2 *IN-SITU* LEACH URANIUM RECOVERY AND ALTERNATIVES

Chapter 2 provides information on uranium recovery using the *in-situ* leach (ISL) process. The first part of the chapter gives basic information on the type of uranium deposits that are amenable to ISL technology and an overview description of the different parts of an ISL facility. Sections 2.2 through 2.6 describe different stages of an ISL facility's lifecycle, including pre-construction, construction, operation, aquifer restoration, and decommissioning. Sections 2.7 through 2.10 include discussions of aspects such as occupational health radiation monitoring, waste management, transportation, and financial assurance that are common to all ISL uranium facilities and not confined to any one stage. Section 2.11 summarizes operational experience of ISL facilities regulated by the U.S. Nuclear Regulatory Commission (NRC). Sections 2.12 and 2.13 discuss the alternatives considered in this Draft GEIS.

As stated, this chapter is organized by different stages in the life of an ISL facility. NRC recognizes that other than the pre-construction phase, aspects of the other four phases could be performed concurrently. However, by describing the ISL process in terms of these stages, NRC considers that this aids in the discussion of the ISL process and in the evaluation of potential environmental impacts during the lifecycle of an ISL facility.

2.1 Overview of ISL Uranium Recovery

Only certain uranium deposits are amenable to the ISL recovery process. To understand why the ISL recovery process is an effective recovery method for certain uranium deposits, it is necessary to understand the chemical and physical characteristics of uranium ore. This section will describe the geochemistry of uranium, provide a brief geologic overview of uranium ore bodies in the four Draft GEIS regions, and a general description of ISL facilities.

Characteristics of Uranium Deposits That Are Amenable to ISL Extraction

Certain geologic and hydrological features make a uranium deposit suitable for ISL technologies (based on Holen and Hatchell, 1986):

- **Deposit geometry.** The operator defines well field boundaries based on the geometry of the specific uranium mineralization. The deposit should generally be horizontal and have sufficient size and lateral continuity to economically extract uranium.
- **Permeable host rock.** The host rock must be permeable enough to allow the mining solutions to access and interact with the uranium mineralization. Preferred flow pathways such as fractures may short circuit portions of the mineralization and reduce the recovery efficiency. The most common host units are sandstones.
- **Confining layers.** Hydrogeologic (formation) geometry must prevent uranium-bearing fluids (i.e., lixiviant) from vertically migrating. Typically, low permeability layers such as shales or clays confine the uranium-bearing sandstone both above and below. This isolates the uranium-producing horizon from overlying and underlying aquifers.
- **Saturated conditions.** For ISL extraction techniques to work, the mineralization should be located in a hydrologically saturated zone.

2.1.1 Geochemistry of Uranium

Natural uranium occurs in minerals as each of these isotopes: U-238 (99.274 percent), U-235 (0.720 percent), and U-234 (0.0055 percent) (EPA, 2007a) and predominantly exists in one of two ionic states: U^{6+} (the uranyl oxidized ion) and U^{4+} (the uranous reduced ion) (EPA, 1995). In the oxidized (uranyl) state, uranium is more readily dissolved. In the uranous (U^{4+}) state, uranium solubility is very low (i.e., it does not readily dissolve in water). Common uranous minerals include uraninite (UO_2), pitchblende (a crystalline variant of uraninite), and coffinite [$U(SiO_4)(OH)_4$] (EPA, 1995; Nash et al., 1981).

2.1.2 Physical Characteristics of Uranium Deposits

Uranium deposits subject to recovery in the United States are primarily found in four types of deposits: stratabound, breccia pipes, vein, and phosphatic (EPA, 1995). Deposits that are generally amenable to ISL recovery in the four Draft GEIS regions are stratabound deposits. These deposits are contained within a single layer (strata) of sedimentary rock. It is believed that these deposits were formed through the transport of uranium (and associated elements) by oxidizing groundwater (i.e., groundwater with chemical properties that cause the uranium ion to lose electrons) (EPA, 1995; Nash et al., 1981). The groundwater flowed through the uranium-containing rocks, causing the uranium to dissolve and leach from the rock. The uranium remained soluble in the groundwater until it encountered a reducing environment (i.e., an environment with chemical properties that caused the uranium ion to gain electrons), became less soluble in water and precipitated.

Depending upon the environmental conditions, stratabound deposits can take different physical forms and are typically described as either roll-front deposits or tabular deposits. Roll-front deposits (Figure 2.1-1) are found in basins in Wyoming, southwestern South Dakota and northwestern Nebraska. Tabular deposits (see Figure 2.1-2) are found in the Colorado Plateau, including northwestern New Mexico.

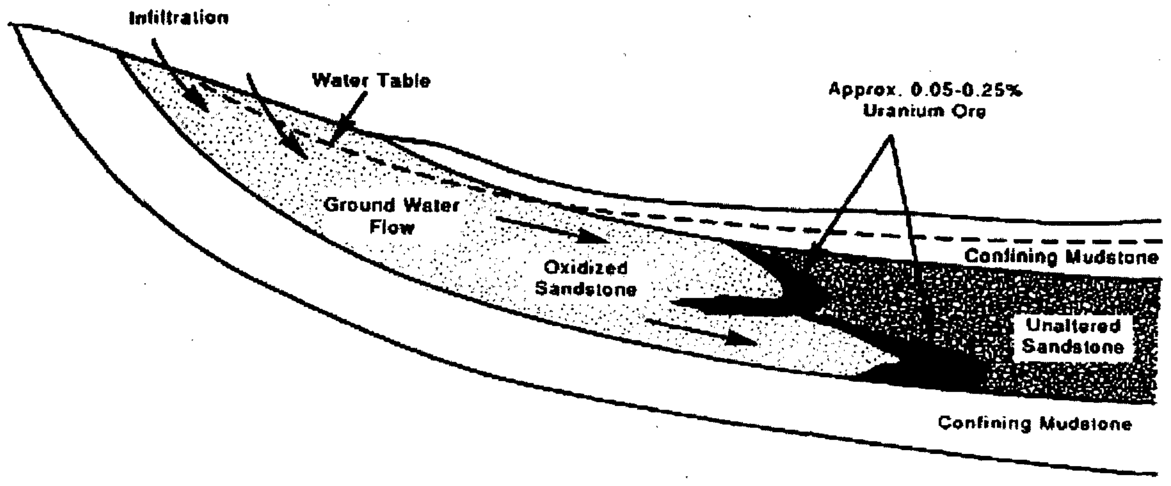

Figure 2.1-1. Simplified Cross-Section of Sandstone Uranium Roll-Front Deposits Formed by Regional Groundwater Migration (NRC, 1997a)

A roll-front deposit is a uranium ore-body deposited at the interface of oxidizing and reducing groundwater (EPA, 1995; Nash et al., 1981). In basins in Wyoming, oxidized groundwater containing uranium flowed through permeable sandstone beds until reducing groundwater was reached, and the uranium precipitated out at this interface. The sandstone beds are generally confined by low- or semi-permeable units such as claystones, siltstones, mudstones, or shales. As the oxidizing and reducing environments migrated within the sandstone beds, the uranium ore deposited over a laterally extended area (EPA, 1995). These roll-front deposits have a crescent shape and may extend hundreds of meters [feet] in length, but may only be a few meters [feet] thick.

The tabular deposits of the Colorado Plateau were formed when oxidized groundwater with higher concentrations of uranium and vanadium flowed through zones of highly permeable organic matter (humates), gases (hydrogen sulfide), or liquids capable of reducing the uranyl ion (EPA, 1995). The uranium deposited in the areas where the reducing conditions were created. The deposits are typically tabular in shape and can be found in sandstones, limestones, siltstones, and conglomerates scattered throughout various portions of the Colorado Plateau, including northwestern New Mexico. The tabular deposits found in northwestern New Mexico result from organic matter and occur in sandstones and siltstones. These deposits can range from about 0.5 to 2 m [2 to 6 ft] thick and hundreds of meters [feet] wide. These deposits have provided over 50% of the total uranium production in the United States (EPA, 1995).

