	BDL	.001/.001	.003/.003	.03/.02	0.1	S	0.1	N
Zinc	.18/.18	.35/.29	.04/.03	.65/.14	5	S	2	N

*( ) Indicates number of samples per method; P=primary; S=secondary; C=cancer; N=non-cancer.
BDL=Below Detection Limit

Source: Kim, 1997

Table 5d. Summary of Fluidized Bed Combustion Ash Leachate Test Results* (concentrations in ppm)

Material Type	Constituent	Num.of Values	Minimum Value	25th Percentile	50th Percentile	75th Percentile	90th Percentile	95th Percentile	Maximum Value
Bed Ash	Aluminum	26	0.05000	0.13000	0.3250	1.6000	10.5000	13.140	20.600
	Antimony	26	0.00250	0.05000	0.3350	0.5000	0.7100	0.920	1.250
	Arsenic	69	0.00100	0.01000	0.0500	0.0500	0.1250	0.180	0.300
	Barium	67	0.02500	0.05000	0.2000	0.4520	0.9000	1.000	8.400
	Beryllium	11	0.00008	0.00500	0.0250	0.0500	0.0500	0.280	0.280
	Boron	23	0.00300	0.10000	0.1200	0.5500	2.6000	2.800	3.950
	Cadmium	63	0.00100	0.01600	0.0250	0.0300	0.0500	0.090	0.500
	Chromium	68	0.00500	0.02500	0.0250	0.0550	0.1770	0.220	0.320
	Cobalt	15	0.05000	0.12500	0.1400	0.1750	0.2500	0.310	0.310
	Copper	30	0.01000	0.02000	0.0495	0.0600	0.1340	0.158	0.184
	Iron	29	0.04000	0.09900	0.1900	0.5100	2.7900	3.200	38.800
	Lead	69	0.00500	0.02500	0.0500	0.2500	0.3600	0.418	0.710
	Manganese	28	0.00400	0.03350	0.0545	0.1900	0.7800	7.600	10.900
	Mercury	61	0.00010	0.00030	0.0010	0.0010	0.0014	0.010	0.100
	Molybdenum	23	0.05000	0.12500	0.1600	0.2400	0.6100	0.940	1.200
	Nickel	54	0.00500	0.02500	0.0500	0.1600	0.2360	0.250	2.500
	Potassium	13	0.12500	2.00000	5.6000	8.4000	11.0000	18.600	18.600
	Selenium	64	0.00050	0.00250	0.0500	0.0500	0.1000	0.134	2.500
	Silver	63	0.00150	0.02400	0.0250	0.0430	0.1000	0.125	0.310
	Thallium	7	0.00500	0.04500	0.0500	0.3250	0.5000	0.500	0.500
	Vanadium	32	0.02500	0.10500	0.3300	0.4550	1.6400	3.400	40.000
	Zinc	34	0.00250	0.02000	0.0650	0.1110	0.5100	1.040	4.460
Fly Ash	Aluminum	35	0.04000	0.22000	0.5000	8.4500	23.9000	111.000	120.800
	Antimony	37	0.00250	0.03070	0.1000	0.5000	1.1700	1.290	1.520
	Arsenic	81	0.00050	0.01100	0.0500	0.0500	0.1190	0.250	0.600
	Barium	90	0.02500	0.08000	0.3000	0.6250	1.5500	6.500	42.000
	Beryllium	14	0.00008	0.00330	0.0105	0.0500	0.0500	0.050	0.050
	Boron	33	0.03000	0.10000	0.2800	0.6000	0.9800	1.400	23.317
	Cadmium	76	0.00100	0.02000	0.0250	0.0400	0.0600	0.100	0.500
	Chromium	83	0.00500	0.02500	0.0500	0.1200	0.2000	0.260	0.910
	Cobalt	18	0.00500	0.04500	0.0980	0.1370	0.2500	0.270	0.270
	Copper	39	0.00500	0.02000	0.0580	0.0850	0.1330	0.160	0.183
	Iron	38	0.01000	0.09000	0.1800	0.5000	0.7600	0.900	7.790
	Lead	80	0.00100	0.02500	0.0500	0.2685	0.4450	0.518	0.700
	Manganese	37	0.00250	0.03000	0.0500	0.3300	0.7300	1.100	1.130
	Mercury	76	0.00010	0.00025	0.0010	0.0010	0.0040	0.010	0.290
	Molybdenum	35	0.02320	0.07000	0.2000	0.3200	0.5900	0.610	0.720
	Nickel	65	0.00500	0.02500	0.0500	0.1600	0.2500	0.330	1.200
	Potassium	20	1.21000	4.63000	17.7000	39.3000	54.2500	63.400	66.800
	Selenium	81	0.00050	0.00700	0.0500	0.1000	0.2000	0.266	0.420
	Silver	74	0.00400	0.02000	0.0250	0.0400	0.0520	0.100	0.240
	Thallium	9	0.00500	0.04500	0.0500	0.0500	0.5000	0.500	0.500
	Vanadium	35	0.00750	0.09000	0.1300	0.2040	0.7000	1.640	3.200
	Zinc	42	0.00500	0.02000	0.0568	0.1400	0.3700	1.040	4.460
Combined Ash	Aluminum	44	0.01000	0.53500	1.8650	4.0550	8.8900	10.700	18.670
	Antimony	42	0.00010	0.00500	0.0950	0.2700	0.5000	0.590	1.200
	Arsenic	62	0.00230	0.01000	0.0250	0.0500	0.2500	0.350	0.890
	Barium	60	0.00500	0.05600	0.1700	0.5950	1.1585	3.925	37.000
	Beryllium	6	0.00200	0.00200	0.0095	0.0500	7.8000	7.800	7.800
	Boron	43	0.00500	0.09000	0.1600	0.4600	0.6000	0.650	26.700
	Cadmium	51	0.00250	0.00250	0.0050	0.0130	0.0500	0.050	0.130
	Chromium	60	0.00330	0.02500	0.0500	0.1150	0.2450	0.280	0.600
	Cobalt	24	0.00070	0.00500	0.0180	0.0250	0.0315	0.250	0.400
	Copper	52	0.00250	0.01000	0.0225	0.0855	0.4400	1.860	6.100
	Iron	46	0.00005	0.01500	0.0700	0.1780	0.3100	0.360	2.045
	Lead	54	0.00100	0.02500	0.0500	0.1290	0.2500	0.430	1.540
	Manganese	47	0.00250	0.00500	0.0500	0.3100	0.4700	0.619	0.660
	Mercury	51	0.00010	0.00010	0.0002	0.0010	0.0020	0.100	0.100
	Molybdenum	46	0.02500	0.05000	0.0865	0.2000	0.4100	0.540	1.200
	Nickel	48	0.00500	0.02000	0.0250	0.0920	0.2640	0.420	0.900
	Potassium	23	1.55400	7.50000	14.5000	20.0000	24.0000	27.200	45.300
	Selenium	63	0.00100	0.00800	0.0200	0.0500	0.2400	0.256	0.350
	Silver	51	0.00250	0.00500	0.0050	0.0150	0.0400	0.130	0.250
	Thallium	5	0.00100	0.00100	0.0500	0.4600	0.5000	0.500	0.500
	Vanadium	6	0.00500	0.08599	0.1535	1.0000	2.2000	2.200	2.200
	Zinc	54	0.00250	0.00500	0.0215	0.1340	0.3000	0.480	2.400

* Leachate date obtained primarily using EP and TCLP procedures, with some SPLP and other methods also used.

Source: Council of Industrial Boiler Owners (CIBO), 1997

4.1.3 Flue Gas Desulfurization Sludge

Flue gas desulfurization (FGD) sludge is generated by flue gas scrubber units at electric power plants. The material is primarily composed of anhydrite, sulfite, and small amounts of unreacted calcium oxide and calcium carbonate (Jude, 1995). Exact constituent concentrations, including metals, vary with the type of coal burned and the technologies used. When FGD is injected as backfill in underground mines, it is usually mixed with fly ash and quicklime, slurried, and pumped down surface boreholes into abandoned mine workings (Jude, 1995).

Available data on the chemical composition of FGD slurries that are injected into mines are limited. Table 6 presents chemical characteristics information for FGD sludge. Table 7a provides similar data from EP toxicity testing of FGD sludge. As shown, median concentrations in the EP leachate exceed the MCL or HAL for four constituents -- antimony, arsenic, boron, and thallium. Mean values exceed the relevant MCL or HAL for these constituents plus five others (beryllium, cadmium, lead, mercury, and selenium), while maximum values also exceed the applicable reference level for barium, chromium, nickel, and silver. The extent to which leachate from FGD sludge under field conditions (i.e., injected into an underground mine) will be similar to these laboratory EP leaching test results will vary depending on a variety of factors, such as pH.

Table 7b provides data on leachate from mixtures of FGD sludge and coal combustion ash obtained with a modified version of the TCLP procedure (USEPA Method 1311) that used mine water (also shown in Table 7b) for the leaching solution. As shown, concentrations of arsenic, boron, sulfate, and total dissolved solids measured in leachate were above the levels in the mine water and above MCLs or HALs. In contrast, concentrations of beryllium, iron, and manganese water in the mine water were above the relevant benchmark but were reduced to levels below the relevant benchmark in the leachate.

4.1.4 Coal Cleaning Waste

Coal cleaning waste that results from the wet cleaning of raw coal is comprised of extremely fine solids, including coal particles and coal associated minerals, suspended in water. At some mines, coal cleaning wastes are injected into underground mine workings. The chemical composition of the injected material depends primarily on the characteristics of the coal, the associated rock, and the quality of the water used in the coal cleaning process. At the New Elk Mine in Colorado, for example, the injected slurry is comprised of a slightly alkaline, sodium bicarbonate water and as much as 30 percent coal, shale, and sandstone solids. Data shown in Table 8 indicate that coal cleaning wastes and injected slurry at this facility do not exceed the relevant primary or secondary MCLs or HALs for the constituents tested, with the exception of arsenic and TDS[4] (USEPA, 1995a; Lopez, 1995). Table 8 also indicates, however, that coal cleaning waste slurry and slurry leachate from the Kindall 3 mine in Indiana exceed the

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[4] Available data for the injectate are for dissolved rather than total concentrations, which may be higher and, thus, in some cases could exceed MCLs or HALs. It seems unlikely that the total values would be greater than MCLs in this case, however, because the total values measured for the injectate were less than the relevant health-based benchmarks.

Table 5e. Leachate Characterization Data for Fly Ash Grout Mixtures

	Leachate Concentration [1] (mg/l)												Drinking Water Standard		Health Advisory Level	
	Grout Mixture (% Cement/% Fly Ash/% Sand) Curing Time (Days)															
Constituent	5/45/50 (28)	5/55/40 (28)	5/65/30 (28)	5/75/20 (28)	5/85/10 (28)	7/55/38 (28)	7/65/28 (28)	7/75/18 (28)	7/85/8 (28)	5/95/0 (41)	7/93/0 (41)	9/91/0 (91)	mg/l	P/S*	mg/l	C/N*
Arsenic	0.004	0.009	0.014	0.017	0.019	<0.004	<0.004	<0.004	0.004	0.033	0.016	<0.004	0.05	P	0.002	C
Barium	0.860	0.898	0.731	0.832	0.834	1.040	1.250	1.340	1.090	0.632	0.767	1.140	2	P	2	N
Cadmium	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	0.005	P	0.005	N
Chromium	0.022	0.033	0.033	0.033	0.028	0.019	0.017	0.020	0.022	0.027	0.031	0.019	0.1	P	0.1	N
Lead	<0.001	<0.002	0.004	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	0.015	P	--	
Mercury	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	0.002	P	0.002	N
Selenium	0.017	0.020	0.013	0.020	0.020	0.006	0.008	0.010	0.014	0.051	0.035	0.009	0.05	P	--	

* P = primary; S = secondary; C = cancer; N = non-cancer

[1] Analyzed by the modified TCLP Method using deionized water as the extractant.

Source: Pappas, 1994

Table 6. FGD Sludge Characteristics from 1993 Study

			Concentration (ppm)			
Analyte	Number of Samples	Number of Non-Detected Values	Mean	Minimum	Maximum	Median
Antimony	31	25	15.8	3.65	90.0	6.0
Arsenic	36	5	53.6	0.0075	341.0	32.5
Barium	35	3	352.1	0.08	2280	162.5
Beryllium	14	7	27.7	0.900	49.5	29.3
Boron	18	11	144.8	5.00	633.0	60.0
Cadmium	36	22	19.2	0.005	81.9	3.9
Chromium VI	36	5	90.7	0.17	312.0	73.0
Copper	36	0	62.4	0.04	251.0	46.1
Lead	34	2	121.7	0.01	527.0	25.3
Mercury	15	7	5.2	0.073	39.0	4.8
Nickel	35	1	72.5	3.7	191.0	68.1
Selenium	34	9	12.1	0.0150	162.0	4.5
Silver	29	20	3.5	0.01	10.3	3.3
Thallium	6	6	9.0	9.00	9.0	9.0
Vanadium	33	16	104.9	0.01	302.0	65.0
Zinc	36	1	921.0	0.01	5070	90.9

Statistics calculated assuming that values below the reported detection limit equal ½ the detection limit.

Source: USEPA, 1993b

Table 7a. FGD Sludge Leachate Characteristics from Selected Studies*

				Concentration (mg/l)				Drinking Water Standard		Health Advisory Level	
Data Source	Analyte	Number of Samples	Number of Non-Detected Values	Mean	Minimum	Maximum	Median	mg/l	Primary or Secondary	(mg/l)	Cancer or Noncancer
ADL (a)	Arsenic	n/a	n/a	0.20	0.002	0.065	n/a	0.05	P	0.002	C
	Barium	n/a	n/a	0.18	0.15	0.23	n/a	2	P	2	N
	Cadmium	n/a	n/a	0.01	0.002	0.020	n/a	0.005	P	0.005	N
	ChromiumVI	n/a	n/a	0.02	0.011	0.026	n/a	0.1	P	0.1	N
	Lead	n/a	n/a	0.01	0.005	---	n/a	0.015	P	--	
	Mercury	n/a	n/a	<0.002	<0.002	---	n/a	0.002	P	0.002	N
	Selenium	n/a	n/a	0.020	0.008	0.049	n/a	0.05	P	--	
	Silver	n/a	n/a	<0.001	<0.001	---	n/a	0.10	S	0.1	N
1993 Data (b)	Antimony	10	6	0.129	0.010	0.570	0.030	0.006	P	0.003	N
	Arsenic	25	9	0.11	0.001	1.60	0.030	0.05	P	0.002	C
	Barium	23	5	0.448	0.075	2.80	0.230	2	P	2	N
	Beryllium	10	6	0.0013	0.0005	0.003	0.0005	0.004	P	0.0008	C
	Boron	12	1	9.60	0.050	36.0	5.95	---		0.6	N
	Cadmium	25	17	0.066	0.0003	1.50	0.0025	0.005	P	0.005	N
	ChromiumVI	23	8	0.075	0.0055	0.200	0.050	0.1	P	0.1	N
	Copper	11	1	0.040	0.005	0.120	0.022	1.3	P	--	
	Lead	22	19	0.056	0.0005	0.680	0.009	0.015	P	--	
	Mercury	23	18	0.002	0.00005	0.013	0.0003	0.002	P	0.002	N
	Nickel	11	3	0.043	0.0015	0.220	0.006	0.1	P	0.1	N
	Selenium	25	9	0.051	0.0015	0.230	0.040	0.05	P	--	
	Silver	22	10	0.037	0.0005	0.200	0.0195	0.10	S	0.1	N
	Thallium	10	8	0.070	0.045	0.170	0.045	0.002	P	0.0005	N
	Vanadium	11	0	0.126	0.030	0.270	0.074	---		--	
	Zinc	12	2	0.040	0.0015	0.172	0.007	5	S	2	N

* Leachate data based on Extraction Procedure (EP) testing.
(a) Data from Arthur D. Little's 1985 Study and presented in the 1988 RTC.
(b) Statistics calculated assuming that values below the detection are equal to ½ the detection limit.
---: data not available.

Source: USEPA, 1993b

Table 7b. FGD Sludge and Ash Mixture Leachate Characteristics Data

	Drinking Water Standard		Health Advisory Level			Modified TCLP Leachate (1) (mg/l)	
Constituent	mg/l	Primary or Secondary	mg/l	Cancer or Noncancer	Mine Water (1) (mg/l)	Low Ash Grout *	High Ash Grout **
Acidity	--		--		158	<1	<1
Alkalinity	--		--		<1	77	79
Aluminum	0.05 to 0.2	S	--		2.88	0.89	1.12
Arsenic	0.05	P	0.002	C	<0.004	0.017	0.018
Barium	2	P	2	N	0.021	0.148	0.196
Beryllium	0.004	P	0.0008	N	0.001	0.0003	0.0002
Boron	--		0.6	N	0.16	1.16	1.14
Cadmium	0.005	P	0.005	N	<0.0005	<0.0005	<0.0005
Calcium	--		--		54.1	210	207
Chloride	250	S	--		<1	65	63
Chromium	0.1	P	0.1	N	0.002	0.005	0.005
Cobalt	--		--		0.015	<0.002	<0.002
Copper	1.3	P	--		0.004	0.002	0.003
Cyanide	0.2	P	0.2	N	<0.02	<0.02	<0.02
Iron	0.3	S	--		45.3	<0.01	0.01
Lead	0.015	P	--		0.003	<0.002	<0.002
Lithium	--		--		<0.1	0.4	0.4
Magnesium	--		--		22.3	3.0	1.7
Manganese	0.05	S	--		3.65	<0.01	<0.01
Mercury	0.002	P	0.002	N	<0.0002	<0.0002	<0.0002
Molybdenum	--		0.04	N	<0.003	0.064	0.090
Nickel	0.1	P	0.1	N	0.039	<0.003	<0.003
Nitrate-Nitrite	10	P	--		<0.05	<0.05	<0.05
pH	6.5 to 8.5	S	--		3.67	--	--
Phosphorus	--		--		0.04	<0.01	<0.01
Potassium	--		--		3.1	33.6	34.1
Selenium	0.05	P	--		<0.005	0.008	0.011
Silicon	--		--		24.6	5.75	5.98
Silver	0.1	S	0.1	N	0.002	<0.0002	<0.0002
Sodium	--		--		23.0	35.4	35.8
Sulfate	500	P	--		429	557	541
TDS	500	S	--		626	977	959
Turbidity	5 NTU	P	--		14.0 NTU	–	–
Zinc	5	S	2	N	0.073	0.012	0.015

* TCLP text on low ash group (1.0:1.0 - Fly Ash: FGD sludge ratio by dry weight) using mine water as the leaching solution.

** TCLP test on high ash grout (1.25:1.0 - Fly Ash: FGD sludge ratio by dry weight) using mine water as the leaching solution.

(1) Roberts-Dawson Mine

Source: Whitlatch, 1998

Table 8. Coal Cleaning Waste and Injectate Characteristics

	Drinking Water Standards		Health Advisory Levels		New Elk Mine(1)			Kindall 3 Mine(2)	
					Coal Cleaning Waste (mg/l)		Injectate Slurry (dissolved conc. in mg/l)	Coal Cleaning Waste (total conc. in mg/l)	Injectate Slurry (mg/l)
Constituent	mg/l	P/S*	mg/l	C/N*	Total	Dissolved			
Aluminum	0.05 to 0.2	S	--		--	<0.05	0.04	--	--
Antimony	0.006	P	0.003	N	--	0.002	--	--	--
Arsenic	0.05	P	0.002	C	0.006	0.004	0.001	<5	<0.050
Barium	2	P	2	N	--	0.6	0.02	0.4	0.76
Beryllium	0.004	P	0.0008	C	--	<0.005	--	--	--
Boron	--		0.6	N	--	0.03	0.02	0.14	--
Cadmium	0.005	P	0.005	N	<0.005	<0.005	0.0013	0.01	0.0062
Chloride	250	S	--		8	--	72	11	--
Chromium	0.1	P	0.1	N	<0.01	<0.01	--	<0.03	<0.0050
Copper	1.3	P	--		<0.01	<0.01	0.01	0.02	--
Cyanide, free	0.2	P	0.2	N	<0.1	--	--	--	--
Fluoride	4	P	--		2	--	1.5	0.51	--
Hardness (CaCO$_3$)	--		--		27	--	49	994	--
Iron	0.3	S	--		0.35	0.08	0.03	0.02 **	--
Lead	0.015	P	--		<0.02	<0.02	--	<0.05	0.058
Lithium	--		--		--	0.04	--	--	--
Manganese	0.05	S	--		<0.01	<0.01	--	0.46	--
Magnesium	--		--		3	--	--	--	--
Mercury	0.002	P	0.002	N	<0.0002	<0.0002	--	<0.3	<0.00020
Molybdenum	--		0.04	N	0.02	--	--	<0.7	--
Nickel	0.1	P	0.1	N	<0.02	<0.02	0.01	0.09	--
Nitrate as N	10	P	--		0.02	--	0.38	--	--
Nitrite as N	1	P	--		0.02	--	0.3	--	--
Nitrogen, ammonia	--		--		1.32	--	0.16	--	--
pH	6.5 to 8.5	S	--		8.1	--	8.2	7.83	7.5
Selenium	0.05	P	--		<0.001	0.001	0.007	<5	<0.050
Silver	0.1	S	0.1	N	<0.01	<0.01	--	<0.01	<0.0050
Sodium	--		--		518	--	39	230	--
Sulfate	500	P	--		128	--	130	1175	--
Thallium	0.002	P	0.0005	N	--	<0.002	--	--	--
Thiocyanate	--		--		<0.1	--	--	--	--
Total alkalinity	--		--		--	--	215	210	--
TDS	500	S	--		1280	--	--	--	--
Vanadium	--		--		--	<0.01	--	--	--
Zinc	5	S	2	N	0.02	0.02	--	0.1	--

(1) Source: Lopez, 1995
(2) Source: Endress, 1996
* P=primary; S=secondary; N=non-cancer, C=cancer
** dissolved

primary MCLs for arsenic, cadmium, and lead and the secondary MCLs for TDS, sulfate, and manganese.

4.1.5 Mine Drainage Precipitate Waste

Mine drainage precipitate waste, or sludge, resulting from treatment (generally neutralization) of AMD is composed of ferric oxide, gypsum, hydrated aluminum oxide, variable amounts of sulfates, calcium salts, carbonates, bicarbonates and trace amounts of silica, phosphate, manganese, copper, and zinc compounds (Smith, 1987). Additional metals (e.g., lead, arsenic, selenium) may be present depending on the mineralogy of the coal and associated rocks of the drainage area.

4.2 Well Characteristics

Mine backfill materials are typically injected into underground mines through one or more drilled wells or through a pipeline installed in the mine shaft and appropriate portions of the underground workings. In some situations, injection may be directly into a mineshaft without a pipeline for distributing the injected material within the mine workings.[5] The specific injection method(s) selected by a facility depends primarily on the backfilling objectives and method (see Section 4.3) to be used.

If drilled wells are used, the details of well construction (e.g., diameter, casing, cementing) are determined by site-specific factors such as depth to the mine workings to be backfilled and the geology of the overlying strata, as well as backfilling practices. If the mine workings to be backfilled are mostly horizontal and relatively shallow (e.g., a few hundred feet or less below ground surface), backfilling may be accomplished by injecting backfill material down a well until the well will not accept any additional material, plugging the well, and then drilling and "filling" additional wells located at appropriate locations throughout the mine workings. For example, the underground workings at the abandoned Roberts-Dawson underground coal mine in Ohio were backfilled with 23,000 cubic yards of fly ash and FGD sludge injected through 318 injection points (DOE, 1998a). Similarly, 227 injection points were used to backfill a 23-acre portion of the Omega underground coal mine in West Virginia (DOE, 1998b).

In this type of backfill operation, each injection well is used for a relatively short period of time (e.g., days). Such wells may have a casing run from the surface to the top of the mine workings (see Figure 1). Conductor pipe may also be used depending on the stability of near-surface rock and soil (Crislip, 1998). Alternatively, material may be injected down the drill pipe and a casing does not need to be installed.

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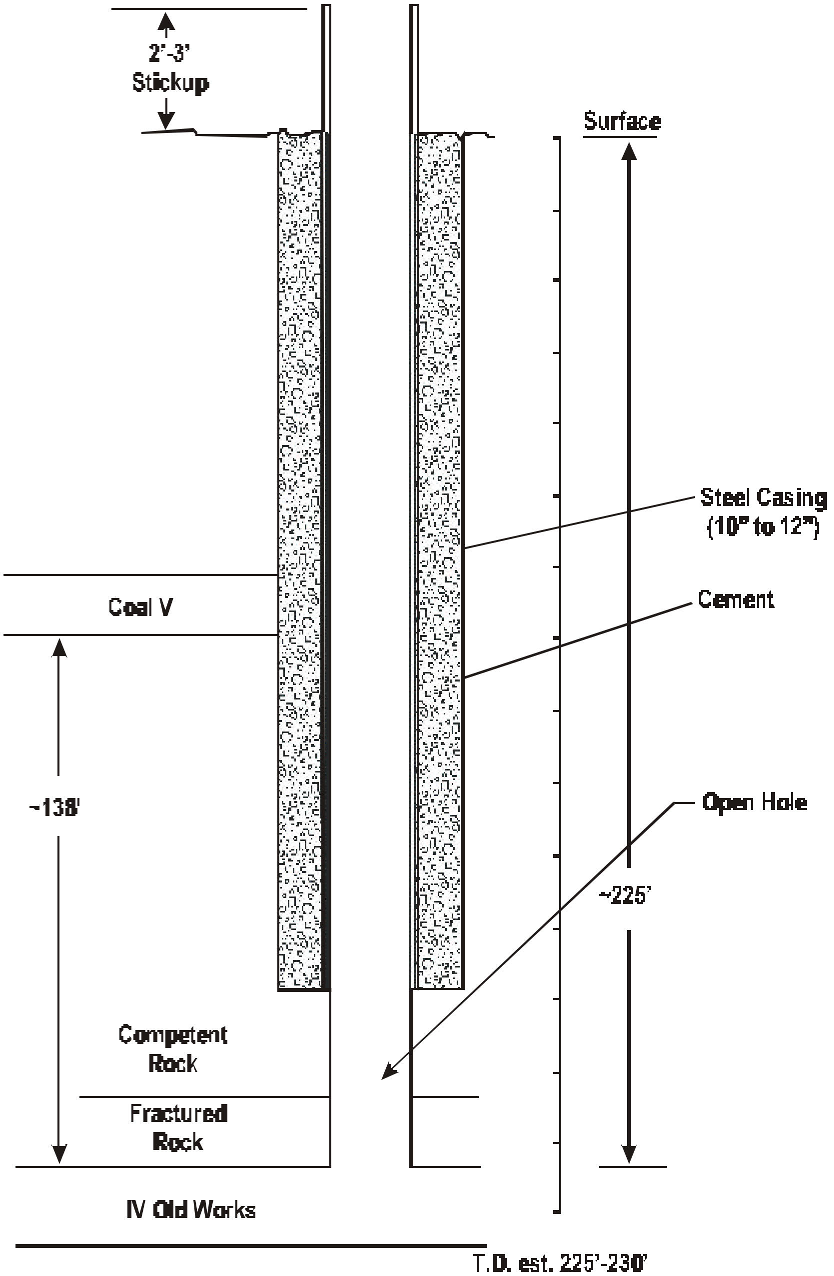
[5] This approach might be used when the goal is to fill the mineshaft to prevent access rather than to fill substantial portions of the mine workings.

Figure 1. Example of Shallow Mine Backfill Injection Well Construction



Source: Endress, 1996

When the mine workings to be backfilled are deeper, fewer injection points may be needed but more piping and related distribution equipment in the mine workings may be required. When deeper wells are used, well construction may more typically involve the use of multiple casings, as illustrated in Figure 2. When pipelines are used, as illustrated in Figure 3, they are used to convey the backfill to the desired location in the mine. Distribution of backfill material by piping within a mine is common when active mines are backfilled, especially mines that use mining methods dependent on on-going backfilling of mined-out stopes.

4.3 Operational Practices

The operational practices for mine backfill wells vary depending on how the backfill material is placed in the mine and the relationship between mining and backfilling activities. In general, operational practices do not appear to make mine backfill wells particularly vulnerable to accidental contamination of the injectate or to misuse, although monitoring of the injectate and ground water help minimize the potential for misuse. In addition, backfill injection often occurs into zones already affected by prior activities (e.g., AMD formation following mining), sometimes with the primary objective of reducing existing contamination problems.

4.3.1 Placement Methods

Injection of backfill into underground mines may be accomplished using hand, gravity, mechanical, pneumatic, and hydraulic placement methods. The most popular methods are pneumatic and hydraulic (Underground Injection Council Research Foundation, 1988). Hand and mechanical methods, such as belt or sling packing machines, are restricted to construction of selected supports from within a mine.

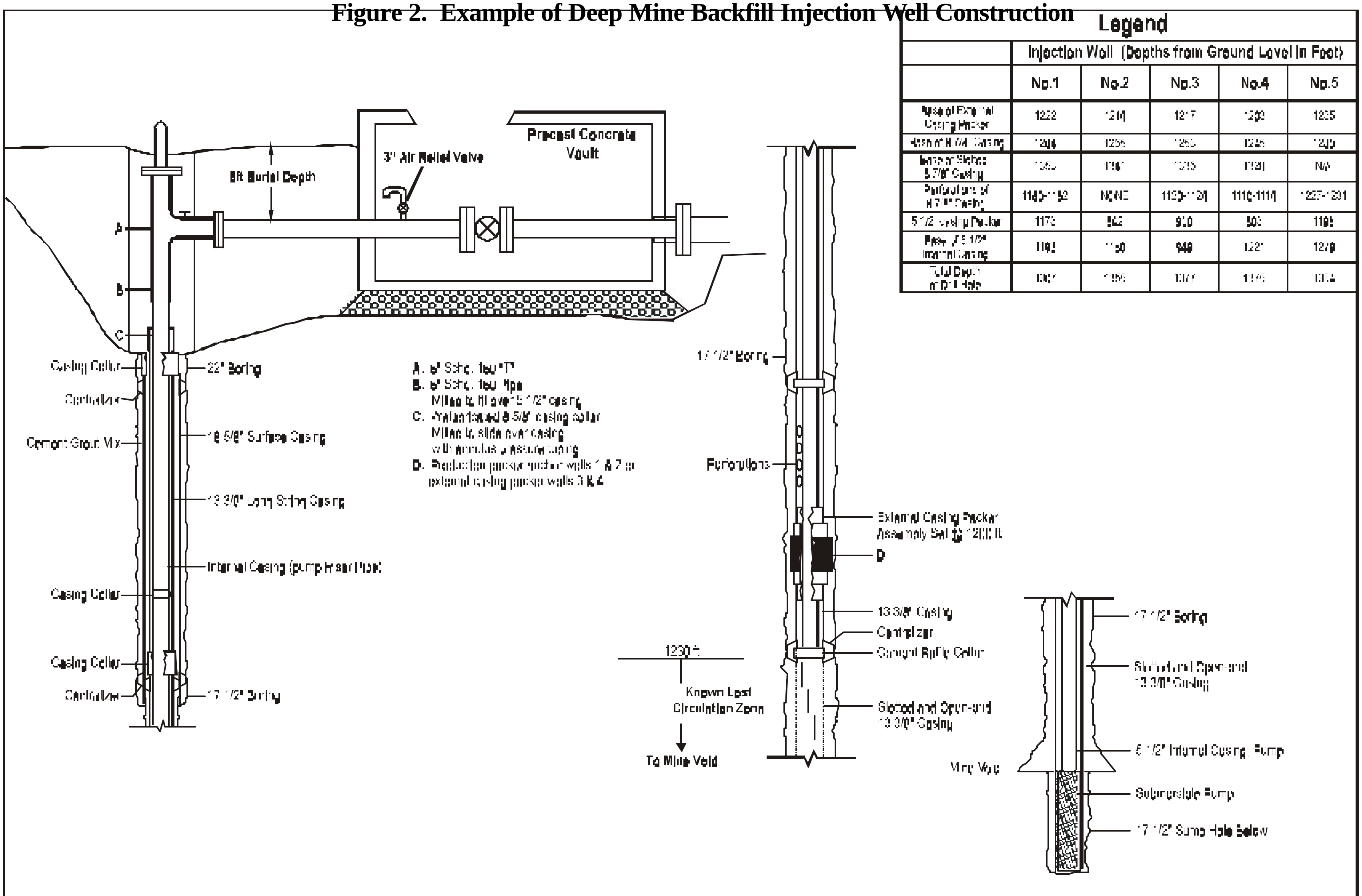
Pneumatic Backfilling

In pneumatic backfilling operations, backfill material is transported into a mine through a well or pipeline in a stream of continually flowing air, either in a vacuum or under pressure (see Figure 4). When a “dense phase” approach is used, the pipeline is nearly filled with material that is moved as a fluid with low velocity air pressure in slugs. When the more common “dilute phase” approach is used, an air/backfill mixture typically consisting of less than 5 percent fill material is moved through a pipeline at relatively high velocity as a fluid. Both approaches tend to be used where water is scarce, the mine is dry, or where water would interfere with mining or the backfill process (Walker, 1993; Sand, 1990).

Hydraulic backfilling

Hydraulic backfilling, which is more common than pneumatic backfilling, is the practice of filling mine voids with backfill material by washing or pumping the backfill material as a slurry through a well or pipeline into the mine (see Figure 5). Hydraulic backfilling is normally accomplished by one of three methods: controlled flushing, blind flushing, and pumped slurry injection.