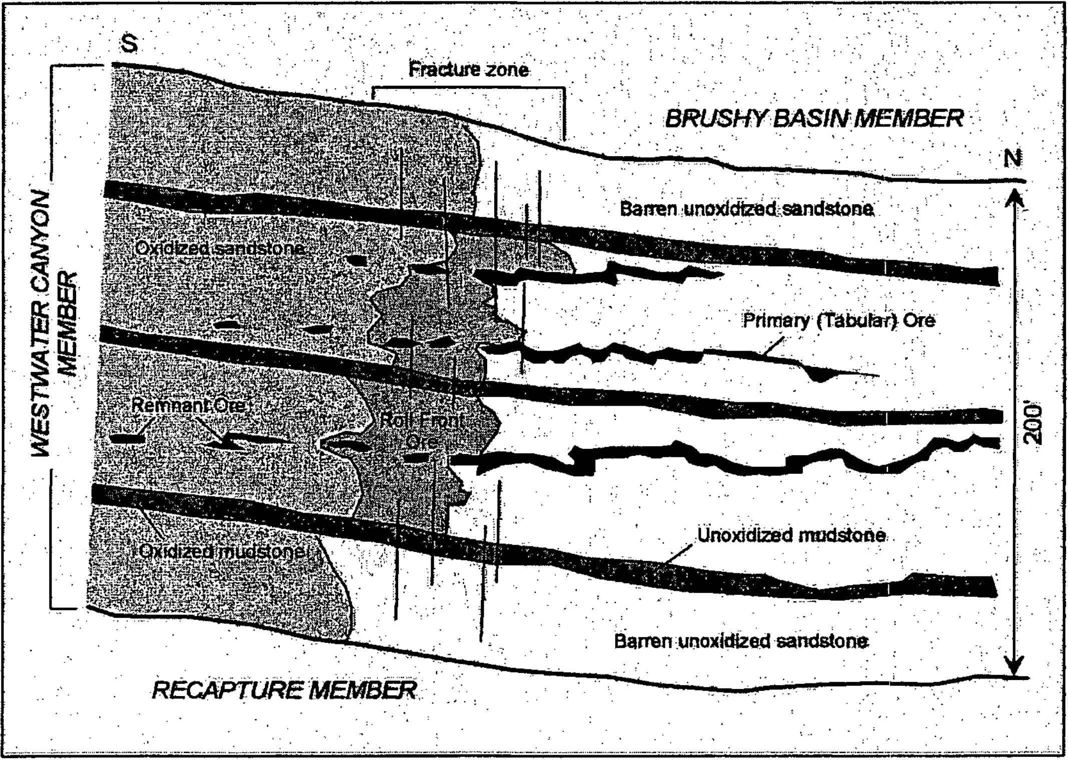

Figure 2.1-2. Schematic Diagram of the Different Types of Stratabound Uranium Deposits in the Grants Uranium District, New Mexico (Modified from Holen and Hatchell, 1986)

Uranium concentrations in the ore deposit vary depending on system geochemistry and hydrology. For example, in New Mexico, uranium deposits typically contain about 0.2 to 0.3 percent U_3O_8 by weight, while deposits in Wyoming contain about less (about 0.1 to 0.25 percent) (Energy Information Administration, 2004; McLemore, 2007). The depth to the uranium mineralization ranges from about 100–300 m [328 to 984 ft] (e.g., Church Rock, New Mexico; Gas Hills, Wyoming; Smith Ranch, Wyoming, and Crow Butte, Nebraska) to greater than 560 m [1,840 ft] at Crownpoint, New Mexico. The most common uranium minerals in roll-front deposits are uraninite (UO_2), pitchblende, and coffinite [$U(SiO_4)(OH)_4$]. Minor quantities of the uranium-vanadium mineral tyuyamunite [$Ca(UO_2)_2(VO_4)_2 \cdot H_2O$] are also typically present (Nash, et al., 1981).

2.1.3 General Description of ISL Facilities

This section briefly describes the layout of an ISL facility. More detailed descriptions of the individual stages of ISL uranium recovery (construction, operations, aquifer restoration, decommissioning/reclamation) are included in Sections 2.3 through 2.6. A commercial ISL facility consists of both an underground and a surface infrastructure. The underground infrastructure includes injection and production wells drilled to the uranium mineralization zone, monitoring wells drilled to the adjacent overlying and underlying aquifers, and perhaps deep injection wells to dispose of liquid wastes. Pipelines to transfer groundwater extracted from the well fields to the uranium processing circuit are buried to avoid freezing and thus are also considered in this Draft GEIS to be part of the underground infrastructure.

ISL facilities also include a surface infrastructure that supports uranium processing. The surface facilities can include a central uranium processing facility, header houses to control flow to and from the well fields, satellite facilities that house ion exchange columns and reverse osmosis for ground water restoration, and ancillary buildings that house administrative and support personnel. Surface impoundments such as solar evaporation ponds may be constructed to manage liquid effluents from the central processing plant and the ground water restoration circuit (Figure 2.1-3).

The surface extent of a full-scale (i.e., commercial) ISL facility includes a central processing facility and supporting surface infrastructure for one or more well fields (sometimes called mine units) encompasses about 1,000 to 6,000 ha [2,500 to 16,000 acres] (NRC, 1992, 1997a) (see Section 2.11). However, the total amount of land disturbed by such infrastructure and ongoing activities at any one time is much smaller, and only a small portion around surface facilities is fenced to limit access (Figures 2.1-3 and 2.1-4). Using license conditions, NRC establishes the total flow rates and the maximum amount of uranium that can be produced annually at a commercial ISL facility. NRC-licensed flow rates typically range from about 15,100 to 34,000 L/min [4,000 to 9,000 gal/min], and licensed maximum limits on annual uranium production range from about 860,000 to 2.5 million kg/yr [1.9 million to 5.5 million lb/yr] of yellowcake (NRC, 1995, 1998a,b, 2006, 2007). Actual production rates are somewhat lower (Energy Information Administration, 2008).

What is Yellowcake?

Yellowcake is the common name given to the uranium concentrate produced by milling and chemical processing. The yellowcake produced by most modern mills is a coarse, insoluble (does not dissolve in water) powder that is actually brown or black, not yellow. The name comes from the color and texture of the concentrates produced by early uranium milling production methods.

U_3O_8 depends on the processes used, but modern yellowcake typically contains 70 to 90 percent U_3O_8 by weight. Yellowcake is produced by all countries in which uranium is milled.

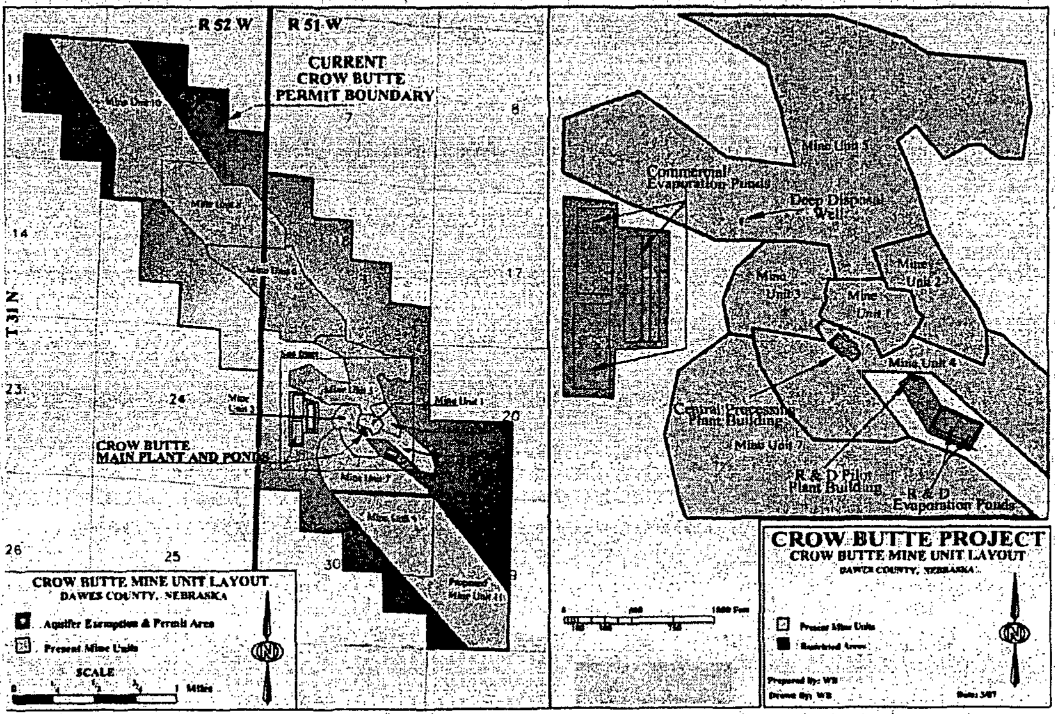

Figure 2.1-3. Layout of the Crow Butte Uranium Project in Dawes County, Nebraska (From Crow Butte Resources, Inc., 2007)

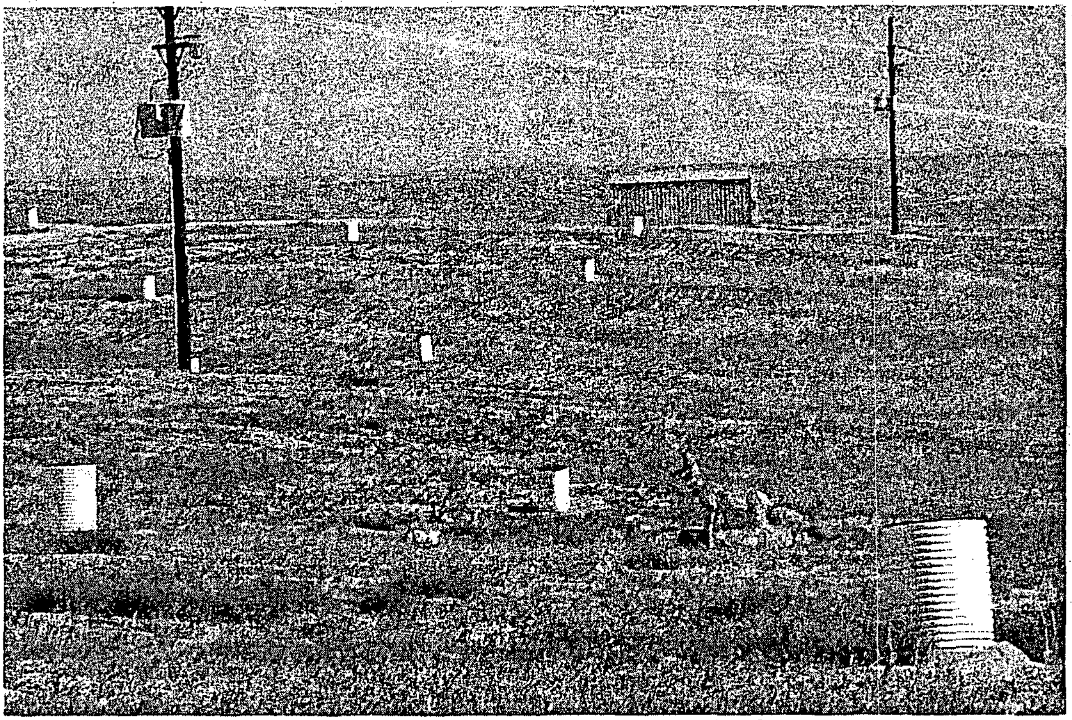

Figure 2.1-4. Well Heads and a Header House at Smith Ranch, Converse County, Wyoming

2.2 Pre-Construction

The applicant must characterize the potential site to support an application for a license to construct and operate an ISL facility (NRC, 2003a, Chapters 2 and 7). During the initial licensing review for a new ISL facility, NRC does not require a comprehensive discussion of all aspects of the site and of planned operations (NRC, 2003a). Instead, at this stage, the applicant needs to provide enough information to generally locate the uranium mineralization, understand the natural systems involved, and establish baseline conditions prior to operation. If a license is granted, the licensee would collect more detailed information as each well field is developed and brought into production (NRC, 2003a).

A number of general types of site baseline information to be provided by the license applicant are described in NRC guidance (NRC, 2003a, Chapter 2; 1982). Specific features of the site or its environs may also be identified and used by the applicant to support the proposed facility description. The applicant would provide maps to locate the proposed site, and identify proposed surface facilities, well fields, and other features of the ISL facility. In addition to providing information about the proposed site location and the environment in the vicinity of that location (e.g., water use, subsurface geology, hydrology, ecology, historical and cultural resources), the applicant also provides required population data and assessments of trends in population and industry patterns (NRC, 2003b, Appendix C).

Given the nature of the ISL uranium recovery process, hydrologic characterization of the site is a critical component of the applicant's pre-construction activities. This characterization describes surface-water features in the site area and the specific groundwater hydrogeologic setting, including detailed hydrogeologic and hydraulic descriptions of the proposed uranium production zone, adjacent aquifers, and low-permeability units that isolate the production zone.

Applicants are to determine baseline water quality for both the production zone and for adjacent un-mineralized zones (NRC, 2003a). An NRC-accepted list of constituents to be sampled is shown in Table 2.2-1, although an applicant can propose a list of constituents that is tailored to a particular location. To establish appropriate groundwater restoration standards, NRC requires that applicants and licensees establish pre-operational nonradiological and radiological groundwater quality baselines within the proposed permit boundaries and adjacent properties. These baseline conditions are based on samples collected over a period of at least 1 year, with a distribution that is sufficient to characterize the different aquifers and surface water bodies (NRC, 2003a).

Table 2.2-1. Typical Baseline Water Quality Parameters and Indicators*

Physical Indicators		
Specific Conductivity	Total Dissolved Solids†	pH‡
Major Elements and Ions		
Alkalinity	Chloride	Sodium
Bicarbonate	Magnesium	Sulfate
Calcium	Nitrate	
Carbonate	Potassium	
Trace and Minor Elements		
Arsenic	Iron	Selenium
Barium	Lead	Silver

Table 2.2-1. Typical Baseline Water Quality Parameters and Indicators* (continued)

Trace and Minor Elements (continued)		
Boron	Manganese	Uranium
Cadmium	Mercury	Vanadium
Chromium	Molybdenum	Zinc
Copper	Nickel	
Fluoride	Radium-226§	
Radiological Parameters		
Gross Alpha@	Gross Beta	

*Based on U.S. Nuclear Regulatory Commission (NRC). NUREG–1569, "Standard Review Plan for *In-Situ* Leach Uranium Extraction License Applications—Final Report." Table 2.7.3-1. Washington, DC: NRC. June 2003.
† Laboratory only.
‡ Field and laboratory determination.
§ If site initial sampling indicates the presence of thorium-232, then radium-228 should be considered in the baseline sampling, or an alternative may be proposed.
@ Excluding radon, radium, and uranium.

License applicants also collect site-specific data to establish background radiological characteristics of the site. These data may include measurements of radionuclides occurring in important flora and fauna species, soil, air, and surface and groundwaters that ISL operations could affect.

2.3 Construction

General construction activities associated with ISL facilities include drilling wells, clearing and grading associated with road construction and building foundations, building construction, trenching and laying pipelines, and building evaporation pond impoundments. Construction-related activities continue throughout much of the life of the project as different well fields are developed and additional wells and surface structures are added. For a satellite facility, the initial construction of the surface facilities would take about 2–3 months (NRC, 2004). Construction and testing of a well field may take about a year and a half (NRC, 2006), with about four to eight drill rigs and support vehicles operating in the field (NRC, 2004, 1997a). Well field construction would require about 50 to 75 contractors and full-time employees (NRC, 2004).

2.3.1 Underground Infrastructure

The underground infrastructure at an ISL facility is established to inject, produce, and monitor groundwater, and to transfer fluids between the wells and other production facilities.

2.3.1.1 Well Fields

Well Field Design. The licensee establishes the injection and production well patterns to recover uranium. The well patterns are developed for a specific site, and installation for a given well field is based on the subsurface geometry of the ore deposit. Various pattern shapes are used, although five-spot and seven-spot patterns are common (NRC, 2003a). A typical well arrangement using five- and seven-spot patterns is shown in Figure 2.3-1. Because roll-front uranium deposits normally have irregular shapes, some of the well patterns in a given well field are also irregular, and the licensee may alter well patterns to fit the size, shape, and boundaries of individual ore bodies.