Figure 2. Example of Deep Mine Backfill Injection Well Construction

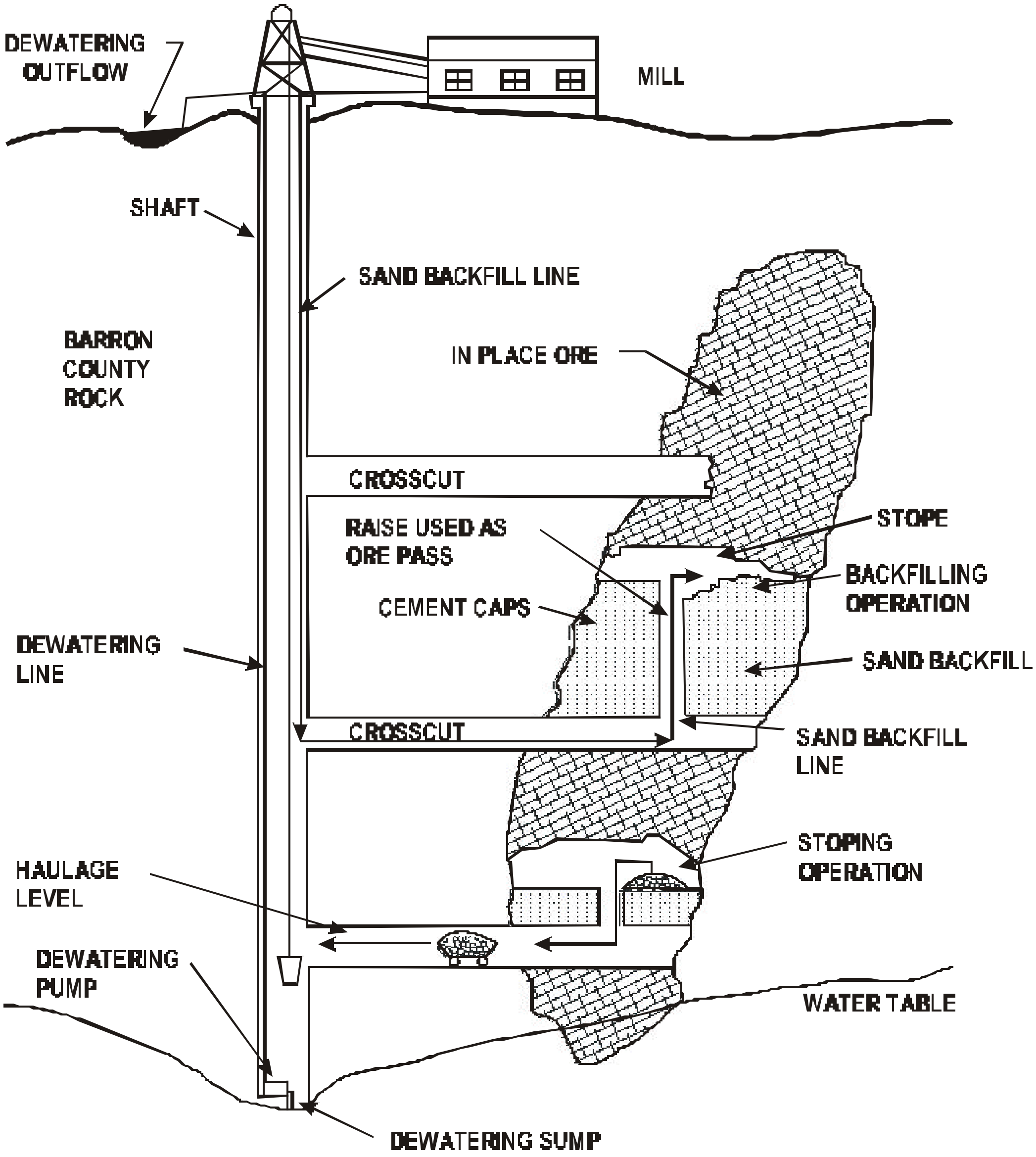


Legend

	Injection Well (Depths from Ground Level in Feet)				
	No.1	No.2	No.3	No.4	No.5
Base of External Casing Packer	1222	1210	1217	1203	1235
Base of 13 3/8" Casing	1246	1256	1255	1245	1240
Bottom of Slotted 9 7/8" Casing	1065	1161	1015	1120	N/A
Perforations of 13 3/8" Casing	1140-1152	NONE	1120-1121	1110-1114	1227-1231
5 1/2 Casing Packer	1173	942	910	503	1195
Base of 5 1/2" Internal Casing	1191	1150	949	1221	1270
Total Depth of Drill Hole	1307	1356	1377	1175	1314

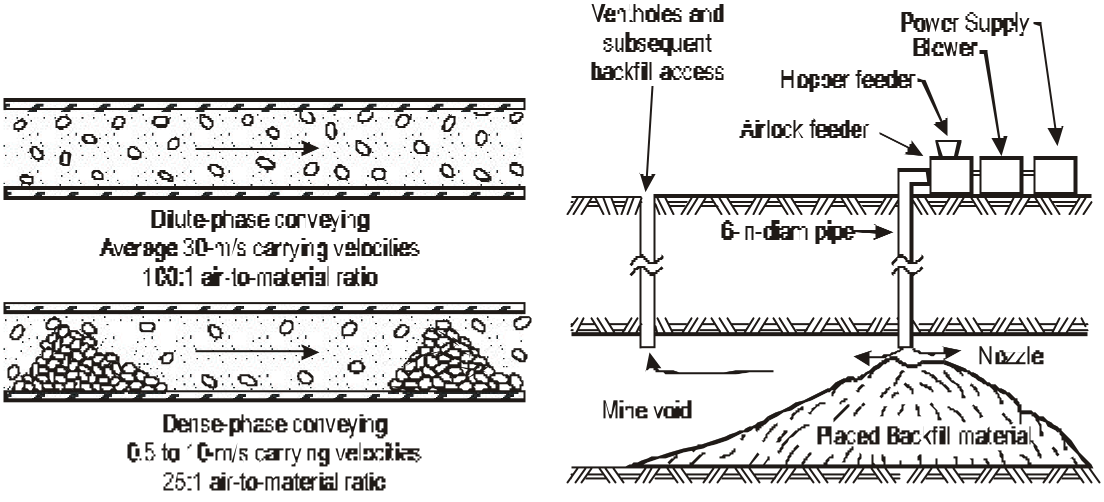
Source: Tg Soda Ash, 1997

Figure 3. Example of Sandfill Injection Using a Mine Shaft Pipeline



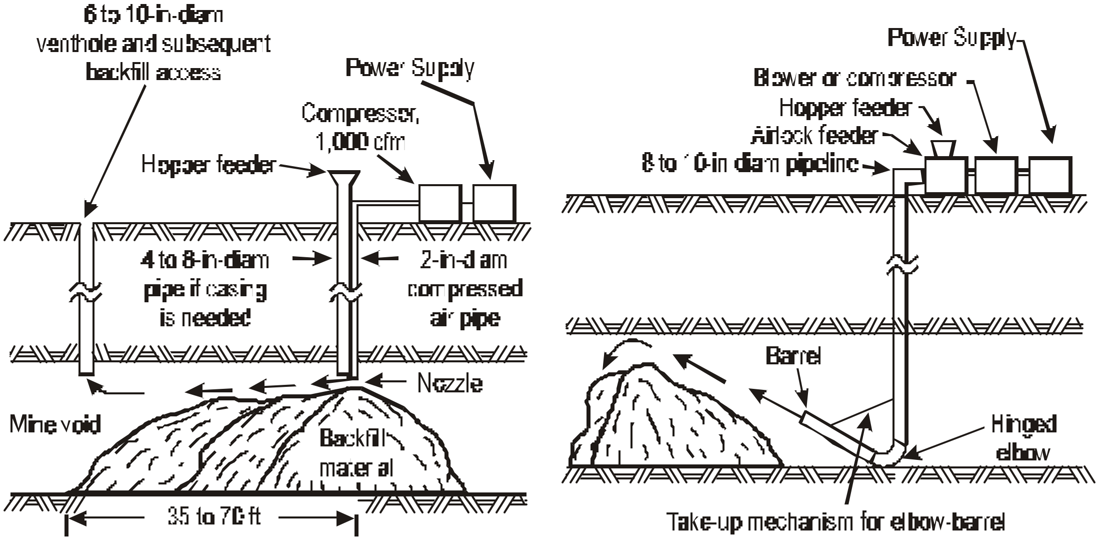
Source: Rouse, 1979

Figure 4. Pneumatic Backfilling Schematics



Dilute - and dense-phase pneumatic transport.

Nondirected system for pneumatic blind backfilling.

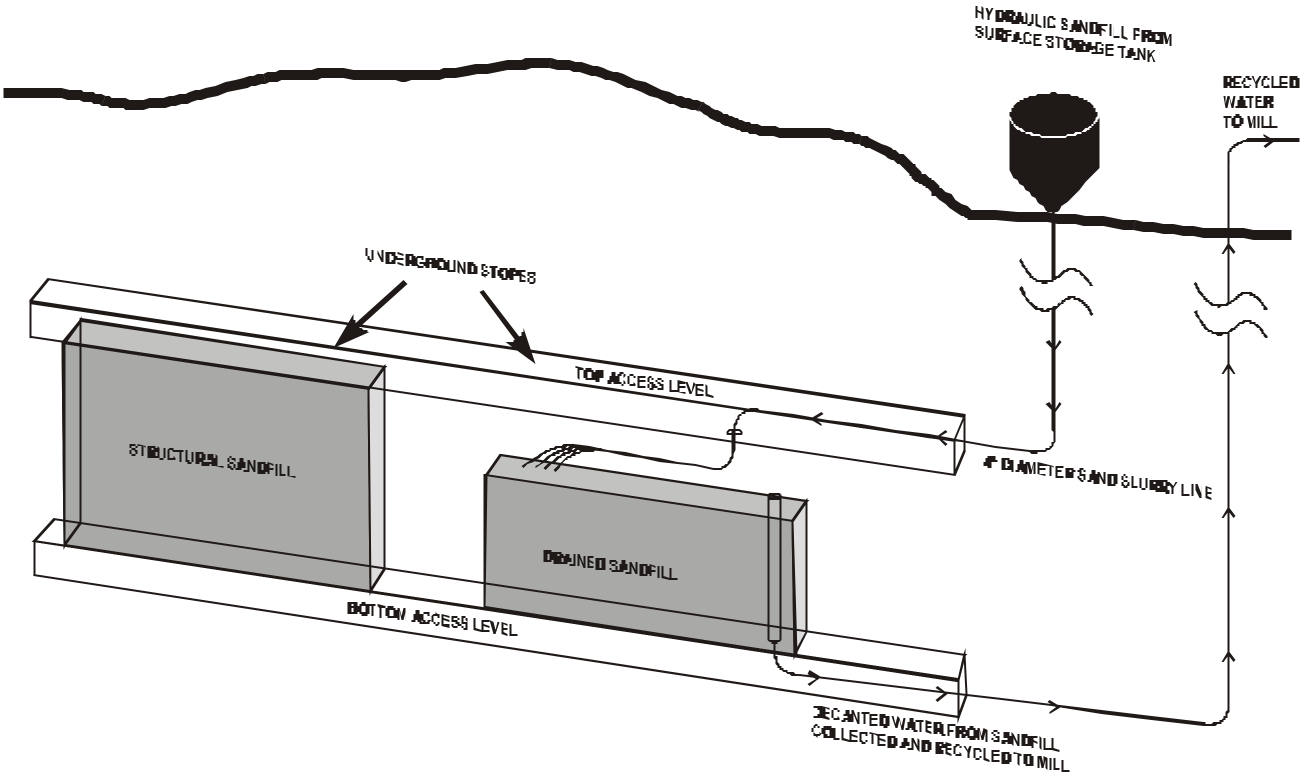


Ejector-nozzel system for pneumatic blind backfilling.

Airlock feeder system for pneumatic blind backfilling.

Source: Sands, 1990

Figure 5. Example Schematic of Stope Backfilling Using Hydraulic Sandfilling



Source: Sutter Gold Mining, 1998

Controlled flushing is used in mines where workers can safely enter and gain access to key areas during the filling operations. When this approach is used, bulkheads may be built in mine passages around the perimeter of the area to be filled. One or more wells are constructed and cased from the surface to the upper portion of the mine workings to be filled. At the base of the vertical portion of the well, additional piping may be used to aid in distributing the slurry into the mine workings. Horizontal dispersal from the point of discharge ranges from 300 to 1,000 or more feet, depending on the vertical distance from the ground surface to the mine opening and the solids concentration of the slurry. Because controlled flushing provides relatively uniform distribution of backfill material, it generally provides better structural support than the other methods and so is preferred where conditions permit (Whaite, 1975).

Blind flushing is used when the mine workings are inaccessible to workers. With this approach, a slurry of backfill material is gravity fed through a well (either a drilled well or a mine shaft) into the mine until the well will not accept any additional backfill material. The quantity that can be injected down a single well depends on the conditions underground, such as the slope, height, and the proximity of pillars in the mine workings. Usually, hundreds of injection points are required (Whaite, 1975).

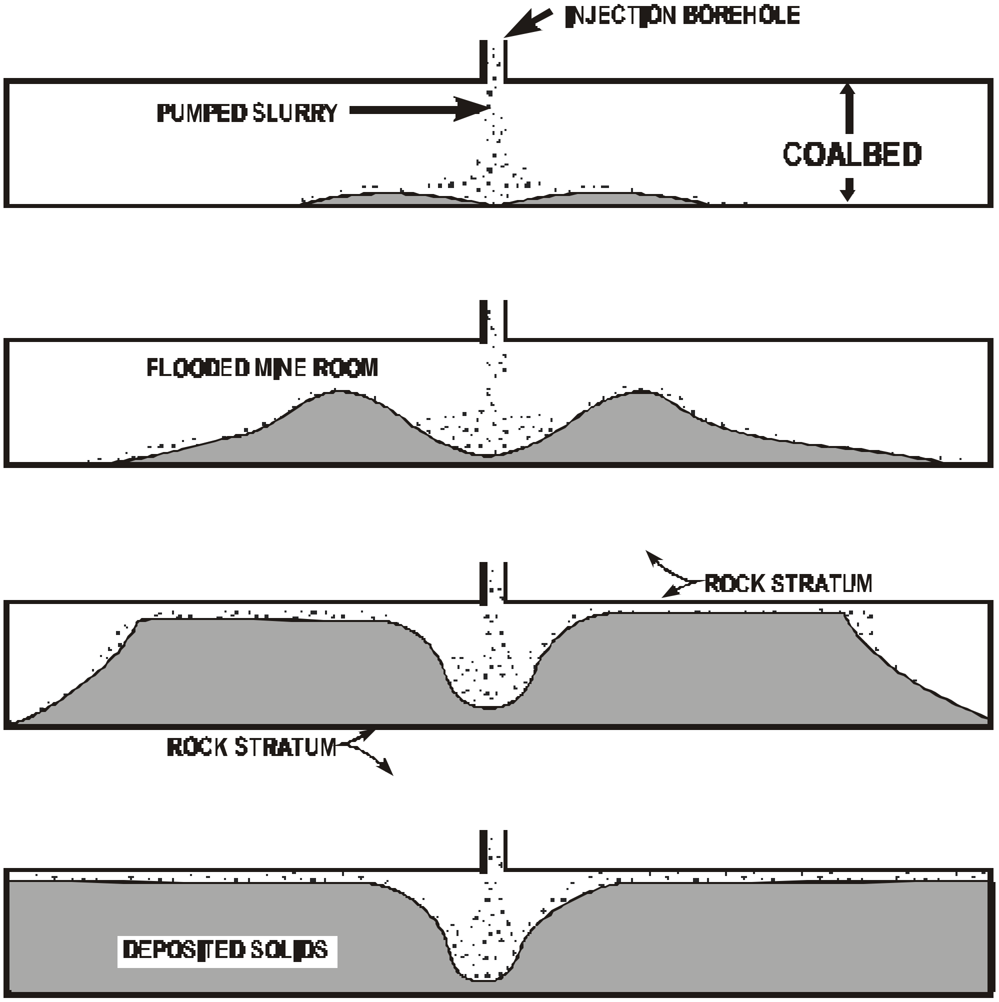
Pumped slurry injection is similar to blind flushing except that the slurry is pumped down a well rather than injected by gravity. With this approach, increased distribution of the fill material within the mine can be achieved due to the increased velocity at which the slurry is injected. As shown in Figure 6, solid particles settle out near the borehole when the slurry is first delivered and the velocity of the injected slurry drops as it enters the mine workings. As more material is injected, the fluid velocity increases in the mine workings and the solid materials are transported farther from the borehole (Whaite, 1975).

4.3.2 Integrated Mining and Backfilling

At some mines, backfill activities are closely integrated with mining activities. For example, in the case of base metal and uranium mining, a common operational practice is to develop a mine using a cut-and-fill method, illustrated in Figure 3. This method involves the following steps:

- a cross cut is driven from the main access shaft to the ore vein;
- a raise, later to be used as an ore pass for delivering the broken ore to the haulage level, is driven upwards to intersect the vein;
- the raise is used as a platform to excavate a “slice” of ore to create a stope or excavated room above the level of the raise;
- after each horizontal “slice” is cleaned of ore, the orepass is extended upward; and

Figure 6: Schematic Depiction of Pumped Slurry Backfill Injection



Source: Whaite, 1975

- the void is slurry backfilled and capped with cement which provides a floor from which the next "slice" of ore, and process is repeated (Underground Injection Practices Council Research Foundation, 1988).