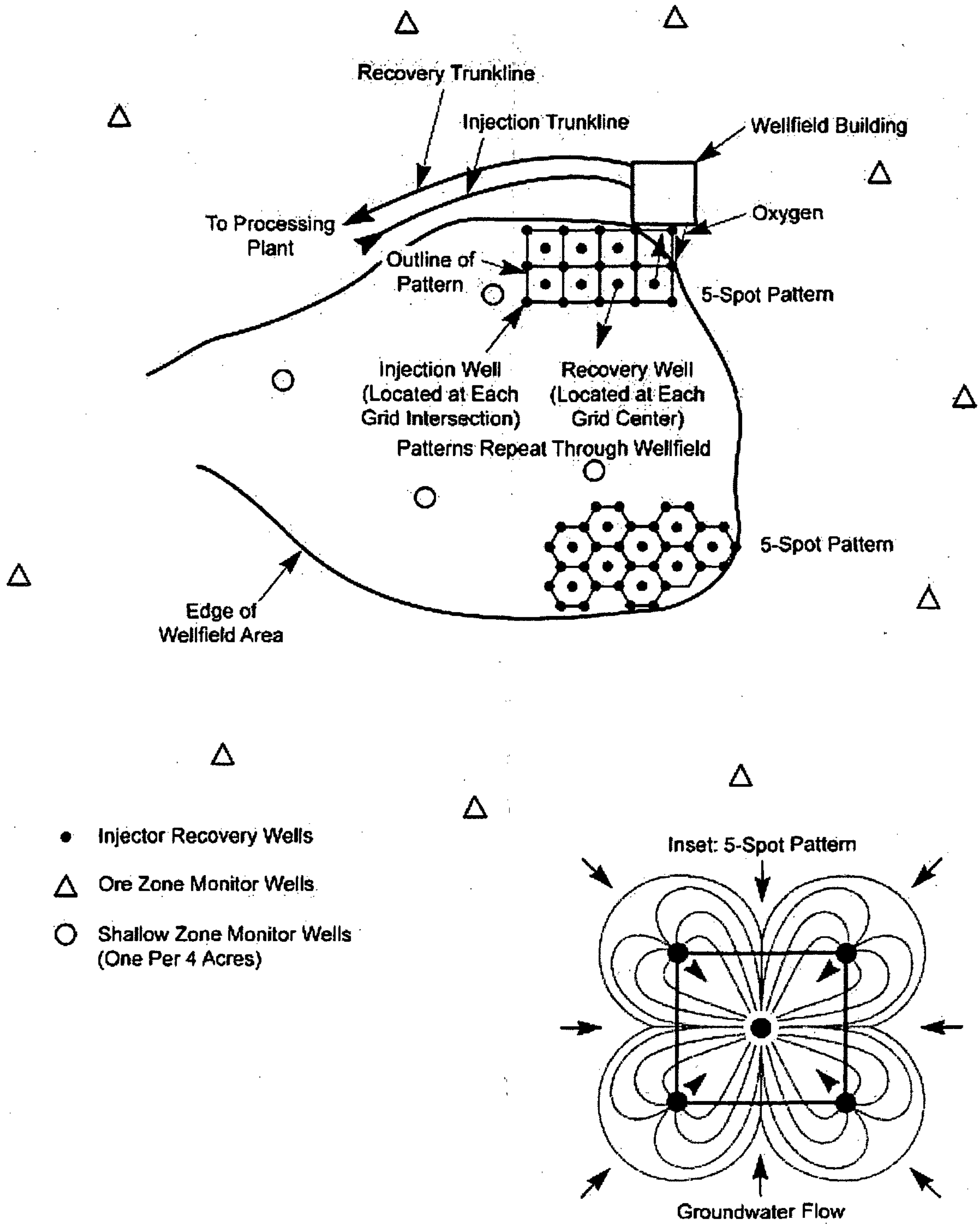

Figure 2.3-1. Schematic Diagram of a Well Field Showing Typical Injection/Production Well Patterns, Monitor Wells, Manifold Buildings, and Pipelines (From NRC, 1997a)

These characteristics will also influence the number of wells in a well field. For example, at the Crow Butte ISL facilities in Dawes County, Nebraska, the number of injection and production wells varied from about 190 in the first well field (MU-1) to about 900 wells in later well fields (MU-5 and MU-6) (NRC, 1998b).

Three types of wells are predominant at uranium ISL facilities:

- Injection wells for introducing solutions into the uranium mineralization
- Production wells for uranium production
- Monitoring wells for assessing ongoing operations

In addition, the licensee or applicant may also drill deep injection wells permitted by the EPA or state for liquid waste disposal. Injection and production wells are connected to manifolds in a nearby header house (Figure 2.3-2). The manifolds connect to a series of pipelines that carry solutions to and from the recovery plant or satellite facility. Meters and control valves (usually computerized) in individual well lines monitor and control flow rates and pressures for each well to maintain water balance and to aid in identifying leaks in the system (Figure 2.3-3). The well field piping is typically high-density polyethylene pipe, polyvinyl chloride (PVC), and/or steel. Individual well lines and larger trunk lines to the recovery plant are buried below the frost line {e.g., 2 m [6 ft] in Wyoming} to prevent transferred solutions from freezing (NRC, 2006).

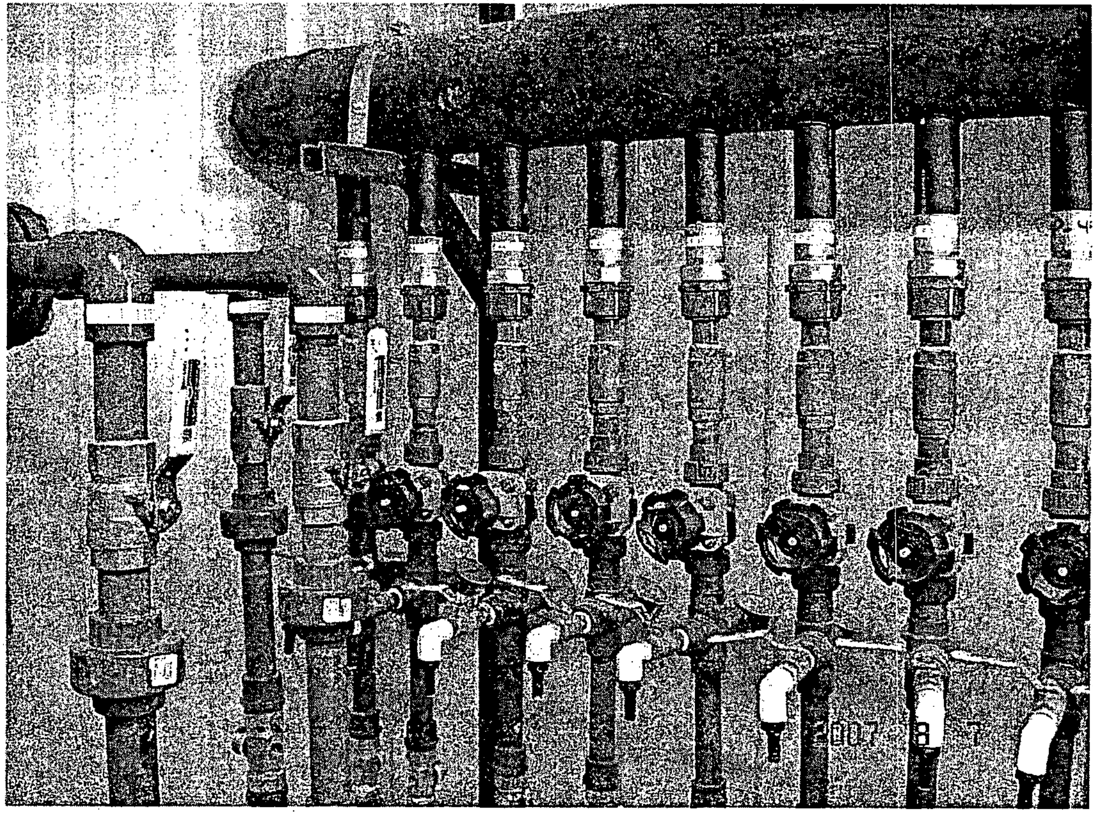

Figure 2.3-2. Manifold Inside Well Field Header House at an ISL Facility

Commercial-scale uranium ISL facilities usually have more than one well field. For example, the Crow Butte facility in Dawes County, Nebraska, has constructed 10 well fields since 1991 and has plans for an eleventh (Crow Butte Resources, Inc., 2007). The Reynolds Ranch satellite facility in Converse County, Wyoming, plans to include eight well fields (NRC, 2006). As described in Section 2.1.1, the well fields are developed in sequence, and at any one time, different well fields are likely to be in different stages of construction, operation, aquifer restoration, and decommissioning/reclamation (Crow Butte Resources, Inc., 2007). Construction and testing for each well field may take up to a year and a half before production begins (NRC, 2006). The locations and boundaries for each well field are adjusted as more detailed data on the subsurface stratigraphy and uranium mineralization distribution are collected during well field construction.

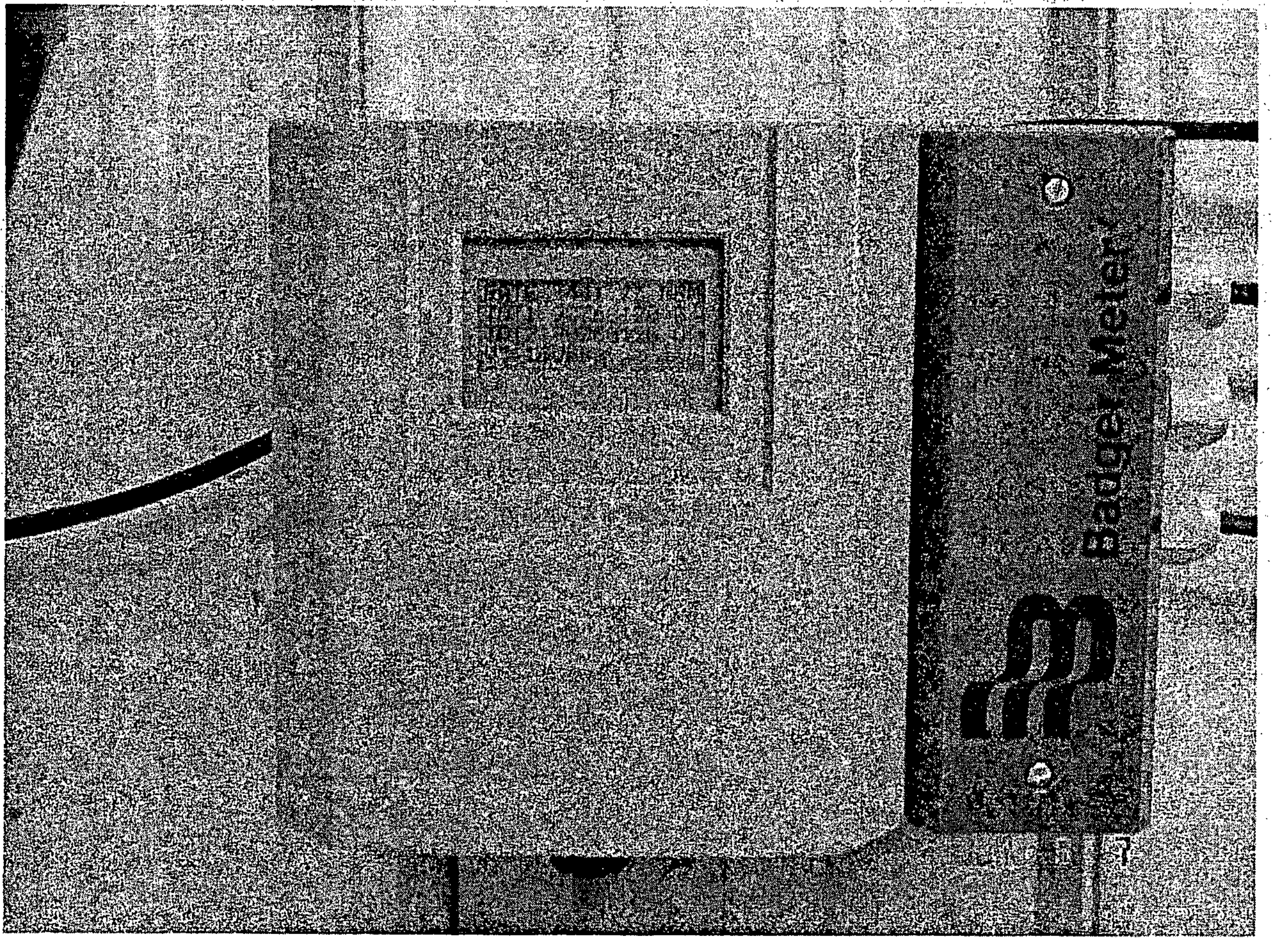

Figure 2.3-3. Computerized Meter for Monitoring Well Field Flow Rates

Well Drilling. Standard drilling techniques are used to develop ISL well fields. Temporary access roads for drilling rig trucks, support vehicles, and excavators lead to each well location. At the drilling location, a flat drill pad may be graded. At most ISL well fields, injection, production, and monitoring wells are drilled to the desired depth {e.g., 100–300 m [328–984 ft] for a target uranium production zone} by a standard method such as mud rotary drilling. In this method, a string of drill pipe and a drill bit is rotated against the formation. A water-based drilling fluid (mud) is circulated through the hole to lubricate the bit and to carry the drilled material to the surface. A temporary mud pit is excavated directly in the ground next to the drill site to contain the drilling mud. Depending on the depth to the uranium mineralization and site-specific hydrogeological characteristics, other drilling methods may be used. While a well field is being drilled, detailed stratigraphic information and uranium ore occurrence data are collected. The locations and boundaries of a well field are then adapted to the subsurface geometry of a specific ore body. As the driller reaches the final depth of a well, it is usually logged with a variety of downhole geophysical tools (e.g., natural gamma ray logging, electrical resistivity) to characterize the well stratigraphy and reamed out to adjust the borehole diameter to construct a well. Residual cuttings and drilling fluids are typically held in the mud pit after drilling and construction activities are completed. Depending on state and local regulations, such pits are backfilled and graded or are alternatively emptied and cleaned, and residual solids and liquids are transported and disposed of offsite (NRC, 2006).

Well Construction. The geologic units above the aquifer of interest typically are sealed with steel or PVC casing grouted in place (Figure 2.3-4). This firmly sets the casing and prevents groundwater leakage from or to overlying aquifer(s). Grouts and casing materials are selected by the licensee or applicant to be inert with respect to the lixiviant and based on the depth of the well and anticipated well pressures. Depending on local hydrogeologic conditions, these well construction steps generally are followed:

- Sections of the uranium mineralized aquifers are left as open holes and screened with either steel or PVC screen material.

- Screens are then connected to the ground surface with steel or PVC riser pipes.

- The space between the casing and the borehole (i.e., the annulus) is filled with properly graded sand or gravel pack material, or the formation is simply left to collapse around the screen.

- A seal of bentonite clay is installed above the top of the screen.

- The annulus above the bentonite seal between the screen/riser pipe assembly and the borehole is typically grouted to the ground surface with a mixture of cement, bentonite, and water.

To make access and maintenance easier, well heads are completed above ground. Depending on local weather and land conditions, a variety of protective enclosures is used around the well head to protect it from the elements. Before the well head construction of an injection or production well is completed, the well is connected by underground piping to an injection or production manifold of a nearby header house.

Monitoring wells are not usually connected to any other structure but can have cables connected to different sensors in the well (NRC, 2006).