Alternatively, an "underhand" cut-and-fill method involving a "top down" rather than "bottom up" sequence of cut and fill, such that the ceiling rather than the floor of the stope is comprised of cemented backfill, is used. An example is the Bulldog Mountain Mine in the Creede Mining District of Colorado. In both "bottom up" and "underhand" operations, backfill material is normally delivered through a pipeline down the mine shaft to the stope being filled.

4.3.3 Retroactive Backfilling

When backfilling is performed after mining is complete or largely complete, blind gravity or pumped slurry injection are common approaches. As discussed above in Section 4.2, such applications may involved hundreds of injection wells, each of which may be operated for only a few days, in an effort to get thorough distribution of the fill material within the mine workings.

4.3.4 Well Maintenance and Closure

As mentioned, most backfill wells are used for short periods of time (e.g., days or weeks) and, thus, little maintenance is required. When a backfill injection well is used on an on-going basis, periodic integrity testing may be performed, as discussed in more detail in Section 6. When injection is through a pipeline down a mine shaft, as would be typical at a site where backfilling is an integral part of mining activity, maintenance would normally be a part of mine operations and would include inspection and repair or replacement of piping as needed.

Available information provides few descriptions of well closure and abandonment practices. Where wells are used to backfill slurries that are similar in may respects to grouts (i.e., self-cementing), it appears that the injection borehole is simply grouted to the surface. In some cases, cementing of the borehole may occur either near the surface or from the injection zone to the surface.

5. POTENTIAL AND DOCUMENTED DAMAGE TO USDWs

5.1 Injectate Constituent Properties

The primary constituent properties of concern when assessing the potential for Class V mining, sand, or other backfill 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 UIC Study provides information on the health effects associated with contaminants found above MCLs or HALs in the injectate of mining, sand, or other backfill wells and other Class V wells. Based on the information presented in Section 4, the following constituents that were found to routinely or frequently exceed health-based standards in TCLP or other leachate from one or more types of backfill material: antimony, arsenic, barium, beryllium, boron, cadmium, chromium, lead, mercury, molybdenum, nickel, selenium, thallium, and zinc. Aluminum, copper, iron, manganese, TDS, sulfate, and pH have been measured above secondary MCLs in TCLP or other leachate and are also discussed, although these standards are designed to minimize aesthetic (taste) effects not adverse health effects (health-based standards do not exist for these parameters).

Persistence is the ability of a chemical to remain unchanged in composition, chemical state, and physical state over time. Appendix E to the Class V UIC Study presents published half-lives of common constituents in fluids released in mining, sand, or other backfill 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 mining, sand, or other backfill wells and other Class V wells.

The persistence of constituents that leach from mine backfill following injection will depend on complex solution-mineral equilibria that will be determined by site-specific conditions such as leachate and ground water characteristics, host rock characteristics, and oxygen availability in the mine workings and the surrounding formation. Because the point of injection for most backfill wells is typically within a permeable unit, or into a zone where prior mining activity has created a preferential (as compared to adjacent undisturbed formations) flow pathway, physical conditions are relative conducive to mobility. It should be noted, however, that in some situations backfilling occurs under dry conditions, while in others the primary objective of backfilling is to reduce the mobility of metals and other constituents in mine water by altering the physical and chemical conditions in the mine.

For injected backfill, mobility of metals in the mine environment is primarily dependent on their tendency to dissolve rather than remain in a solid form, which generally increases as pH decreases for most metals. For iron, for example, the solubility decreases abruptly when pH increases above 6.5 due to the oxidation of ferrous iron (Fe^{+2}) to the much less soluble ferric iron (Fe^{+3}), which readily precipitates as iron oxide or iron hydroxide. This oxidation to ferric iron can also occur, with the resulting marked decrease in solubility, under acidic conditions created by oxidation and hydrolysis reactions that occur when mine water from a strongly reducing environment is exposed to an oxygen supply. In either case, the resulting decrease in dissolved iron concentrations also reduces the concentrations of many other metals, notably arsenic and selenium, that co-precipitate with iron and/or adsorb onto the iron oxides and hydroxides. Mine water is frequently acidic due to the oxidation of sulfide minerals, with the result that the mobility of most metals is generally relatively high absent measures that limit oxygen availability, such as backfill injection (Levens, 1996; EPRI, 1998; Freeze and Cherry, 1979; Robl, 1999).

Unlike most metals, the solubility of chromium in the +6 form is not especially dependent on pH. Chromium in the +3 form is much more common in coal mines, however, and shows decreasing solubility with increasing pH.

Some other constituents present in injected backfill and backfill leachate, such as boron and sulfate, do not have solubilities controlled by pH. Most sulfate is likely to remain in solution although some precipitation of sulfate may occur when enough calcium or magnesium is present. In addition, adsorption may occur at very low pH values. Similarly, boron is also likely to be present in backfill leachate (EPRI, 1998).

As discussed in more detail below in Section 5.2, injection of backfill material often occurs at sites where low pH water is present or in contact with the backfill injection zone. At these sites, mobility of most metals present in the backfill will be greater than if injection occurred under neutral or alkaline pH conditions. Nevertheless, backfill injection under these conditions can result in a decrease in total (injectate plus in-situ sources) metal mobility in the mine for several reasons. First, some backfills can reduce water flow rates through the mine. Second, backfill can reduce the oxidation of sulfides by reducing or eliminating direct contact with air through sealing or flooding of the mine voids.[6] Third, some backfill materials that are alkaline in nature, such as coal ash and FGD sludge, can at least temporarily increase the pH of acidic mine water present in the injection zone (Levens, 1996; Whitlatch, 1998; Kim, 1998).

5.2 Observed Impacts

None of the 23 states included in Table 1 indicated documented cases in which mine backfill wells have caused contamination of a USDW.[7] Studies have been conducted, however, by government, industry, and universities that examine the effects of backfill injection on ground water quality, in part because coal beds in some areas supply water to domestic wells (University of Kentucky, 1998).

This section summarizes studies of the effects of backfill injection on ground water quality. It is organized in two parts. The first part discusses backfill in metal mines and the second discusses backfill in coal mines.[8]

5.2.1 Metal Mines

The potential or observed impacts of underground mine backfilling on ground water quality have been evaluated in several studies of metal mines. For the Lincoln Mine Project, a gold mine in California, the leachability of backfill material was measured and evaluated in the context of the conditions that occur naturally at the mine. Ground water at the site is limited, occurring in the weathered bedrock (generally not deeper than 20 to 30 feet) and limited bedrock fractures.[9] Because the gold deposit contains arsenopyrite (FeAsS) (0.2 to 0.65 percent by weight of the ore), the focus of ground water quality investigations has been on arsenic. Analysis of samples from bedrock ground water monitoring wells over a four year period shows naturally occurring arsenic concentrations that range from 0.0014 to 0.185 mg/l, with well-specific averages ranging from 0.008 to 0.063 mg/l for the six wells examined (Sutter Gold Mining Company, 1998). Maximum concentrations in three wells and the average concentration in one well exceed the MCL

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[6] Because the diffusion of oxygen in water is about four orders of magnitude less than in air, flooding of a mine to eliminate direct air contact with pyrite or other sulfide minerals greatly reduces acid generation and, thus, metal solubility and mobility (Sutter Gold Mining Company, 1998).

[7] Where ground water contamination has been identified at mining sites, it has not been clearly attributable to backfilling.

[8] It should be noted, however, that backfill of tailings occurs in other contexts as well. For example, at Solvay Soda Ash Joint Venture in Green River, Wyoming, tailings are injected along with processing plant wastewater and fly ash from coal fired boilers. The injected tailings consist of shale breaks from within the ore itself, calcium carbonate from the caustic soda plant, and low grade oil shale (Wyoming, 1996). The available data do not include specific studies related to ground water impacts from this or other similarly “unique” situations and, thus, they are not discussed in this section.

[9] Total water production from 4,450 feet of mine workings ranges from 5 gallons per minute (gpm) in summer to 20 gpm in winter, with most of this water entering the mine from the surface through ventilation boreholes.

of 0.05 mg/l. The minimum concentration in five of the six wells exceeds the HAL of 0.002 mg/l. In addition, assessment of the acid formation potential of the backfill material indicates that it was quite low, with an acid neutralization/acid generation potential ratio of 98:1, due to the presence of carbonate minerals that yield a mine water pH of 8.3+. Deionized water leaching of the backfill (sandfill) material showed an arsenic concentration of 0.13 mg/l compared to a reported average concentration of 0.2 mg/l for ground water in the ore zone (Sutter Gold Mining Company, 1998). Thus, it appears that the potential for release of arsenic from backfill material to degrade ground water is low. In addition, suitability of ground water for use as drinking water is low due to limited availability and naturally occurring arsenic.

The U.S. Bureau of Mines (USBM) also examined the impact of mine backfill material on ground water quality. At a moderately deep underground lead-zinc mine located in the Coeur d'Alene Mining District of northern Idaho, samples of ground water both before and after contact with a sandfilled stope showed an increase in electrical conductance. Increased concentrations of Ca, Mg, SO_4^{-2}, and HCO_3^- account for most of the increase. Sulfate levels increased from levels slightly below the MCL of 500 mg/l to levels that ranged from 797 to 1,171 mg/l. Changes in other metal concentrations were generally mixed, with relatively small increases observed for some sampling events and decreases observed for others. Zinc was an exception, showing consistently higher levels after contact with the sandfill (at levels consistently less than the non-cancer lifetime HAL of 2 mg/l). Lead and arsenic levels were present at levels above the MCL before and after contact with the sandfill. For all of the metals, the levels observed both before and after contact with backfill material were well below the maximum leachability values measured in the laboratory, as shown above in Tables 2 and 3 (Levens, 1993).

In a related investigation, USBM also examines the effect of cemented sandfill on ground water by analyzing samples collected both before and after contact with the backfill. In this investigation, samples from exploratory boreholes represent water quality within the native rock, whereas samples from a sump and seeps that contact the backfill within the mine represent water quality affected by backfilling. Comparison with the uncemented backfill examined above showed a much greater acid neutralization capacity. This is consistent with the higher pH values observed after contact with the cemented backfill (6.5 to 9.3) as compared to the pH measured in the native rock boreholes (6.29 to 7.98).

Concentrations of Ca, K, Mg, and SO_4^{-2} are also higher after backfill contact, with SO_4^{-2} concentrations increasing to levels that in most cases exceeded the primary MCL. Concentrations of zinc and lead also increased. Zinc levels remained well below the non-cancer lifetime HAL of 2 mg/l. Lead levels, in contrast, were typically several times the MCL action level of 0.015 mg/l before contact with the backfill. After backfill contact, levels were sometimes increased and sometimes decreased, but generally were above the MCL. Secondary MCLs were also exceeded both before and after contact with backfill for Iron and Mn. Iron concentrations were generally lower after backfill contact while Mn concentrations showed both increases and decreases following backfill contact (Levens, 1996).

Notable increases in the concentrations of Ca, K, and SO_4^{-2} were also observed in the laboratory for three cemented backfill samples after washing with deionized water (see Table 3). Further laboratory exposure (for 227 days) to a sulfuric acid wash showed additional increases in Ca, SO_4^{-2}, and metal concentrations. Concentrations of most constituents measured in the laboratory were notably higher than those measured in the field following contact with backfill. Notable exceptions are Ba, K, and Na, which showed lower concentrations in the laboratory than were observed in the field. Cadmium, lead, and SO_4^{-2} concentrations exceeded primary MCLs while concentrations of iron, manganese, silver, and zinc exceeded secondary MCLs in the laboratory leaching tests (Levens, 1996).

Observed differences in leachate concentrations appear to be due to differences in the particle-size distribution of the backfill (tailings) material, with generally lower concentrations for backfill containing a wide size distribution. In addition, the presence of sulfide minerals and Ca and Mg carbonates in the backfill appeared to be important in determining the acid neutralizing capacity of the cemented material and, thus, the release of some metals. The data also indicate that backfill cementing may help reduce metal release and that ground water, to which releases occur, may contain metals at concentrations above MCLs (Levens, 1996).

At the Homestake mine in South Dakota, samples were collected from drainage from the sand backfill that was placed in stopes. Results indicate that the pH fluctuates around 8.0. As shown in Table 9, concentrations of arsenic, iron, and nickel in exceed MCLs or HALs in some samples of drainage from a backfilled stope. Arsenic and iron concentrations also exceed MCLs in mine water collected at a variety of locations in the mine (Scheetz, 1999).

Backfill injection has also been widely used in uranium mines. Field sampling of tailings and backfill, and studies of water discharging from where backfill was used suggest that short- and long-term effects on ground water quality are negligible both during and following completion of mining (Levens, 1996).

5.2.2 Coal Mines

A study conducted in 1987 assessed the injection of coal slurry wastes from coal preparation and sludge from treatment of AMD into underground coal mines in West Virginia. The study examined water quality using samples from 9 mines that had received injection of slurry or AMD treatment sludge. Slurry injection (at 6 mines) was found to improve the already degraded water quality by increasing alkalinity and pH[10], and decreasing concentration of iron and manganese. Sulfate concentrations also increased, however. Only minor changes in trace

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[10] Mine water pH at the mines examined was 7 or greater, so the results indicated by these sites may not apply to mines with acidic water (Smith, 1987).

Table 9. Backfill Drainage At Homestake Mine, South Dakota

Constituent	Units	Drinking Water Standards		Health Advisory Levels		(1)	(2)				(3)	(4)		
							a	b	c	d		a	b	c
Aluminum	mg/l	0.05-0.2	S	--		--	0.229	0.346	0.649	0.309	--	--	--	--
Arsenic	mg/l	0.05	P	0.002	C	0.063	0.032	0.019	0.028	0.056	<0.005	0.001	0.001	0.003
Cadmium	mg/l	0.005	P	0.005	N	<0.001	--	--	--	--	<0.001	0.001	0.001	0.001
Chromium	mg/l	0.1	P	0.1	N	<0.001	--	--	--	--	--	<0.001	NF	<0.001
Copper	mg/l	1.3	P	--		0.006	0.037	0.015	0.018	0.020	<0.005	0.01	0.092	0.035
Gold	mg/l	--		--		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	0.002
Iron	mg/l	0.3	S	--		0.59	--	--	--	--	0.348	0.06	0.08	0.43
Lead	mg/l	0.015	P	--		<0.001	--	--	--	--	<0.001	0.005	NF	0.01
Mercury	mg/l	0.002	P	0.002	N	--	--	--	--	--	<0.0002	0.0	0.0	0.0
Nickel	mg/l	0.1	P	0.1	N	0.148	0.010	0.005	0.005	0.005	0.008	NF	NF	NF
Selenium	mg/l	0.05	P	--		--	<0.005	<0.005	<0.005	<0.005	<0.005	--	--	--
Zinc	mg/l	5	S	2	N	0.016	0.054	0.056	0.061	0.055	<0.050	NF	NF	0.016
CN Total	mg/l	--		--		13.71	--	--	--	--	--	--	--	--
CN WAD	mg/l	--		--		0.40	--	--	--	--	--	--	--	--

NF = not found (not detected)
(1) Water issuing from sand backfill on the 7,100 foot level of the mine
(2) Water from selected underground sumps (labeled a-d) in the mine
(3) A combination of surface water and ground water from the upper underground levels of the mine
(4) Three samples (labeled a-c) of mine water (stope drainage) prior to treatment
Source: Scheetz, 1999

element concentrations were apparent following injection, and these changes do not appear to be threats to drinking water (Smith, 1987).

Sludge injection (at 3 mines) appeared to increase alkalinity, pH, sulfate, and total suspended solids (TSS). However, pH and alkalinity decreased when injected sludge had a much lower pH than the native mine water. Sludge injection into mines with high (> 7) pH water resulted in lower iron and manganese concentrations, except where the concentration of these elements were very low (<0.1 mg/l) prior to injection. Injection into mines with low pH resulted in a great increase of iron concentrations, presumably as a result of dissolution from the sludge. Most changes in trace element concentrations were negligible, with the possible exception of arsenic, which showed a large apparent increase at one mine. However, concern about potential analytical error complicate assessment of this result (Smith, 1987).

A recent study also examined the impact of injection of a grouting material composed of fly ash, FBC, and FGD sludge into an abandoned underground mine near Friendsville, Maryland. At this site, ground water (AMD) seeping from the mine was a known cause of surface water quality degradation, and injection was initiated with the intention of improving both ground and surface water quality. Seepage water quality measured before injection indicated Fe and Mn concentrations above secondary MCLs, SO_4^{-2} concentrations generally above the primary MCLs, and Zn concentrations sometimes above the HAL.