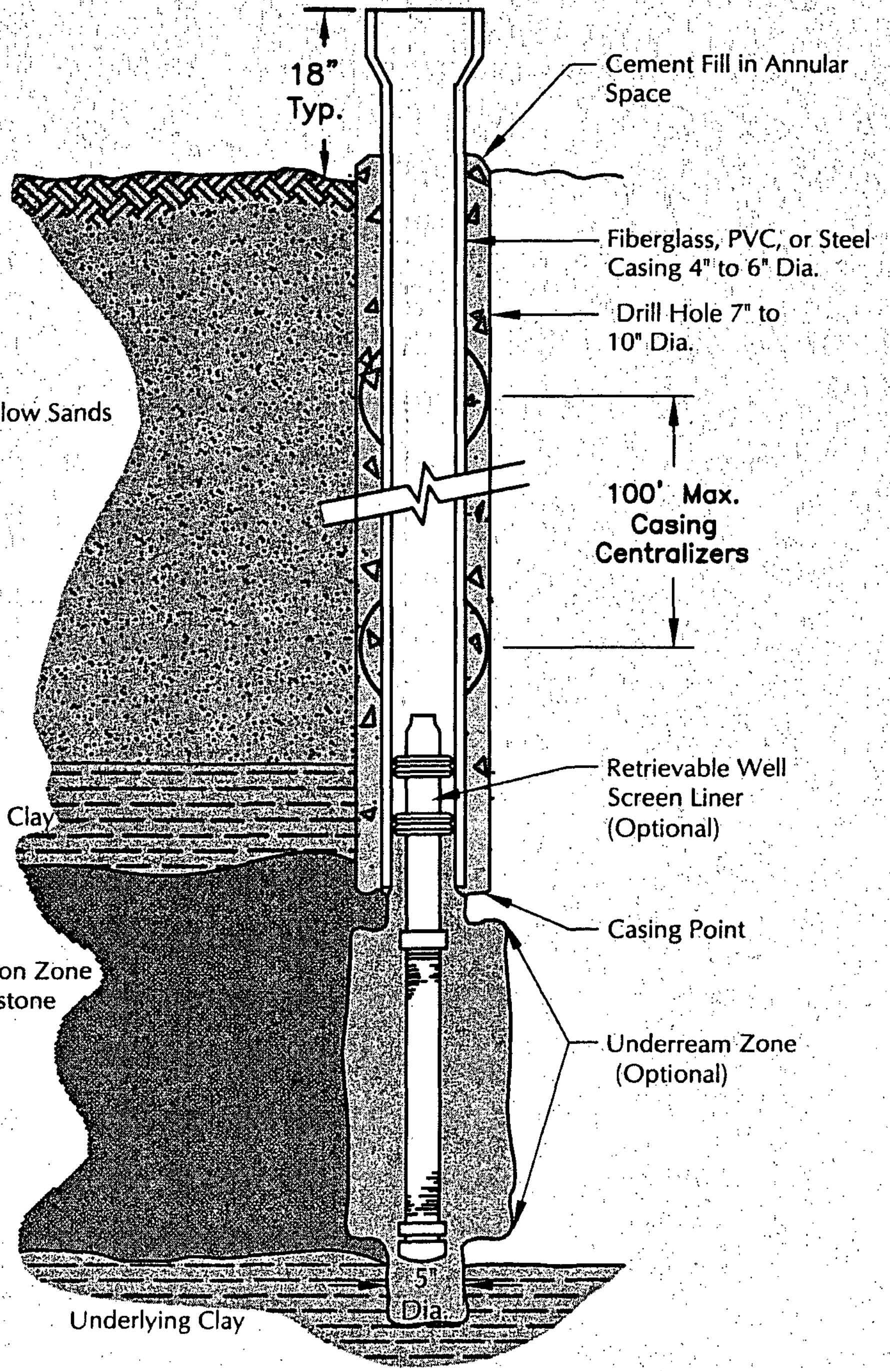

Figure 2.3-4. Cross Section of a Typical Injection, Production, or Monitoring Well Completed Using the Underreamed Method (Modified From NRC, 1997)
[1 in = 2.54 cm; 1 ft = 0.305 m]

1

Well Development and Integrity Testing. Wells are usually developed using an air lift method or other pumping method appropriate for local conditions. Well development removes remaining drilling mud, cuttings, and fine particles (i.e., silt and clay) from inside the well, the screen, and surrounding gravel/sand pack. Development improves well yield by enhancing hydraulic communication between the undisturbed aquifer and the well. The licensee also performs a mechanical integrity test (MIT) to verify that the well casing does not fail, causing water loss during injection or recovery operations. In an MIT, the bottom and top of the casing are plugged (sealed) with an inflated downhole packer or similar sealing device. The well is pressurized, and pressure gauges monitor pressure changes inside the casing. Based on site-specific conditions, after maintaining a specified pressure for a specified period without a measurable decrease, the well casing is considered to have passed an MIT and the well is fit for injection or production operations (NRC, 2006).

Mechanical Integrity Testing

After completion and before brining into service, injection and recovery wells are tested for mechanical integrity. As described in NRC (2003a, Section 3.1.3), a packer is set above the well screen and the well casing is filled with water. At the surface, the well is pressurized with either air or water to 125 percent of the maximum operating pressure, which is calculated based on the strength of the casing material and depth. The well pressure is monitored to ensure significant pressure drops do not occur through borehole leaks. A pressure drop of no more than 10 percent in a period of 10 to 20 minutes indicates the casing and grout are sound and the well is fit for service. Well integrity tests are also performed if a well has been serviced with equipment or procedures that could damage the well casing. Additionally, each well is retested periodically (once each 5 years or less) to ensure its continued integrity.

2.3.1.2 Pipelines

The following piping systems are typically installed as part of the underground infrastructure:

- Between the central uranium processing facility or the satellite facility and the pump house for transporting lixiviant

- Between the pump house and well field for injecting and recovering lixiviant

- Between processing facilities and wastewater disposal sites (e.g., deep injection wells, evaporation ponds)

The network of process pipelines and cables required in ISL operations would be buried because of freezing temperatures that are common in the regions considered in this Draft GEIS and because of safety and land imprint issues. This network of pipelines and cables connects

- Injection and recovery wells to manifolds inside pumping/injection header houses

- Header houses to a central uranium processing facility or to satellite resin facilities (if present)

- Header houses to a central uranium processing facility or the central facility to deep injection wells used for liquid waste disposal

Depending on local winter conditions, burial trenches can be excavated as deep as 2 m [6 ft] below the ground surface to avoid any potential freezing problem (e.g., NRC, 2006). High-density polyethylene, PVC, or steel pipes used to convey water, lixiviant, resin, and wastewater are placed in these unlined trenches along with numerous electrical, communication, and sensor cables. Trenches are typically backfilled with native soil and graded to surrounding ground topography. Pipeline pressures are instrumented and recorded to monitor for potential leaks and spills that might result from the failure of pipeline fittings and valves.

2.3.2 Surface Facilities

ISL facilities require construction of different surface facilities, ranging from standard industrial buildings with associated power, water, and heating, ventilation, and air conditioning to specialized structures such as evaporation ponds (NRC, 2003a). Examples of surface facilities may include

- Central uranium processing facilities, with a typical footprint of about 3,060 m^2 [33,000 ft^2] (NRC, 1998b)
- Satellite facilities {about 1,200 m^2 [13,000 ft^2] (NRC, 2006)} that contain remote ion exchange columns
- Administration, operation, and field office or other support facilities
- Pump and header houses that house equipment to transfer lixiviant between the wells and pipelines
- Liquid effluent handling facilities, such as solar evaporation ponds. Typical evaporation ponds have surface areas ranging from 0.04 to 2.5 ha [0.1 to 6.2 acres] (NRC, 1998a; Crow Butte Resources, Inc., 2007)

In addition, to provide access between the well field and various surface facilities, the applicant or licensee would construct roads (dirt and/or paved) for

- Access to well fields and pump houses
- Access between the well fields/pump houses and the satellite facilities
- Access between the satellite facilities and the central processing facility
- Access between the processing plant and main transportation routes

The surface facilities and access roads are designed and built using standard construction techniques. Specific building codes are used as appropriate. Construction vehicles may include bulldozers, drilling rigs, water trucks, forklifts, pump hoist trucks, coil tubing trucks, pickup trucks, portable air compressors, and other support vehicles.

Evaporation ponds may be constructed to dispose of effluent from the processing circuit or from aquifer restoration activities. These impoundments are designed and constructed with liners and leak detection systems installed in accordance with applicable NRC guidance (NRC, 1977, 2003a, 2008). Embankments for these evaporation ponds are constructed to resist erosion from wave action in the pond. The size and shape of the ponds are designed based on the amount of water that must be managed and the evaporation rates for the region. Sufficient space is conserved so that the contents of one pond may be transferred to another to allow any identified pond system leaks to be repaired and also to meet freeboard requirements from possible wave action.

2.4 Operations

Although specific operations will vary depending on the individual operator and site-specific characteristics, the ISL uranium recovery process generally involves two primary operations: (1) injection of barren lixiviant to mobilize uranium in underground aquifers and (2) extracting and processing the pregnant lixiviant in surface facilities to recover the uranium and prepare it for shipment.

2.4.1 Uranium Mobilization

During ISL operations, chemicals are added to the groundwater to produce a leaching solution or lixiviant. The lixiviant is injected into the production zone to mobilize (dissolve) uranium from the underground formation and subsequently remove uranium from the deposit.

Basic Steps in Uranium Mobilization

- **Groundwater Injection.** The operator injects a nonuranium-bearing (barren) extraction solution or lixiviant through wells into the mineralized zone. The lixiviant moves through pores in the production zone, dissolving uranium and other metals.
- **Groundwater Extraction.** Production wells withdraw the resulting "pregnant" lixiviant, which now contains uranium and other dissolved metals, and pump it to a central processing plant or to a satellite processing facility for further uranium recovery and purification.

2.4.1.1 Lixiviant Chemistry

The lixiviant that is selected must leach uranium from the host rock and keep it in solution during groundwater pumping from the host aquifer. Based on experience with conventional uranium milling, early ISL facilities tended to use aggressive acid-based lixiviants, such as sulfuric acid (International Atomic Energy Agency, 2001). These acid-based systems generally achieved high yield and efficient, rapid uranium recovery, but they also dissolved other heavy metals associated with uranium in the host rock and other chemical constituents that required additional remediation. In the United States, acid-based lixiviants have been used only for small-scale research and development operations [e.g., Nine Mile Lake and Reno Ranch in Wyoming (Mudd, 2001)], but have not been used in commercial operations (Davis and Curtis, 2007; International Atomic Energy Agency, 2005). Licensees or applicants may propose the use of acid-based lixiviants in the future. Other technologies that used ammonia-based lixiviants experienced difficulties: the ammonia tended to adsorb onto clay minerals in the subsurface. The ammonia desorbs slowly from the clay during restoration, and therefore the system requires that much larger amounts of groundwater be removed and processed during aquifer restoration (Energy Information Administration, 1995; Davis and Curtis, 2007). Although applicants or licensees may decide to use different lixiviants for a given deposit (see text box "Lixiviant Selection" in Section 2.4.1.2), ISL operations in the United States are expected to use alkaline lixiviants that are based on sodium carbonate-bicarbonate as the complexing agent and gaseous oxygen or hydrogen peroxide as the oxidizing agents (Table 2.4-1). For the purposes of the analyses presented in this Draft GEIS, it is assumed that alkaline lixiviants will be used in uranium recovery operations.

Table 2.4-1. Typical Lixiviant Chemistry (From NRC, 1998b)

Species	Range (in mg/L)*	
	Low	High
Sodium (Na)	≤400	6,000
Calcium (Ca)	≤20	500
Magnesium (Mg)	≤3	100
Potassium (K)	≤15	300
Carbonate (CO_3)	≤0.5	2,500
Bicarbonate (HCO_3)	≤400	5,000
Chloride (Cl)	≤200	5,000
Sulfate (SO_4)	≤400	5,000
Uranium (as U_3O_8)	≤0.01	500
Vanadium (as V_2O_5)	≤0.01	100
Total Dissolved Solids	≤1,650	12,000
pH (in std unit)	≤6.5	10.5

* 1 mg/L is approximately equal to 1 part per million (ppm)

The principal geochemical reactions caused by the lixiviant are the oxidation and subsequent dissolution of uranium and other metals from the ore body (Davis and Curtis, 2007). These reactions are effectively the reverse of those that initially caused the uranium deposition. The oxidant (oxygen or hydrogen peroxide) in the lixiviant oxidizes uranium from the relatively insoluble tetravalent state (U^{4+}) to the more soluble hexavalent state (U^{6+}). Once the uranium is in the 6+ oxidation state, the dissolved carbonate/bicarbonate causes the formation of aqueous uranyl-carbonate complexes that maintain oxidized uranium in solution as uranyl ion (UO_2^{2+}).

Lixiviant Selection

The geology and groundwater chemistry determine the proper leaching techniques and chemical reagents ISL milling uses for uranium recovery. For example, if the ore-bearing aquifer is rich in calcium (e.g., limestone or gypsum), alkaline (carbonate) leaching might be used [e.g., as discussed by Hunkin (1977), acid systems were generally considered unsuitable for Texas deposits because of higher carbonate]. Otherwise, acid (sulfate) leaching might be preferable. The leaching agent chosen for the ISL operation may affect the type of potential contamination and vulnerability of aquifers during and after ISL operations.

For example, acid leaching ISL uranium recovery at Nine Mile Lake and Reno Ranch, Wyoming, presented two major problems: (1) gypsum precipitated on well screens and within the aquifer during uranium recovery, plugging wells and reducing the formation permeability (critical for economic operation) and (2) the precipitated gypsum gradually dissolved after restoration, increasing salinity and sulfate levels in groundwater (Mudd, 2001).

Typical ISL uranium recovery operations in the United States use an alkaline sodium bicarbonate system to remove the uranium from ore-bearing aquifers. Alkaline lixiviants are used in all currently active and proposed ISL facilities in Wyoming, Nebraska, and New Mexico (NRC, 2006, 2004, 1998a, 1997a; Energy Metals Corporation, U.S., 2007) (see Table 2.4-1). Alkaline-based ISL operations are considered to be easier to restore than acid mine sites (Tweeton and Peterson, 1981; Mudd, 1998).

2.4.1.2 Lixiviant Injection and Production

Dissolved carbonate/bicarbonate lixiviants are created by introducing reagents such as sodium carbonate/bicarbonate or by injecting carbon dioxide gas (CO_2) into the groundwater. Carbon dioxide can also be added for pH control (Table 2.4-1). Lixiviant is pumped down injection wells to the mineralized zones, where it oxidizes and dissolves uranium from the sandstone formation (Figure 2.4-1). The uranium-bearing solution migrates through the pore spaces in the sandstone and is recovered by production wells. This uranium-rich (pregnant) lixiviant is pumped to the processing plant or satellite ion exchange facility, where the uranium is extracted through a series of chemical processes. Stripped of its uranium, the now-barren lixiviant is recharged with carbonate/bicarbonate and oxidant and the solution is returned through the injection wells to dissolve additional uranium. This process continues until the operator determines that further uranium recovery is uneconomical.

During the uranium recovery process, the groundwater in the production zone becomes progressively enriched in uranium and other metals that are typically associated with uranium in nature. The most common metals are arsenic, selenium, vanadium, iron, manganese, and radium. These and other constituents such as chloride, which is introduced by the ion exchange resin system, are removed or precipitated from the groundwater during aquifer restoration after uranium recovery is completed. Aquifer restoration will be detailed in Section 2.5.

The production wells are normally positioned to pump pregnant lixiviant from a number of injection wells. After processing but before reinjection, about 1–3 percent of the lixiviant, called the production bleed, is removed from the circuit and disposed of (see Section 2.7.2). The purpose of the production bleed is to ensure that more groundwater is extracted than re-injected. Maintaining this negative water balance helps to ensure that there is a net inflow of groundwater into the well field to minimize the potential movement of lixiviant and its associated contaminants out of the well field.

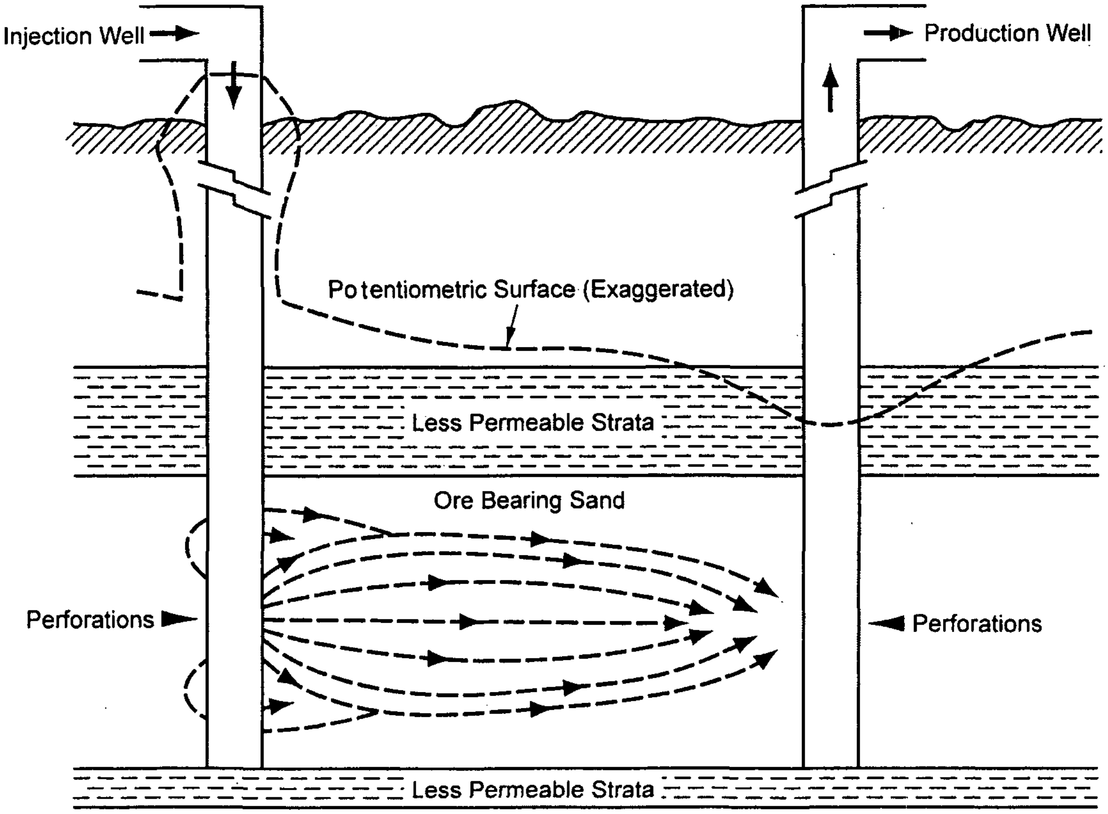

Figure 2.4-1. Idealized Schematic Cross Section To Illustrate Ore-Zone Geology and Lixiviant Migration From an Injection Well to a Production Well (From NRC, 1997a)

Pregnant lixiviant is pumped from the well fields by submersible pumps located in each production well. In some cases, booster pumps are installed in the lines to the processing plants or satellite facilities. Given the seasonal temperature variation in the four regions considered in this Draft GEIS, the main injection and production lines to and from the processing plants will be buried up to several meters [feet] to prevent freezing. These lines are usually 10.2- to 35.6-cm [4- to 14-in] diameter high density polyethylene or PVC pipes. The pregnant lixiviant is enriched in uranium relative to groundwater {typically about 60 mg/L [0.0005 lb/gal]} and is also likely to contain the trace elements and contaminants as discussed previously. The pipeline pressures are monitored continuously for spills and leaks.