Immediately after injection[11], acidity of the AMD increased markedly along with dissolved iron and aluminum concentrations, and then decreased to pre-injection levels by the following summer. Ca and SO_4^{-2} concentrations also increased in the AMD following injection and remain high (as of April 1998), apparently due to dissolution of these materials from the injected grout (see Figure 7) (Aljoe, 1999).

The initial increase in acidity of the AMD following grouting most likely resulted from changes in mine pool hydrology, including a drop in mine pool elevation that occurred when water was pumped from the mine to prepare the grout.[12] This drop in elevation would have exposed an estimated 10,500 cubic feet of highly-fractured, previously-submerged material within the mine to atmospheric oxygen. Another change could have been re-routing of flow through new areas of the mine workings, thereby mobilizing acidic products that had previously been stored in stagnant zones within the mine. The intention of the backfilling effort had been to entirely fill the mine voids with grout, thereby isolating the pyritic surfaces from air and water and reducing the AMD production rate. This did not occur, however, because limited information available on the size of the mine workings led to an underestimate of the quantity of grout needed (Aljoe, 1999).

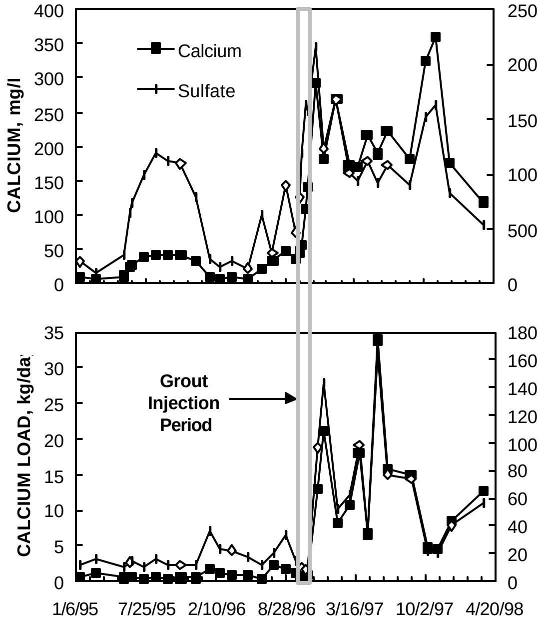

Figure 7. Calcium and Sulfate Concentrations and Loads at an Abandoned Maryland Coal Mine (from Aljoe, 1999)

In a similar project initiated in 1997, grout comprised of a 1.25:1.00 (by dry weight) mixture of fly ash and FGD filter cake with 5 percent added lime was injected through 318 drilled grout holes into an abandoned underground coal mine near Conesville, OH. The objective of the injection project was to inject grout that would seal old mine entries and coat the floor and walls of the abandoned mine chambers, thereby reducing the amount of oxygen available and slowing the process of acid formation. Because grouting was only completed in early 1998, it is too early to determine the net effect on water quality, which will be monitored for three additional years.[13] For all surface and ground water monitoring locations

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[11] About 5,600 cubic yards of fly ash, FBC ash, and FGD sludge were injected as a slurry via 38 boreholes in October and November 1996.

[12] Water to make the slurry was pumped from the main mine pool, which temporarily lowered the level by about 2 feet.

[13] Ground water is being monitored in the overlying Freeport Sandstone, the Middle Kitanning No. 6 coal seam, and the underlying Clarion Sandstone. Two perched aquifers exist: one in the Freeport Sandstone, caused by the underlying claystone and siltstone which immediately overlies the No. 6 coal;

(continued...)

(through September 1998), no measurable increase in arsenic, chromium, boron, or pH levels have been observed since grout injection (Whitlatch, 1998).

Laboratory studies of the reaction between the grout and AMD showed a significant increase in solution pH to approximately 8 and in the concentration of a number of ions, including arsenic and boron. Only 1.32 percent of the arsenic present in the grout was released over the 168-day reaction time and the resulting arsenic levels were below the primary MCL. Because further solubilization could result in higher concentrations, both arsenic and boron will receive particular attention in the on-going monitoring program (Whitlatch, 1998).

The reason for the apparent difference in the reaction between the grout and AMD in the laboratory and the field is not yet clear, but it appears that conditions within the mine are unfavorable for the development of acid neutralization reactions. This may be due to the fact that longer contact times are required than are achieved in the mine. It should be noted, however, that the project is designed to achieve AMD reduction through successful sealing of the mine and does not rely on acid neutralization by the grout. Observations to date show that the water level has risen in the mine, indicating that the grout was of sufficient strength to provide effective seals. In-situ core samples taken after about nine months indicate that the grout is highly impermeable and has weathered very little (Whitlatch, 1998).

At sites in Greene and Clinton counties in Pennsylvania and Upshur county in West Virginia, injection of mixtures of fly ash, FBC ash, lime, AMD treatment sludge, and/or cement with water has been used in attempt to reduce AMD from reclaimed surface mined areas as well. At these sites, grout was injected at relatively shallow (< 30 feet) depths in an attempt to fill voids in the spoil material, thereby reducing contact between the buried pyrite and air and water (Kim, 1998).

At the Greene county site, the pH in wells in the injection area increased by 0.5 pH units and the pH of the seep (discharge from the spoil area) increased slightly from 3.2 to 3.3 following grouting. Acidity was unchanged in the injection area but decreased in the seep. In the injection area and the seep, little difference in trace metal concentrations was observed before and after grouting (Kim, 1998).

At the Clinton county site, pH increased and acidity decreased in samples from the injection area and discharges. The pH remained less than 3, however. Average trace metal data from about two years after injection indicate higher concentrations of As, Co, Cu, Ni, and Zn in the injection area, but concentrations in the discharge were closer to the discharge levels from areas without injection (Kim, 1998).

At the Upshur county site, the average pH of the water in the injection area decreased initially after injection, but had increased when the water was sampled five years later. This increase, however, could

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[13] (...continued)
and one in the No. 6 coal caused by claystone, siltstone and limestone layers between it and the underlying Clarion Sandstone. The lowest and most extensive aquifer is in the Clarion Sandstone and intersects major hydrologic boundaries, such as Wills Creek.

be due to the similar increases observed in the inflows and the ungrouted area. Acidity decreased in the injection area, the inflows, and outflows immediately following injection. Five years after injection, acidity had decreased further in the injection area and increased in the discharger, although it remained below the pre-injection level. Also, concentrations of Ba, Be, Cd, Co, Cr, Cu, Ni, Pb, Sb, and Zn were generally higher in the injection area and discharge than the inflow or control areas, but were still less than primary and secondary MCLs (Kim, 1998).

6. ALTERNATIVE AND BEST MANAGEMENT PRACTICES

A number of best management practices (BMPs) can be implemented to provide increased benefits and protection of USDWs with mine backfill wells. As discussed above, the effect of mine backfill operations on ground water quality depends to a large extent on the characterisitics of the backfill and the mine, and the interaction between the two. Thus, selecting the appropriate backfill materials for a mine and selecting appropriate BMPs require characterization of the the backfill materials, including the potential to cause AMD, and an understanding of where the backfill will be placed (especially with respect to the water table) and how the backfill is expected to react over time in this environment.

BMPs are discussed below in relation to injectate characteristics, design and construction, operation, and closure. The discussion is neither exhaustive nor represents an USEPA preference for the stated BMPs. Each state, USEPA Region, and federal agency may require certain BMPs to be installed and maintained based on that organization's priorities and site-specific considerations.

6.1 Injectate Characteristics

Some injected backfill materials have cement-like properties that cause them to harden following injection. Although the importance of the cementing properties of the injected backfill will vary with site conditions and the objectives, cement-like characteristics are generally, but not always, desirable.[14] Cementing properties are intrinsic to some backfilled materials and can be created in all materials commonly used for backfilling through the use of appropriate mixtures and additives. Cementing properties provide both increased structural support (where backfill is provided to control subsidence) and reduced permeability. Reduced permeability generally serves to reduce dissolution of constituents from the injected material. In addition, flow rates through the backfilled zone are reduced, thereby reducing the availability of oxygen and the release of constituents from the mine surfaces as well as the backfill material.

6.2 System Design and Construction

As discussed above, backfill injection is sometimes used with the intention of preventing or abating AMD. Although injection is intended to increase pH and reduce acidity, the acidic conditions present in

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[14] Recent experimental work indicates injection of alkaline FBC ash in dilute slurry form may be more effective in reducing AMD than ash injected in the form of low-permeability grout. In some situations, the benefits from increased neutralization may outweigh the potential increase in the release of trace metals from the ash (Canty, 1999).

these applications will lead to the dissolution of some constituents from the injected backfill. This dissolution can be reduced, however, by ensuring that the mine voids are filled as completely as possible with the injected material, thereby reducing the availability of oxygen and the potential for additional acid formation. To achieve this objective requires adequate distribution of the backfill within the mine workings, which in turn requires appropriate quantities of injection material, appropriate well spacings, and injection pressures that will distribute the material and effectively fill the mine voids. In addition, bonding agents and/or materials to reduce the porosity of the injected backfill can help to reduce the residual void space remaining after backfill injection. These considerations warrant special attention when injection occurs in inactive mines where access and knowledge of the size and geometry of the mine workings are limited.

BMPs for well construction may vary significantly with site conditions and the type of backfill injected. Backfill injection often occurs in abandoned mines or other settings where injection is performed in an effort to improve existing poor ground water quality. In these situations, injection through uncased boreholes may be appropriate if the wells are relatively shallow, the strata have sufficient integrity, the injectate is grout-like in nature, and injection only occurs for a short period, such as a few days. At other injection sites, however, casing is clearly needed to ensure that the injected material reaches the intended formation. This is particularly true when the injection well is relatively deep, operates on an on-going basis, passes through a USDW, and/or injects a low solids content fluid. In some cases, the site setting or the nature of the injected material may make the use of tubing appropriate.

6.3 Well Operation

For backfill wells that operate on an on-going basis, which most often occurs in association with backfilling that is integrated with mining operations, BMPs include mechanical integrity tests (MIT) before the well is put into service and periodically during use. A variety of MITs may be run on backfill wells to check casing integrity. For example, pressure tests may be run prior to initial well operation and subsequently at periodic intervals, generally ranging from one to five years. Because mine backfill injection is normally done without a tubing string, pressure testing requires that a temporary, retrievable bridge plug[15] be set near the bottom of the casing. This retrievable plug approach is used at least at one site in Wyoming. The appropriate pressure for a pressure test depends on anticipated well operating conditions. At the Wyoming facility, testing at a pressure 10 percent greater than the maximum pressure reached during the previous year (or maximum of 200 psi) is required (State of Wyoming 1988, 1996).

Due to the relatively high solids content of injected backfill as compared to other types of injected fluids, abrasion can threaten casing integrity. Thus, caliper logs[16] may be run periodically on the entire length of the surface. A casing log run prior to well use provides a baseline against which subsequent logs can be compared. In Wyoming, casing logs are repeated at nine month intervals unless the results show

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[15] An expandable plug used in a well’s casing to isolate producing zones; also to isolate a section of the borehole to be filled with cement when a well is plugged.

[16] An instrument for measuring the inside diameter of a well.

more than 20 percent reduction in the wall thickness of the casing, in which case the log is repeated every six months (Wyoming 1988, 1996).

Other examples of MIT used in backfilling operations include Multifrequency Electromagnetic Thickness (MET) logs and cement bond logs. MET has been used by Tg Soda Ash, Inc. during the operation of an underground tailings disposal and mine backfilling system to evaluate corrosion and metal loss (Tg Soda Ash, 1997). Cement bond logs (and caliper logs) have been used in the Big Island Trona Mine to evaluate the integrity of cement to pipe and cement to formation bonding (Wickersham, 1995).

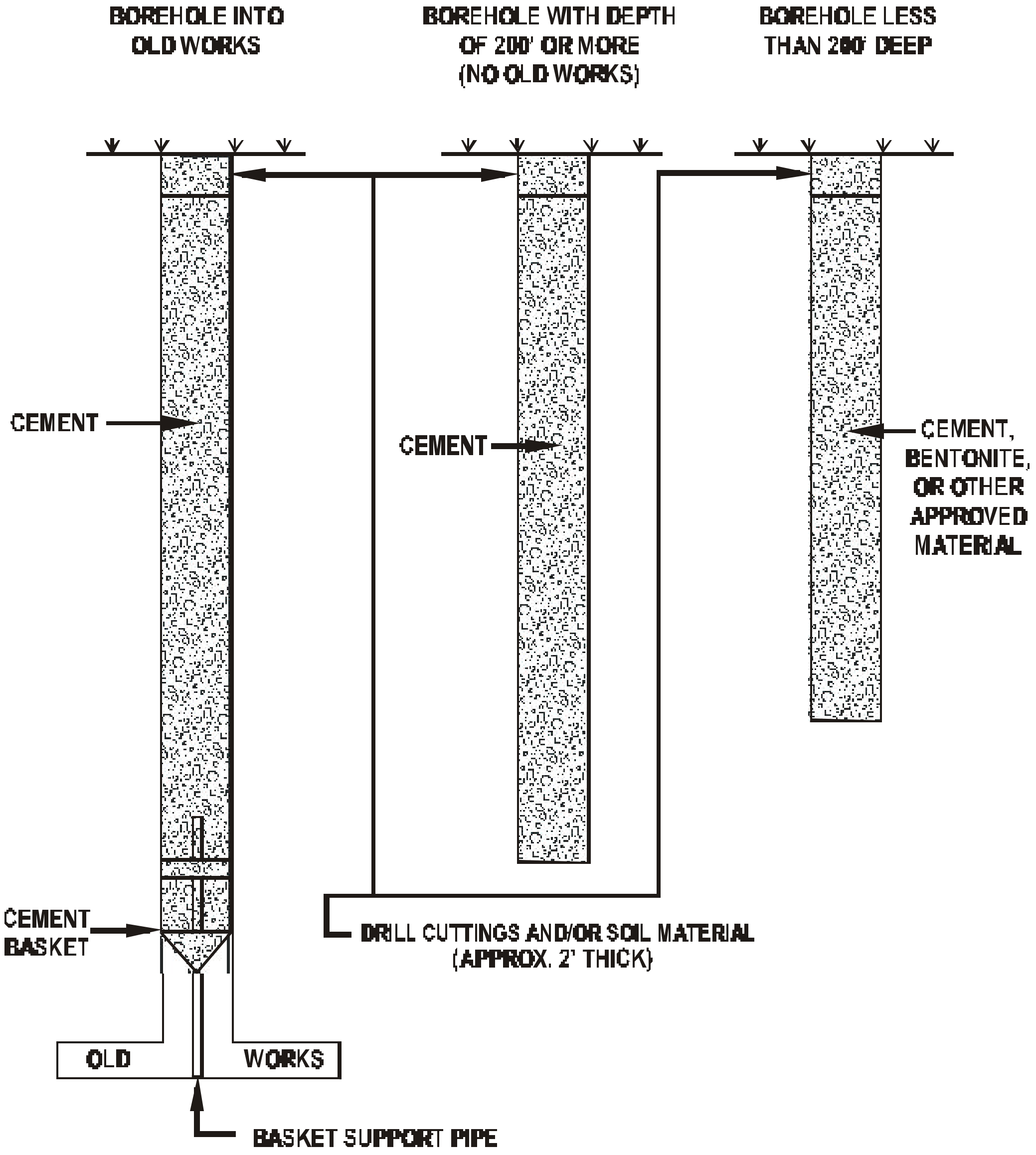
6.4 Well Closure

Appropriate well abandonment is important to ensure that the well does not provide a pathway through which contamination of USDWs could occur. As with well construction and operation, appropriate closure practices depend onsite conditions. In some situations, abandonment may be as simple as allowing the injected material to fill the well bore after the mine stops accepting additional injected material. This approach is most likely to be appropriate for shallow wells used for short periods to inject self-cementing grouting materials into closed or abandoned mines.

In other situations, protection of USDWs may require plugging and abandonment using more “conventional” cementing techniques. For example, in Wyoming abandonment includes setting a cast iron bridge plug approximately 50 feet above the bottom of the casing. Cement is placed in the casing by pumping through a tubing string in stages as the tubing is withdrawn. This is performed until the entire casing is cemented to the surface. At the surface, the casing is cut off 5 feet below the ground surface and the land surface reclaimed in accordance with mine abandonment permits (Wyoming 1988, 1996).

In another example, all injection wells, water withdrawal wells, and monitoring boreholes at the Kindall 3 Mine in Indiana were required to be plugged and sealed with cement from the bottom to the surface. Figure 8 provides example cross sections showing borehole plugging methods. In this example, a cement basket is used instead of a bridge plug to establish the location in the casing at which cementing begins.

Figure 8. Cross Sections of Typical Borehole Plugging Methods



Source: Endress, 1996

7. CURRENT REGULATORY REQUIREMENTS

As discussed below, several federal, state, and local programs exist that either directly manage or regulate Class V mining, sand, and other backfill wells. On the federal level, management and regulation of these wells falls primarily under the UIC program authorized by the Safe Drinking Water Act (SDWA). Some states and localities have used these authorities, as well as their own authorities, to extend the controls in their areas to address concerns associated with mining, sand, and other backfill wells.

7.1 Federal Programs

7.1.1 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.

Mining, sand, and other backfill 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 mining, sand, and other backfill 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 mining, sand, and other backfill 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.

State staff must conduct source water assessments that are comprised of three steps. First, state staff 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, state staff 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 staff must identify contaminants of concern, and for those contaminants, they must inventory significant potential sources of contamination in delineated source water protection areas. Class V wells, including mining, sand, and other backfill wells, should be considered as part of this source inventory, if present in a given area. Third, the state staff must "determine the susceptibility of the public water systems in the delineated area to such contaminants." State staff should complete all of these steps by May 2003 according to the final guidance.[17]

7.1.2 SMCRA

The Office of Surface Mining Reclamation and Enforcement (OSM) in the U. S. Department of the Interior oversees state mining regulatory and reclamation activities under the Surface Mining Control and Reclamation Act (SMCRA), or directly implements mining programs in states that have not obtained primacy under SMCRA. The Office also directly regulates coal mining and reclamation activities on federal and Indian lands. The Bureau of Land Management (BLM), also a part of the U. S. Department of the Interior, is responsible for the management of public lands, including minerals leasing and oversight for the development of energy and mineral leasing and compliance with regulations governing the extraction of mineral resources. It is also responsible for subsurface resource management where mineral rights, but not the land surface, are federally owned.

Regulations promulgated by the Office of Surface Mining in Title 30 Chapter 7 apply to mine backfill wells if the well is located in a state that has not accepted primacy under SMCRA. In some Primacy States, the federal requirements have also served as the model for the state regulations.

Part 784 of Chapter 7 addresses underground mining permit application requirements, and contains minimum requirements for the reclamation and operation plan that must be submitted as part of the permit application. Section 784.25 provides that each underground mining permit application must supply a plan describing the design, operation, and maintenance of any proposed coal processing waste disposal facility, including flow diagrams and any other necessary drawings and maps, for the approval of the state

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

regulatory authority and the Mine Safety and Health Administration under 30 CFR 817.81(f), the permanent program performance standards for underground disposal of coal mining waste. The section provides further that:

C Each plan shall describe the sources and quality of waste to be stowed, area to be backfilled, percent of the mine void to be filled, method of constructing underground retaining walls, influence of the backfilling operation on active underground mine operations, surface area to be supported by the backfill and the anticipated occurrence of surface effects following backfilling;

C The applicant shall describe the source of the hydraulic transport mediums, method of dewatering the backfill that is emplaced, retention of water underground, treatment of water if released to surface streams, and the effect on the hydrology; and

C The plan shall describe each permanent monitoring well to be located in the backfilled area, the stratum underlying the mined coal, and gradient from the backfilled area except where pneumatic backfilling operations are exempted from hydrologic monitoring (30 CFR 784.25).

Both §817.81(f), the permanent program requirements on underground disposal of coal mine waste described above, and §817.71(j), the permanent program requirements on underground disposal of excess spoil, provide that coal mine waste or excess spoil may be disposed of in underground mine workings "only in accordance with a plan approved by the regulatory authority and MSHA under §784.25."

SMCRA also authorizes the promulgation of regulations addressing the surface effects of underground coal mining operations. The statute provides in 30 U.S.C.A. §1266 that with respect to surface disposal of mine wastes, tailings, coal processing wastes, and other wastes in areas other than the mine workings or excavations, permitted mining operations are required to stabilize all waste piles and ensure that the leachate from such piles will not fall below the water quality standards established under federal or state law for surface or ground waters. The provision does not specify that leachate must result from precipitation, and could be applied to leachate from injection into a surface rubble pile (which could be defined as a Class V well).

BLM regulations establish performance standards for coal mining and for solid minerals other than coal under federal leases and licenses. The rules pertaining to underground coal mining specify that backfilling of exploratory drill holes, openings, and excavations must be in accordance with sound engineering practices and an approved plan (43 CFR 3484.2). Non-coal mineral mining also must be conducted according to an approved plan, which must address backfilling of drill holes (see e.g., 43 CFR 3522.3-3(c)(3)). In addition, BLM rules provide that the operator/lessee must dispose of all wastes resulting from the mining, reduction, concentration, or separation of mineral substances in accordance with the terms of the lease, approved mining plan, applicable federal, state, and local law and regulations and the directions of the authorized officer (43 CFR 3596.2).

7.2 State and Local Programs

Ninety-eight percent of the documented mine backfill wells and 99 percent of estimated wells in the United States exist in 10 states: Idaho, Illinois, Indiana, Kansas, North Dakota, Ohio, Pennsylvania, Texas, West Virginia, and Wyoming. Attachment A of this volume describes how each of these states current regulate mining, sand, and other backfill wells.

In Indiana and Pennsylvania, USEPA Regions 5 and 3, respectively, directly implement the UIC Class V program. The USEPA Regions apply inventory requirements and use permit by rule to ensure non-endangerment of USDWs. Indiana, in addition, has enacted state regulations that apply to underground mining operations, including backfilling of mines, that are implemented by the state's Department of Natural Resources. Indiana's requirements for backfilling plans parallel requirements established in 30 CFR 817.81(f) under SMCRA. Pennsylvania, in addition, regulates mine backfill well projects through regulations implemented by the Bureau of Mining and Reclamation.

In the eight states that are Primacy States for Class V UIC wells, state regulations pertaining to mine backfill wells vary significantly in their scope and stringency.

- Mine tailing backfill wells are authorized by rule in Idaho, unless use of such a well results in exceedance of water quality standards, when the well is required to obtain an individual permit or close.

- Illinois has enacted UIC Class V requirements that are identical to those of the USEPA. The state applies inventory requirements and uses permit by rule to ensure non-endangerment of USDWs. In addition, the state has enacted a Groundwater Protection Act and ground water quality regulations that require responses to ground water contamination before it exceeds specified ground water quality standards.

- Kansas has incorporated the federal UIC Class V regulations by reference. (Mine backfill wells that are designed to backfill salt caverns are covered by the state's Class III UIC requirements. and by water well requirements and are not discussed in this report.) Class V mine backfill wells are permitted by rule.

- North Dakota uses inventory requirements and permit by rule to ensure non-endangerment of USDWs from mine backfill wells. In addition, the state places special requirements for siting, construction, and operation of backfill wells into the contracts that the state enters into for backfilling to address highway subsidence, the predominant backfilling activity that takes place in the state.

- Ohio authorizes by rule Class V UIC mine backfill wells and requires drilling and operating permits for some types of wells, including backfill wells. In addition, Ohio's rules pertaining to underground coal mines, administered by the Division of Mines and Reclamation, require the development of a reclamation plan, including ground water monitoring, and specify that discharge of water into underground mines is prohibited unless approved by the Division of Mines. Ohio's requirements for backfilling plans parallel the requirements in 30 CFR 817.81(f) under SMCRA.

- In Texas, mine backfill wells are authorized by rule. The state's mining regulations exempt shafts and boreholes authorized under the UIC program. The state requirements for Class V wells, however, include siting, construction, and closure standards.

- West Virginia issues individual permits or area permits to mine backfill wells.

- Wyoming covers mine backfill wells under the general permit provisions of the state's Class V UIC requirements. In addition to requiring the submission of information, the general permit requirements also include a well operator to establish a monitoring program. In addition, the state's regulations pertaining to underground coal mining require a permit to return coal-mining waste to abandoned underground workings.

ATTACHMENT A
STATE AND LOCAL PROGRAM DESCRIPTIONS

This attachment does not describe every state's control programs; instead it focuses on the ten states where relatively large numbers of mine backfill wells are known to exist: Idaho, Illinois, Indiana, Kansas, North Dakota, Ohio, Pennsylvania, Texas, West Virginia, and Wyoming. Altogether, these ten states have a total of 4,992 documented mine backfill wells, which is almost 99 percent of the documented well inventory for the nation.

Idaho

Idaho is a UIC Primacy State for Class V wells and has promulgated regulations for its UIC program in the Idaho Administrative Code (IDAPA), Title 3, Chapter 3.

Permitting

Idaho's rules state that mine tailings backfill wells are authorized by rule as part of mining operations "because federal studies show the threat of endangerment from use of these wells is low. They are therefore exempt from the MCLs and permitting requirements of the UIC rules, provided that their use is limited to the injection of mine tailings only." For rule-authorized mine backfill wells inventory information must be supplied (37.03.03.030.01 IDAPA).

The rules provide that the use of a well shall not result in water quality standards at points of beneficial use being exceeded or otherwise affect a beneficial use. If water quality standards are exceeded or beneficial uses affected, the rules state that the well may be put under the permit requirements of Title 3, Chapter 3, or the well may be required to be remediated or closed (37.03.03.025.03.g IDAPA (Rule 25)).

If a mining backfill well is placed under the permitting requirements, detailed permit application information is required. It includes information on location and construction of the proposed well; proposed injectate; local features such as topography, wells producing water, surface waters, residences, and geology; and maps and cross sections depicting all USDWs within a quarter mile radius of the injection well, their location relative to the injection zone, and the direction of water movement. Corrective action and contingency plans must be prepared and submitted, and proof of financial responsibility must be supplied.

Siting and Construction

Class V wells may be required to be located at a distance from a point of diversion for beneficial use sufficient to minimize or prevent ground water[18] contamination resulting from unauthorized or accidental injection (37.03.03.050.03.a IDAPA)

Operating Requirements

Idaho's requirements for use of Class V wells are based on the premise that if the injected fluids meet MCLs for drinking water 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 necessary "to protect the ground water resource from deterioration and preserve it for diversion to beneficial use," 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 MCLs 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)). As a condition of use of mine tailings backfill wells, the owner or operator may be required to monitor ground water (37.03.030.025.03.g IDAPA (Rule 25)).

Financial Responsibility

No financial responsibility requirement exists for rule-authorized mine backfill wells. Operators of permitted wells are required to demonstrate financial responsibility through a performance bond or other appropriate means (the rule does not specify the amount(s) required) to abandon the injection well according to the conditions of the permit (37.03.03.35.03.e IDAPA).

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:

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[18] "Ground water" is defined as "any water that occurs beneath the surface of the earth in a saturated geological formation of rock or soil." A "Drinking Water Source" is defined as "an aquifer which contains water having less than ten thousand (10,000) mg/l total dissolved solids" that has not been exempted from that designation by the Director of the Department of Water Resources.

- The casing should be pulled, if possible, or cut a minimum of two feet below the land surface.

- The total depth of the well should be measured.

- If the casing is left in place, it should be perforated and neat cement with up to 5 percent bentonite can be pressure-grouted to fill the hole. As an alternative, when the casing is not pulled, course bentonite chips or pellets may be used. 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. Perforation of the casing is not required under this alternative

- If the well extends into the aquifer, a clean pit-run gravel or road mix may be used to fill the bore up to ten feet below the top of the saturated zone or ten feet below the bottom of the casing, whichever is deeper, and cement grout or bentonite clay used to the surface. Gravel may not be used if the lithology is undetermined or unsuitable.

- A cement cap should be placed at the top of the casing if the casing is not pulled, with a minimum of two feet of soil overlying the filled hole/cap.

- Abandonment of the well must be witnessed by an IDWR representative.

Illinois

Illinois is a UIC Primacy State for Class V wells. The Illinois Environmental Protection Agency (IEPA), Bureau of Land, has promulgated rules establishing a Class V UIC program in 35 Illinois Administrative Code (IAC) 704. These rules are identical in substance to USEPA rules in 40 CFR 144 (704.101 IAC). In addition, Part 702, "RCRA and UIC Permit Programs," establishes requirements for those UIC wells required to obtain a permit, while Part 705 describes the procedures for issuing UIC permits. Finally, 35 IAC Part 730 sets out technical criteria and standards for the UIC program. Part 730 Subpart F currently does not specify technical criteria and standards for siting, construction, operating, monitoring and reporting, mechanical integrity, or closure for Class V UIC wells, although other subparts of Part 730 do so for other classes of UIC wells (730.151 IAC).

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). However, injection into Class V wells is authorized by rule (704.146 IAC). Owners or operators of wells authorized by rule must submit inventory information (704.148 IAC). In addition, IEPA may require submission of other information deemed necessary by IEPA (704.149 IAC). In addition to the inventory information required from all Class V wells, certain categories of wells, including sand or other backfill wells as defined by 35 IAC 730.105(e)(8), are required to submit additional information, including the following:

- Location of each well by township, range, section, and quarter-section;
- Date of completion of each well,
- Identification and depth of the formation(s) into which each well is injecting,
- Total 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, and
- Date of the last MITs, if any (704.148(b)(2) IAC).

Operating Requirements

No operating requirements are specified for Class V UIC wells permitted by rule. Such wells, however, are subject to the state's ground water protection requirements. Under Illinois' Ground Water Quality regulations, found in 35 Ill. Adm.Code Part 620, a classification system is established for the State's ground waters. The regulations also enact a nondegradation provision, establish standards for quality of ground waters, and create procedures for the management and protection of ground waters. The regulation defines "potential route" of ground water contamination to include, among others, abandoned and improperly plugged wells of all kinds, drainage wells, and all injection wells. The regulation provides that no person shall cause a violation of the state's Environmental Protection Act, the Groundwater Protection Act, or regulations adopted under those Acts, including the Ground Water Quality regulations.

The fours classes of ground water established by the classification system are (I) potable resource ground water;[19] (II) general resource ground water, which cannot easily be tapped to supply drinking water; (III) special resource ground water, which is "demonstrably unique (e.g., irreplaceable"), vital for a particularly sensitive ecological system (not further defined), or contributes to a dedicated nature preserve; and (IV) other ground water, which is naturally saline, contaminated, or is limited in its resource potential (e.g., within a zone of attenuation for a solid waste landfill, under a coal mine refuse disposal area, under a potential contaminant source, within a previously mined area, or ground water that has been designated as an exempt aquifer under the underground injection policy of 730.104 IAC (620.201 - 240 IAC). (Under 730.104 IAC an aquifer or portion of an aquifer that otherwise meets the criteria for a USDW may be determined to be an exempted aquifer if it does not currently serve as a source of drinking water and it cannot now and will not in the future serve as a source of drinking water.)

The Ground Water Quality regulations prohibit impairment of resource ground water and require preventive notice and response procedures to detect and address contaminants before they exceed the ground water quality standards for Class I and III ground waters. The regulations also include ground water quality standards for each class of ground water, as well as ground water quality restoration standards. The latter include coal reclamation ground water quality standards, addressing inorganic chemical constituents and pH in ground water, within an underground coal mine, or within the cumulative

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[19] "Potable" is defined as "generally fit for human consumption in accordance with accepted water supply principles and practices."

impact area of ground water for which the hydrologic balance has been disturbed from a permitted coal mine (620.450(b). These requirements also address coal mine refuse disposal areas, but do not explicitly address mine backfill activities.

Indiana

USEPA Region 5 directly implements the UIC program for Class V injection wells in Indiana. In addition, however, state regulations found in Title 310 Indiana Administrative Code (IAC) administered by the Indiana Department of Natural Resources (DNR), Division of Reclamation, apply to mine backfill wells.

Permitting

The DNR permitting rules require applications for underground mining operation permits to describe proposed disposal methods and sites for placing underground development waste and excess spoil generated at surface areas (310 IAC 12-3-86). Each plan also must describe the design, operation, and maintenance of any proposed coal processing waste disposal facility, including the source and quality of waste, the area to be backfilled, the method of constructing underground retaining walls, the source of the hydraulic transport mediums, the method of dewatering the emplaced backfill, the retention of water underground, the effect on the hydrology, each monitoring well to be located in the backfilled area, the stratum underlying the mined coal, and the gradient from the backfilled area (310 IAC 12-3-91).

Regulations of the Water Pollution Control Board also specify that if an applicant for an National Pollutant Discharge Elimination System (NPDES) permit proposes to dispose of pollutants by underground injection as part of the overall effort to meet the requirements of the NPDES program, the application shall be denied, unless conditions can be placed in the NPDES permit that will control the proposed discharge to prevent pollution of ground water resources of such character and degree as would endanger or threaten to endanger the public health and welfare (327 IAC 5-4-2).

Siting and Construction

Approval must be obtained for return of coal processing waste to abandoned underground workings (310 IAC 12-3-91). Plans submitted to the Division of Reclamation must identify the locations of the wells.

Operating Requirements

Coal processing waste may be returned to underground mine workings only in accordance with the waste disposal program approved under 310 IAC 12-3-91 (310 IAC 12-5-46 and 310 IAC 12-5-110). The Division of Reclamation specifies operating requirements on a case-by-case basis. Quarterly ground water analyses must be submitted, and must continue to be submitted following completion of injection activities until a demonstration can be made that no adverse effects on the hydrologic balance have occurred. Each drilled hole, well, or other exposed underground opening identified in the approved permit application for use to return coal processing waste or water to underground workings must be temporarily sealed before use and protected during use (310 IAC 12-5-9).

Mechanical Integrity Testing

Not specified by statute or regulation.

Financial Responsibility

Operators are required to post a performance bond with DNR's Division of Reclamation. The bond is released upon a showing that following cessation of injection activities no adverse effects to the hydrologic balance have occurred.

Plugging and Abandonment

If no longer in use, a drilled hole or well must be cased, sealed, or otherwise managed to prevent acid or other toxic drainage from entering ground or surface waters and to minimize disturbance to the prevailing hydrologic balance (310 IAC 12-5-74 and 310 IAC 12-5-76).

Kansas

Kansas is a UIC Primacy State for Class V wells. It has incorporated the federal UIC regulations by reference in Kansas Administrative Regulations (KAR) Article 28-46.

Permitting

Mine backfill wells, except for wells backfilling salt caverns, are permitted by rule under KAR 28-46. Mine backfill wells that are designed to backfill salt caverns are covered by regulations for Class III salt solution mining wells (KAR 28-43) and also are covered by KAR 28-30.

Siting and construction

There are no siting or construction requirements for mine backfill wells, except for wells backfilling salt caverns.

Operating requirements

There are no operating requirements for mine backfill wells, except for wells backfilling salt caverns. The state requires salt cavern backfill well operators to prepare a closure plan and to fill wells with grout, relying upon requirements for abandonment in 28-30 KAR.

North Dakota

North Dakota is a UIC Primacy State for Class V wells. Regulations establishing the UIC program are found in Article 33-25 of the North Dakota Administrative Code (NDAC).

Permitting

Underground injection is prohibited, unless authorized by permit or rule (33-25-01-03 NDAC). Injection into a Class V well is authorized by rule indefinitely, subject to the requirements of subsections 4 (evidence of financial responsibility), 5 (maintenance of records until 3 years after plugging and abandonment), and 6 (reporting within 24 hours of any endangerment of a USDW and any noncompliance with a permit condition or malfunction of the injection system that could cause fluid migration into or between USDWs) of § 33-25-01-10 and subsection 3 (notice to the Department of Health before conversion or abandonment of the well) of §33-25-01-12 NDAC. The operator of a Class V well authorized by rule may be required to apply for and obtain an individual or area permit under specific circumstances, including cases in which protection of a USDW requires the injection operation to be regulated by requirements not contained in the rules (33-25-01-16 NDAC).

Siting and Construction

Although not explicitly called for by the Class V requirements, siting and construction requirements are imposed on mine backfill wells by the Abandoned Mine Lands Division of the Public Service Commission on a case-by-case basis through the contract terms that the Division includes in its contracts for backfilling services.. The wells are sited where abandoned underground mines that lie beneath towns or highways have caused subsidence. The contracts call for the wells to be constructed as 5 inch diameter holes cased with 3 inch I.D. Schedule 40 PVC pipe., and to be 50-70 feet deep. None inject into USDWs.

Operating Requirements

Operating requirements are established by contract. The contractors who construct and operate the wells are required to inject grout in conformance with contract specifications, including specifications concerning grout pressure at the well head, flow rates, pumping rates, and cumulative volume pumped; grout constituents and consistency; records and recordkeeping; and permitting.

Subsection 5 of § 33-25-01-10 requires records to be maintained concerning the nature and composition of injected fluids for three years after plugging and abandonment of the well. A single type of injectate, which has been approved by the Department of Health, is utilized by the Abandoned Mines Division of the Public Service Commission. Operations are generally concluded within 24 hours. A qualified inspector is on-site whenever injection occurs.

Subsection 6 of § 33-25-01-10 requires a report within 24 hours of any monitoring or other indication that any contaminant may cause an endangerment to a USDW, or any noncompliance with a permit condition or malfunction of the injection system that may cause fluid migration into or between USDWs.

Mechanical Integrity Testing

Not specified by statute or regulation.

Financial Responsibility

Subsection 4 of § 33-25-01-10 requires operators to have sufficient financial responsibility and resources to close, plug, and abandon the underground injection operation in a manner prescribed by the Division of Water Supply and Pollution Control of the Department of Health. A surety bond, or other evidence of adequate assurance, in an amount satisfactory to the Department, must be provided.

Plugging and Abandonment

Subsection 3 of § 33-25-01-12 requires notice before conversion or abandonment of the well.

Ohio

Ohio is a UIC Primacy State for Class V wells. Regulations establishing the UIC program are found in Chapter 3745-34 of the Ohio Administrative Code (OAC). In addition, the Ohio Department of Natural Resources, Division of Mines and Reclamation, regulates active and abandoned mines.

Permitting

Class V injection wells are defined to include sand backfill and other backfill wells used to inject a mixture of water and sand, mill tailings or other solids into mined out portions of subsurface mines (3745-34-04 OAC). Any underground injection, except as authorized by permit or rule, is prohibited. The construction of any well required to have a permit is prohibited until the permit is issued (3745-34-06 OAC).

Injection into Class V injection wells is authorized by rule (3745-34-13 OAC). However, a drilling and operating permit is required for injection into a Class V injection well of sewage, industrial wastes, or other wastes (including backfill), as defined in § 6111.01 of the Ohio Revised Code, into or above a USDW (3745-34-13 OAC and 3745-34-14 OAC).

Permit applications must include a description of the activities conducted by the applicant; facility location, listing of other permits under specified programs, where the well is to be drilled, name of the geological formation to be used and the proposed total depth of the well, type of drilling equipment to be used, plan for disposal of water and other waste substances, composition of the substance to be injected, topographic map indicating specified features, and description of the business (3745-34-16 OAC).

Class V injection well permits may be issued on an area basis. The permit will specify requirements for construction, monitoring, reporting, operation, and abandonment (3745-34-18 OAC).

Ohio's rules on underground coal mines, administered by the Division of Mines and Reclamation, require the development of a reclamation plan that must be submitted as part of an application for a permit to conduct coal mining (1501:13-4-14 OAC). The plan must include a description of the measures to be used to seal or manage mine openings and to plug, case or manage exploration holes, other bore holes, wells, and other openings within the proposed permit area (1501:13-4-14(D)(2)(g) OAC). It must include a ground water monitoring plan, including identification of the monitoring parameters, sampling frequency, and site locations, sufficient to monitor the suitability of the ground water for current and approved post-mining land uses and the objectives for protection of the hydrologic balance established in the permit (1501:13-4-14(F)(1)(a) OAC).

The rules require submission of a subsidence control plan, including a detailed description of the subsidence control measures that will be taken to prevent or minimize subsidence, such as backfilling voids (1501:13-4-14(M)((2)(e) OAC). The Ohio rules also adopt the MSHA requirements concerning return of coal mine wastes to abandoned underground workings. They require the application to contain a plan that describes the design, operation, and maintenance of any proposed coal processing waste disposal facility. The plan must describe the source and quality of waste to be stowed, area to be backfilled, percent of the mine void to be filled, method of constructing underground retaining walls, influence of the backfilling operation on active underground mine operations, surface area to be supported by the backfill, and the anticipated occurrence of surface effects following backfill. The application is required to describe the source of the hydraulic transport mediums, method of dewatering the emplaced backfill, retention of water underground, treatment of water if released to surface streams, and the effect on the hydrology. The plan must describe each permanent monitoring well to be located in the backfilled area, the stratum underlying the mined coal, and the gradient from the backfilled area. Pneumatic backfilling operations are covered, except they may be exempted from requirements specifying hydrologic monitoring (1501:13-4-14(N)(1)-(5) OAC).

Siting and Construction

The permit applicant must submit plans for testing, drilling, and construction, and no construction may commence before permit issuance. Permits will contain conditions specifying construction requirements (3745-34-27 OAC).

The mining rules specify that each exploration hole, other drill or borehole, shaft, well, or other exposed mine opening must be cased, sealed, or otherwise managed as approved by the Division of Mines. Each well or other opening identified in the approved permit application for use to return coal processing waste or water to underground workings must be temporarily sealed before use and protected during use by barricades, fences, or other protective devices. When no longer needed, they must be capped, sealed, backfilled, or otherwise properly managed as required by the Division of Mines (1501:13-9-02 OAC).

Operating Requirements

Permits contain conditions specifying operation requirements, including maximum injection volumes and/or pressures and monitoring and reporting requirements (3745-34-27 OAC). Permittees are required to maintain records of the nature and composition of all injected fluids for three years. Reports of any noncompliance that may endanger health or the environment, including any monitoring or other information that indicates that any contaminant may cause an endangerment to a USDW, or any noncompliance with a permit condition or malfunction of the injection system that may cause fluid migration into or between USDWs must be reported within 24 hours (3745-34-26 (J) and (K) OAC).

Wells must be inspected before commencing injection. The permittee must provide notice before conversion or abandonment of the well (3745-34-26 (M) and (N) OAC).

The mining rules also establish a general requirement for protection of the hydrologic system from mining activities. Backfilled materials are required to be placed so as to minimize contamination of ground water systems with acid, toxic, or otherwise harmful mine drainage, and to minimize adverse effects of mining on ground water systems outside the permit area (1501:13-9-04(K) OAC). Discharge of water into underground mines is prohibited, unless specifically approved by the Division of Mines and by the federal MSHA, and such discharges are limited to water, coal processing waste, fly ash from a coal-fired facility, sludge from an acid-mine drainage treatment facility, flue-gas desulfurization sludge, inert material used for stabilizing underground mines, and underground mine development wastes (1501:13-9-04(Q) OAC).

Mechanical Integrity Testing

Permits may include a condition prohibiting injection operations until the permittee shows that the well has mechanical integrity, as specified under § 3745-34-34 OAC ((3745-34-27 OAC). Detailed specifications for mechanical integrity are included in § 3734-34-34.

Financial Responsibility

Permittees are required to maintain financial responsibility and resources sufficient to close, plug, and abandon the underground injection operation (3734-34-27 OAC).

Plugging and Abandonment

Permits may include conditions to ensure that plugging and abandonment of the well will not allow the movement of fluids either into or between USDWs (3745-34-27 OAC). There is no established closure guidance or policy that lists specific materials or procedures to be employed. Site-specific closure plans are reviewed by Ohio USEPA.

Pennsylvania

USEPA Region 3 directly implements the UIC program for Class V injection wells in Pennsylvania. However, the Bureau of Mining and Reclamation in the Department of Environmental Protection approves mine backfill well projects. The Department has no specific regulations pertaining to mine backfill wells. Technical specifications are provided to drilling contractors as part of the contract for mine backfill projects. The technical specifications vary depending on the well location (i.e., anthracite coal regions or bituminous coal regions).

Permitting

The drilling contractor is required to obtain all necessary permits, and to comply with all existing laws, ordinances, rules and regulations relating to the contractor's operations.

Siting and Construction

The Department determines well siting. All work is required to be done under the direction of a Resident Engineer or the Technical Specifications of the contract. Technical Specifications address overburden drilling, drilling in material other than overburden, and casing with steel or PVC pipe.

Operating Requirements

Technical specifications address supply, delivery, and injection of grout material. A Department inspector is onsite during operations.

Mechanical Integrity Testing

Not specified by statute or regulation.

Financial Responsibility

Not specified by statute or regulation.

Plugging and Abandonment

A technical specification addresses sealing of boreholes. The contractor is required to seal boreholes according to the directions of the Department's representative. Sealing is required by means of a minimum of 10 feet of cement backfill below the overburden/rock interface or below the bottom of the smaller casing pipe, whichever is deeper. In the event that "significant" quantities of water are encountered, the contractor may be required to set the plug below the aquifer and build the seal from that elevation.

Texas

Texas is a UIC Primacy State for Class V wells. The Injection Well Act (Chapter 27 of the Texas Water Code) and Title 3 of the Natural Resources Code provide statutory authority for the UIC program. Regulations establishing the UIC 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). Injection into a Class V well is authorized by rule, 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). Sand backfill wells used to inject a mixture of water and sand, mill tailings or other solids into mined out portions of subsurface mines are specifically defined as Class V wells (331.11 (a)(4)(H) TAC). The state's mining regulations require permits for the construction, use, or operation of a new shaft, but exempt penetrations or boreholes authorized by the TNRCC under the underground injection control program and penetrations authorized by the TNRCC whose purpose is the transmission of concrete slurries, muds, or bulk materials to underground mine workings (329.4 TAC). Therefore the state's mining backfill wells are regulated under the UIC program and not the mining program.

Siting and Construction

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

- 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 (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. The rules contain additional requirements concerning adaptors.

C 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.

C The well casing must be capped or completed in a manner that will prevent pollutants from entering the well.

C 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

Not specified by statute or regulation.

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 USDWs 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).

Financial Responsibility

Chapter 27 of the Texas Water Code, “Injection Wells,” enacts financial responsibility requirements. However, the requirement, unless incorporated into a individual permit for a Class V well, applies specifically only to Class I and Class III wells (331.142 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 is 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 contains 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 wellbore 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).

West Virginia

West Virginia is a UIC Primacy State for Class V wells. Regulations establishing the UIC program are found in Title 47-13 West Virginia Code of State Regulations (WVAC). The state regulates sand backfill and other backfill wells used to inject a mixture of water and sand, mill tailings or other solids into mined out portions of subsurface mines as Class V wells (47-13-3.4.5.b. WVAC).

Permitting

Class V injection wells are authorized by rule unless the Office of Water Resources of the Division of Environmental Protection (DEP) requires an individual permit (47-13-12.4.a. and 47-13-13.2 WVAC). All backfill wells in the state are required to have either individual permits or, if a group of wells in close proximity injects into the same abandoned mine, an area permit (Parsons, 1999).

Siting and Construction

Individually permitted wells are subject to case-by-case construction requirements, based on plans for testing, drilling, and construction submitted as part of the permit application. Wells subject to area permits also are subject to construction requirements for all wells authorized by the permit (47-13-13.6, .7, and .4.b.2 WVAC).

Operating Requirements

Owners or operators of Class V wells are required to submit inventory information describing the well, including its construction features, the nature and volume of injected fluids, alternative means of disposal, the environmental and economic consequences of well disposal and its alternatives, operation status, location, and ownership information (47-13-12.2 WVAC).

Individual and area permits specify requirements for monitoring, reporting, and operation for all wells authorized by the permit (47-13-13.4, .6, and .7 WVAC). Owners and operators must meet the requirements for monitoring and records (requiring retention of records pursuant to 47-13-13.6.b. WVAC concerning the nature and composition of injected fluids until 3 years after completion of plugging and abandonment); immediate reporting of information indicating that any contaminant may cause an endangerment to USDWs or any malfunction of the injection system that might cause fluid migration into or between USDWs.

The rules enact a general prohibition against any underground injection activity that causes or allows the movement of fluid containing any contaminant into USDWs, if the presence of that contaminant may cause a violation of any primary drinking water regulations under 40 CFR Part 142 or promulgated under the West Virginia Code or may adversely affect the health of persons. If at any time a Class V well may cause a violation of the primary drinking water rules the well may be required to obtain a permit or take other action, including closure, that will prevent the violation (47-13-13.1 WVAC). Inventory requirements for Class V wells include information regarding pollutant loads and schedules for attaining compliance with water quality standards (47-13-13.2.d.1 WVAC).

If protection of a USDW requires, the injection operation may be required to satisfy requirements for corrective action, monitoring, and reporting, or operation, that are not contained in the UIC rules (47-13-13.2.c.1.C. WVAC).

Mechanical Integrity

Backfill wells required to obtain an individual permit will be required to demonstrate that the well has mechanical integrity (47-13-13.7.h WVAC). Wells permitted by rule or subject to an area permit may be required to demonstrate mechanical integrity.

Financial Responsibility

A Class V well required to obtain an individual permit will be required to demonstrate financial responsibility and resources for plugging and abandonment. Evidence of financial responsibility includes submission of a surety bond or other adequate assurance such as a financial statement of other material acceptable to DEP.

Plugging and Abandonment

Backfill wells required to obtain an individual permit will be subject to permit conditions pertaining to plugging and abandonment to ensure that the plugging and abandonment of the well will not allow the movement of fluids into or between USDWs. A plan for plugging and abandonment will be required (47-13-13.7.f WVAC). Wells permitted by rule or subject to an area permit may be required to submit a plan for plugging and abandonment.

Wyoming

Wyoming is a UIC Primacy State for Class V wells and the Wyoming Department of Environmental Quality (DEQ) Water Quality Division, has promulgated regulations pertaining to its Class V UIC program in Chapter 16, Water Quality Rules and Regulations (WQRR). Rules on ground water pollution control permits are promulgated in Chapter 9, WQRR, but Class V wells are specifically exempted from coverage by Chapter 9 (Chapter 9 Section 3(a) WQRR). The DEQ Land Quality Division has promulgated requirements pertaining to coal and non-coal mining.

Permitting

Mining, sand, and backfill facilities (category 5B1) are covered by the General Permit provisions of the state's Class V rules (Chapter 16 Section 7 WQRR). A general permit is a permit issued to a class of operators, all of which inject similar types of fluids for similar purposes. General permits require less information to be submitted by the applicant than individual permits, and do not require public notice for a facility to be included under the authorization of a general permit (Chapter 16 Section 2 (l) WQRR). General permits specify the subclass of injection facility covered, the geographic area covered, the general nature of the fluids discharged, and the location of the receiver where the discharge will be allowed.

The state's coal mining regulations (CRR) provide that a permit applicant who is proposing to return coal-mining waste to abandoned underground workings must:

- Describe the design, operation, and maintenance of any proposed coal-processing waste facility, including flow diagrams and any other necessary drawings and maps, for the approval of the DEQ and the Mine Safety and Health Administration;

- Describe the sources and quality of waste to be stowed, area to be backfilled, percent of the mine void to be filled, method of constructing underground retaining walls, influence of the backfilling operation on active underground mine operations, surface area to be supported by the backfill and the anticipated occurrence of surface effects following backfilling;

- Describe the source of the hydraulic transport mediums, method of dewatering the placed backfill, retainment of water underground, treatment of water if released to surface streams, and the effect on the hydrologic regime;

- Describe each permanent monitoring well to be located in the backfilled area, the stratum underlying the mined coal, and gradient from the backfilled area except where pneumatic backfilling operations are exempted from hydrologic monitoring; and

- Be approved by MSHA as well as DEQ prior to implementation (Chapter 7 Section 2(b)(xv) CRR).

Permit applicants for underground coal mines must describe in their permit application measures to be taken in the mine to prevent or minimize subsidence, including backfilling of voids (Chapter 7 Section 1(a)(v)(C) CRR).

Siting and Construction

Class V facilities may not be located within 500 feet of any active public water supply well, regardless of whether or not the well is completed in the same aquifer. This minimum distance may increase or the existence of a Class V well may be prohibited within a wellhead protection area, source water protection area, or water quality management area (Chapter 16 Section 10(n) WQRR).

A separate permit to construct is not required under Chapter 3 of the WQRR for any Class V facility. Construction requirements are included in the UIC permit issued under Chapter 16 (Chapter 16, Section 5 (v) WQRR). In order to be covered by a general permit, an operator must submit the information required by Chapter 16 Section 6 (i), (ii) and (iii), which includes a brief description of the nature of the business and activities to be conducted, information about the operator, and the location of the facility. Additional information also may be required as a condition of the general permit. The rules specify that certain construction and operating requirements must be included (see operating requirements) (Chapter 16 Section 10(d) WQRR).

A facility is covered by a general permit as soon as the DEQ has issued a general statement of acceptance to allow the construction and operation of the facility (Chapter 16 Section 7 WQRR). The facility must meet construction requirements in Chapter 16 Section 10 WQRR, submit notice of completion of construction to the DEQ, and allow for inspection upon completion of construction prior to commencing any injection activity (Chapter 16 Section 5(c)(I)(U) WQRR).

Operating Requirements

The general permit conditions include a requirement that the permittee properly operate and maintain all facilities and systems, furnish information to the DEQ upon request, allow inspections, establish a monitoring program pursuant to Chapter 16 Section 11 WQRR and report monitoring results, give prior notice of physical alterations or additions, and orally report confirmed noncompliance resulting in the migration of injected fluid into any zone outside of the permitted receiver within 24 hours and follow up with a written report within 5 days. Detailed information requirements also are included in the general permit, including a requirement to monitor the injectate at a specified frequency and report the information to DEQ (Chapter 16 Section 7WQRR). A continuous monitoring program normally will not be required, but monitoring frequency will depend on the ability of the facility to cause adverse environmental damage or affect human health (Chapter 16 Section 7(e)(v) WQRR).

The rules (Chapter 16 Section 10(d) WQRR) also specify that the permittee must demonstrate:

- Mechanical integrity of any well designed to remain in service for more than 60 days;

- Provision for controlling the type of material injected and to insure that no hazardous waste is injected;

- Leak detection in all surface piping;

- Provision for insuring that the backfill remains within the permitted area of injection; and

- Provision to ensure that the injection does not cause a ground water standards violation for the class of use of the receiver.

The mining regulations further provide that surface entries and accesses to underground workings must be located, designed, constructed, and utilized to prevent or control gravity discharge of water from the mine in excess of state or federal water quality standards (Chapter 7 Section 2(b)(ii) CRR).

Public notice must be given of any proposed measures to prevent or control adverse surface effects, such as subsidence (Chapter 7 Section 3(a)(ii) CRR).

Mechanical Integrity

Permittees are required to adopt measures to insure the mechanical integrity of any well designed to remain in service for more than 60 days. No specific regulatory requirements on MIT have been enacted; the specific tests to be used will depend on the specific well conditions.

Financial Responsibility

Not specified by statute or regulation.

Plugging and Abandonment

Wells may be abandoned in place if it is demonstrated to DEQ that no hazardous waste or radioactive waste has ever been discharged through the facility, all piping allowed for the discharge has either been removed or the ends of the piping have been plugged in such a way that the plug is permanent and will not allow for a discharge, and all accumulated sludges are removed from holding tanks, lift stations, or other waste handling structures prior to abandonment (Chapter 16 Section 12 (a) WQRR).

REFERENCES

Affolter, R. H., Brownfield, M.E., and Breit, G. N. 1997. *Temporal Variations in the Chemistry of Feed Coal, Fly Ash, and Bottom Ash and Bottom Ash from a Coal-Fired Power Plant*. Presented at the 1997 International Ash Utilization Symposium, organized by the University of Kentucky Cneter for Applied Energy Research, Lexington, Kentucky, October 20-22.

Agency for Toxic Substances and Disease Registry (ATSDR). 1999. Toxicity Frequently Asked Questions (ToxFAQs) Fact Sheets. Atlanta, GA: Agency for Toxic Substances and Disease Registry, Division of Toxicology. Available: http://www.atsdr.cdc.gov/tfacts.html [March].

Aljoe, W. W. 1999. *Hydrologic and Water Quality Changes Resulting from Injection of CCB Grout into a Maryland Underground Mine*. Presented at the American Coal Ash Association's 13th International Symposium on Use and Management of Coal Combustion Products, Orlando, FL, January 11-15, 1999.

Brackebusch, F.W. 1994. "Basics of paste backfill systems." *Mining Engineering*. 46:1175-1178. October 1994.

Brookins, D.G., Thomson, B.M., and Longmire, P.A. 1982. Early Diagenesis of Uranium Mine Stope Backfill. Paper in Paper in Uranium Mill Tailings Managemetn: Proceedings of the Fifth Symposium (Ft. Collins, CO, December 9-10, 1982). Colorado State Uiversity, Ft. Collins, CO. Pp 27-37.

Canty, G. A., and Everett, J.W. 1999. *An In-Situ Remediation Method for Abandoned Underground Coal Mines Using Coal Combustion Products,* in Proceedings, 13th International Symposium on Use and Management of Coal Combustion Products. Orlando, Florida. January 11-15, 1999. pp. 67-1 - 67-14.

Council of Industrial Boiler Owners (CIBO). 1997. *Interim Final Draft Report on Fossil Fuel Combustion ByProducts from Fluidized Bed Boilers*. October 10, 1997.

Crislip, L. 1998. State of Illinois. Backfill mining questionnaire and associated information.

Crislip, L. 1999. Indiana Environmental Protection Agency. Information provided on injection well. February 26, 1999.

Electric Power Research Institute (EPRI). 1998. "Chemical Changes in Ash-Filled Coal Mines." Attachment II to letter from Gary Gibbs, Utility Solid Waste Activities Group (USWAG) to Dennis Ruddy, U. S. EPA. October 30, 1998.

Endress, J. 1996. Kindall Mining, Inc. Letter of correspondence to Lisa Perenchio, U.S. EPA. June 18, 1996.

Freeze, R. A. And Cherry, J. A. 1979. *Groundwater*. Prentice-Hall, Inc., Englewood Cliffs, NJ.

Jude, C.V. and T.L. Vandergrift. 1995. "Backfilling Materials and Methods for Stress Transfer Modification in Deep Longwall Mines." Washington, DC: U.S. Bureau of Mines.

Karfakis, M.G., C.H. Bowman, and E. Topuz. 1996. "Characterization of Coal Mine Refuse as Backfilling Material." *Geotechnical and Geological Engineering*. 14:129-150.

Kim, A. G., and Cardone. C. 1997. "Preliminary Statistical Analysis of the Effect of Fly Ash Disposal in Mined Areas," in *Proceedings: 12th International Symposium on Coal Combustion By_Product (CCB) Management and Use*, January 26-30, 1997. American Coal Ash Association, Alexandria, VA.

Kim, A. G. 1998. *The Use of Coal Combustion By-Products to Control Acid Mine Drainage*. Federal Energy Technology Center, U. S. Department of Energy. Available: http://www.fetc.doe.gov/products/power/enviro/ccb/amdcntrl.html [February 15, 1999].

Knape, B.K., ed. 1984. *Underground Injection Operations in Texas: A Classification and Assessment of Underground Injection Activities*, pp. 12-1 to 12-6. Texas Department of Water Resources Report 291. Austin, Texas: Texas Department of Water Resources.,

Levens, R. L., and C.M.K. Boldt. 1993. "Environmental Impacts of Mine Waste Sandfill." Spokane, Washington, DC: U.S. Bureau of Mines.

Levens, R. L., Marcy, A. D., and Boldt, C. M. K. 1996. *Environmental Impacts of Cemented Mine Waste Backfill*. U.S. Bureau of Mines Report of Investigation 9599, Spokane Research Center, Spokane, WA.

Longmire, P.A., Hicks, R.T., and Brookins, D.G. 1981. Aqueous Geochemical Interactions Between Ground Water and Uranium Mine-stope Backfilling--Grants Minieral Belt, New Mexico: Applications of Eh-pH Diagrams. Paper in Uranium Mill Tailings Managemetn: Proceedings of the Fourth Symposium (Ft. Collins, CO, October 26-27, 1981). Colorado State Uiversity, Ft. Collins, CO. Pp 389-414.

Lopez, R. 1995. Basin Resources, Inc. Fax to Ron Zdgb, U.S. EPA. October 25 1995.

Maddox, S. 1998. ASARCO, Incorporated. Letter to Scotty Sorrells, Tennessee Dept. of Environment and Conservation, transmitting analysis data for tailings from the Young Mill submitted in support of a Class V permit application. September 15, 1998.

Osborne, P.S. 1992. U.S. EPA Region 8, Ground Water Expert. Memorandum to Thomas Pike, U.S EPA, UIC Implementation Section. May 15, 1992.

Pappas, J. 1994. American Electric Power (AEP). Letter to John J. Sadzewicz, Ohio Environmental Protection Agency regarding Conesville Residual Waste Landfill Expansion Mine Grouting Program. March 14, 1994.

Parsons, Tina. 1999. West Virginia Department of Environmental Protection, Office of Water Resources. Telephone conversation with Craig Dean, ICF Consulting. September 10, 1999.

Ramsey, B. E. 1999. ARIPPA. Comments on USEPA Report to Congress on Fossil Fuel Combustion. USEPA Docket No. F-1000-FF2P-00019. June 12.

Righettini, G. 1999. Sutter Gold Mining Company. Letter of correspondence to K. Temple, ICF Consulting. March 31, 1999.

Robl, T. 1999. University of Kentucky, Center for Applied Energy Research. Letter of correspondence to Amber Moreen, USEPA. June 16, 1999.

Sands, P. F., Boldt, C. M. K., and Ruff, T. M. 1990. *Blind Pneumatic Stowing in Voids in Abandoned Mines*. U.S. Bureau of Mines Information Circular 9268, Spokane Research Center, Spokane, WA.

Scheetz, J. W. 1999. Homestake Mining Company. Letter of correspondence to K. Temple, ICF Consulting. April 16, 1999.

Schrand, W.D. 1992. Beech Coal Company. Letter of correspondence to Matt Mankowshi, U.S. EPA. April 2, 1992.

Smith, D.M, and H.W. Rauch. 1987. "Assessment of Class V Well Injection of Coal Mining Waste into Underground Mines in West Virginia." *International Symposium on Class V Injection Well Technology*, Washington, DC, 20-24 September 1987.

Sutter Gold Mining Company. 1998. "Environmental Analysis of Underground Backfilling at the Lincoln Project." Sutter Creek, California. March.

Thomson, B.M. and Heggen, R.J. 1982. Water Quality and Hydrologic Impacts of Dispsoal of Uranium Mill tailings by Backfilling. Paper in Management of Wawstes from Uranium Mining and Milling, IAEA, Vienna, Austria, IAE-SM-262/51. pp. 373-384.

Thomson, B.M., Longmire, P.A., and Brookins, D.G. 1986. *Geochemical Constraints on Underground Disposal of Uranium Mill Tailings*. Appl. Geochem., v. 1, pp 335-343.

Tg Soda Ash, Inc. 1997. Annual Mining Report, 1996-1997. Appendix C Injection Wells.

Underground Injection Practices Council Research Foundation. 1988. *Proceedings of the International Symposium on Class V Injection Well Technology*, Las Vegas, Nevada, 13-15 September, 1988.

U. S. Department of Energy (DOE). 1998a. Injection of FGD Grout to Abate Acid Mine Drainage in Underground Coal Mines. Project Fact Sheet AR020.1298. Available: http://www.fetc.doe.gov/products/power/enviro/ccb/factshts/factshts.html [February, 1999].

U. S. Department of Energy (DOE). 1998b. Injection of Coal Combustion ByProducts (CCBs) Into the Omega Mine for the Reduction of Acid Mine Drainage. Project Fact Sheet AR022.1298. Available: http://www.fetc.doe.gov/products/power/enviro/ccb/factshts/factshts.html [February 1999]

U.S. EPA. 1984. National secondary drinking water regulations. Publication No. EPA 570/9-76-000.

U.S. EPA. 1992. Integrated Risk Information System (IRIS) Background Document 4: U.S. EPA Regulatory Action Summaries. Cincinnati, OH: Office of Research and Development. January.

U.S. EPA. 1993a. Health Advisories for Drinking Water Contaminants. Office of Water Health Advisories. Lewis Publishers, Ann Arbor.

U.S. EPA 1993b. 1993 Fossil Fuel Combustion Database. Unpublished. Office of Solid Waste
.

U.S. EPA. 1995a. Rule Authorization for Basin Resources, Inc. EPA RA File #C05000-03715. October 31, 1995.

U.S. EPA. 1995b. National Primary Drinking Water Regulations Contaminant Specific Fact Sheets Inorganic Chemicals - Technical Version. Washington, D.C.: Office of Water, Office of Ground Water and Drinking Water. EPA 811-95-002-T. http://www.epa.gov/OGWDW/dwh/t-ioc.html. October.

U.S. EPA. 1996. Drinking Water Regulations and Health Advisories. Office of Water. EPA 822-B-96-002.

U.S. EPA. 1998. National primary drinking water regulations. 40 CFR §141.32.

U.S. EPA. 1999a. Integrated Risk Information System (IRIS). Cincinnati, OH: Office of Research and Development, National Center for Environmental Assessment. Available: http://www.epa.gov/ngispgm3/iris/index.html [March].

U.S. EPA. 1999b. National Primary Drinking Water Regulations Technical Fact Sheets. Washington, D.C.: Office of Water, Office of Ground Water and Drinking Water. Available: http://www.epa.gov/OGWDW/hfacts.html [March].

U.S. EPA. 1999c. Sulfate in Drinking Water. Office of Ground Water and Drinking Water. http://www.epa.gov/OGWDW/sulfate.html. April.

University of Kentucky. 1998. High Volume--High Value Usage of Flue Gas Desulfurization (FGD) By-Products in Underground Mines. Final Technical Report for the period October 1, 1993 to July 31, 1998. U. S. Department of Energy Cooperative Agreement No. DE-FC21-93MC30251. Center for Applied Energy Research, Lexington, Kentucky.

Vlasak, P. et al. 1993. "Ash Slurry Behavior in Process of Hydraulic Backfill in Underground Coal Mine." *Slurry Handling and Pipeline Transport 12th International Conference*, Brugge, Belgium. September 1993.

Walker, J.S. 1993. "State-of-the-act techniques for backfilling abandoned mine voids." Pittsburgh, PA: U.S. Bureau of Mines.

Whaite, R.H. and A.S. Allen. 1975. "Pumped-Slurry Backfilling of Inaccessible Mine Workings for Subsidence Control." Washington, DC: U.S. Bureau of Mines.

Whitlatch, E. E., Bair, E. S., Chin, Y. P., Traina, S. J., Walker, H. W., and Wolfe, W. E. 1998. *Injection of FGD Grout to Mitigate Acid Mine Drainage at the Roberts-Dawson Underground Coal Mine, Coshocton and Muskingum Counties, Ohio*. Final Report to Ohio Coal Development Office, Department of Development, State of Ohio. Columbus, OH. December, 6, 1998.

Wickersham, Dale B. 1995. Wickersham Consulting. Letter to Beth Goodnough, Rhone-Poulence (now known as OCI) of Wyoming. September 29, 1995.

Wyoming. 1996. "Department of Environmental Quality: Groundwater Pollution Control Permit, Authorization to Discharge into Underground Receiver." Permit #96-201. June 14, 1996.

Wyoming. 1988. "Department of Environmental Quality: Groundwater Pollution Control Permit, Authorization to Discharge into Underground Receivers." Permit #UIC88-411. October 11, 1988.