2.4.1.3 Excursions

As described previously, ISL operations may affect the groundwater quality near the well fields when lixiviant moves from the production zone and beyond the boundaries of the well field. These occurrences are known as excursions. These excursions can be caused by

- Improper water balance between injection and recovery rates
- Undetected high permeability strata or geologic faults
- Improperly abandoned exploration drill holes
- Discontinuity within the confining layers
- Poor well integrity, such as a cracked well casing or leaking joints between casing sections
- Hydrofracturing of the ore zone or surrounding units

NRC license and underground injection control (UIC) permit conditions require that licensees conduct periodic tests to protect against excursions. These include but are not limited to

- Conducting pump tests for each well field prior to operations within the well field to evaluate the confinement of the production horizon
- Continued well field characterization to identify geologic features (e.g., thinning confining layers, fractures, high flow zones) that might result in excursions
- Mechanical integrity testing of each well to check for leaks or cracks in the casing

An excursion that moves laterally away from the production zone is a horizontal excursion. Vertical excursions occur where barren or pregnant lixiviant migrates into other aquifers above or below the production zone.

2.4.1.4 Excursion Monitoring

Licensees must maintain groundwater monitoring programs (see Chapter 8) to detect both vertical and horizontal excursions and must have operating procedures to analyze an excursion and determine how to remediate it. Geochemical excursion indicators are identified based on the well fields' pre-operational baseline water quality (see text box "Identifying Excursion Indicators and UCLs").

The spacing of horizontal excursion monitoring wells is based on site-specific conditions, but typically they are spaced about 90–150 m [300–500 ft] apart and screened in the production zone (NRC, 2003a, 1997a; Mackin, et al., 2001a; Energy Information Administration, 1995). The specific location and spacing of the monitoring wells is established on a site-by-site basis by license condition. It is often modified according to site-specific, hydrogeologic characteristics of the uranium deposit and as the licensee gains experience detecting, recovering, and cleaning up these excursions.

NRC licenses also include requirements to establish monitoring wells in overlying and, as appropriate, in underlying aquifers to detect vertical excursions. Although uranium deposits are typically located in hydrogeologic units bounded above and below by adequately confining units, the possibility of vertical contaminant transport must be considered. Historically, these monitoring wells are more widely spaced than those within the host aquifer, although underlying aquifer monitoring wells may not be required under some circumstances (Mackin, et al., 2001a). There are general guidelines for monitoring well placement: (1) one monitoring well per 1.6 ha [4 acres] of well field in the first overlying aquifer, (2) one monitoring well per 3.2 ha [8 acres] in each higher aquifer, and (3) one monitoring well per 1.6 to 3.2 ha [4 to 8 acres] in the underlying aquifer. These monitoring wells are typically sampled every 2 weeks during operations.

An excursion is defined to occur when two or more excursion indicators in a monitoring well exceed their UCLs (NRC, 2003a). If an excursion is detected, the licensee takes several steps to notify NRC and confirm the excursion through additional and more frequent sampling (NRC, 2003a) (see Chapter 8). As described in NRC guidance (NRC, 2003a, Section 5.7.8.3), licensees typically retrieve horizontal and vertical excursions back into the production zone by adjusting the flow rates of the nearby injection and production wells to increase

Identifying Excursion Indicators and UCLs

The applicant or licensee proposes excursion indicators and upper control limits (UCLs) based on lixiviant content and baseline groundwater quality (see Section 2.2.7). NRC staff review and approve the excursion indicators and proposed UCLs. UCLs are set on a well field basis and are concentrations for excursion indicators that provide early warning if leaching solutions are moving away from the well fields. As described in NRC (2003a, Section 5.7.8.3), the best excursion indicators are easily measurable parameters that are found in higher concentrations during ISL operations than in the natural waters. For example, at most ISL uranium recovery operations, chloride is selected because it does not interact strongly with minerals in the subsurface, it is easily measured, and chloride concentrations are significantly increased during ISL operations. Conductivity, which is correlated to total dissolved solids, is also considered to be a good excursion indicator because of the high concentrations of different dissolved constituents in the lixiviant as compared to the surrounding aquifers (Staub, et al., 1986; Deutsch, et al., 1985). Total alkalinity (carbonate plus bicarbonate plus hydroxide) is used as an indicator in well fields where sodium bicarbonate or carbon dioxide is used in the lixiviant.

A minimum of three excursion indicators are selected, and the UCLs are determined using statistical analyses of the preoperational baseline water quality in the well field. The NRC staff has identified several statistical methods that can be used to establish UCLs. For example, in areas with good water quality (total dissolved solids less than 500 mg/L), the UCL may be set at a value of 5 standard deviations above the mean of the measured concentrations. Conversely, if the chemistry or a particular excursion indicator is very consistent, a concentration may be specified as the UCL. If baseline data indicate that the groundwater is homogeneous across the well field, the same UCLs may be used for all monitoring wells. Alternatively, if the water chemistry in the well field is highly variable, UCLs may be set for individual wells. An excursion is defined to occur when two or more excursion indicators in a monitoring well exceed their UCLs (NRC, 2003a).

process bleed in the area of the excursion. Vertical excursions are more difficult to retrieve, persisting for years in some cases (see Section 2.11.4). If an excursion cannot be recovered, the licensee may be required to stop injection of lixiviant into a well field (NRC, 2003a, Section 5.7.8.3).

2.4.2 Uranium Processing

Uranium is recovered from the pregnant lixiviant and processed as yellowcake in a multistep process (Figure 2.4-2). The following sections briefly describe key aspects of the uranium process circuit.

2.4.2.1 Ion Exchange

As pregnant lixiviant from the production wells enters the ion exchange circuit, it may either be stored in a surge tank or sent directly to the ion exchange columns (Figure 2.4-3). The number and size of ion exchange columns in the circuit may vary, depending on facility design. For example, at the Smith Ranch Uranium Project in Converse County, Wyoming, the ion exchange circuit consists of six pressurized downflow vessels, each with a volume of 14.2 m^3 [501.5 ft^3] (Stout and Stover, 1997). At the Crow Butte facility in Dawes County, Nebraska, the ion exchange circuit consists of eight upflow columns, with a recent addition of six downflow columns, each about 3.5 m [11.5 ft] in diameter and 4.6 m [15 ft] tall and a volume of about 44 m^3 [1,554 ft^3] (NRC, 2007; Crow Butte Resources, Inc., 2007). In the ion exchange columns, the uranium is adsorbed onto resin beads that selectively remove uranium from solution. The primary reaction is the exchange of the uranium carbonate complexes for chloride. The (now barren) lixiviant exits the ion exchange columns, is recharged with oxidant and bicarbonate, and is returned to the well field for reinjection and further uranium recovery. It carries chloride that was exchanged for uranium on the resin. The chloride content of the water in the ore-bearing aquifer builds up with time as the lixiviant is circulated and the resin is recharged. The production bleed discussed previously in Section 2.4.1 is removed downstream of the ion exchange columns, before re-injecting the barren lixiviant into the well field (see Figure 2.4-2).

When the resin beads in the ion exchange columns become saturated with uranium, the columns are taken offline and other columns are brought online. Some facilities may not process the ion exchange resins further (NRC, 2004, 2006). In these facilities (called satellite facilities), the resin is discharged to a truck and then transported to a facility that has the capacity for further processing of the uranium-loaded resin. Later sections of this Draft GEIS assess the hazards associated with transferring and transporting loaded ion exchange resin.

2.4.2.2 Elution

At ISL facilities that can process resin, after the resin is loaded with uranium, it enters the elution circuit. In addition, uranium-loaded resins transported from satellite plants in a remote ion exchange operation enter the processing circuit at this point. In the elution circuit, the uranium is washed (eluted) from the resin and the resin is made available for further cycles of uranium absorption. The resin may be eluted directly in the ion exchange column, or it may be transferred to a separate elution tank. In the elution process, the uranium is removed from the resin by flushing with a concentrated brine solution. This process returns chloride ions to the resin exchange sites, regenerating the resin at the same time that the uranium is released for further processing. A sodium carbonate or bicarbonate rinse is also used during this phase to keep the stripped uranium from precipitating in the elution vessel. The resulting uranium-rich

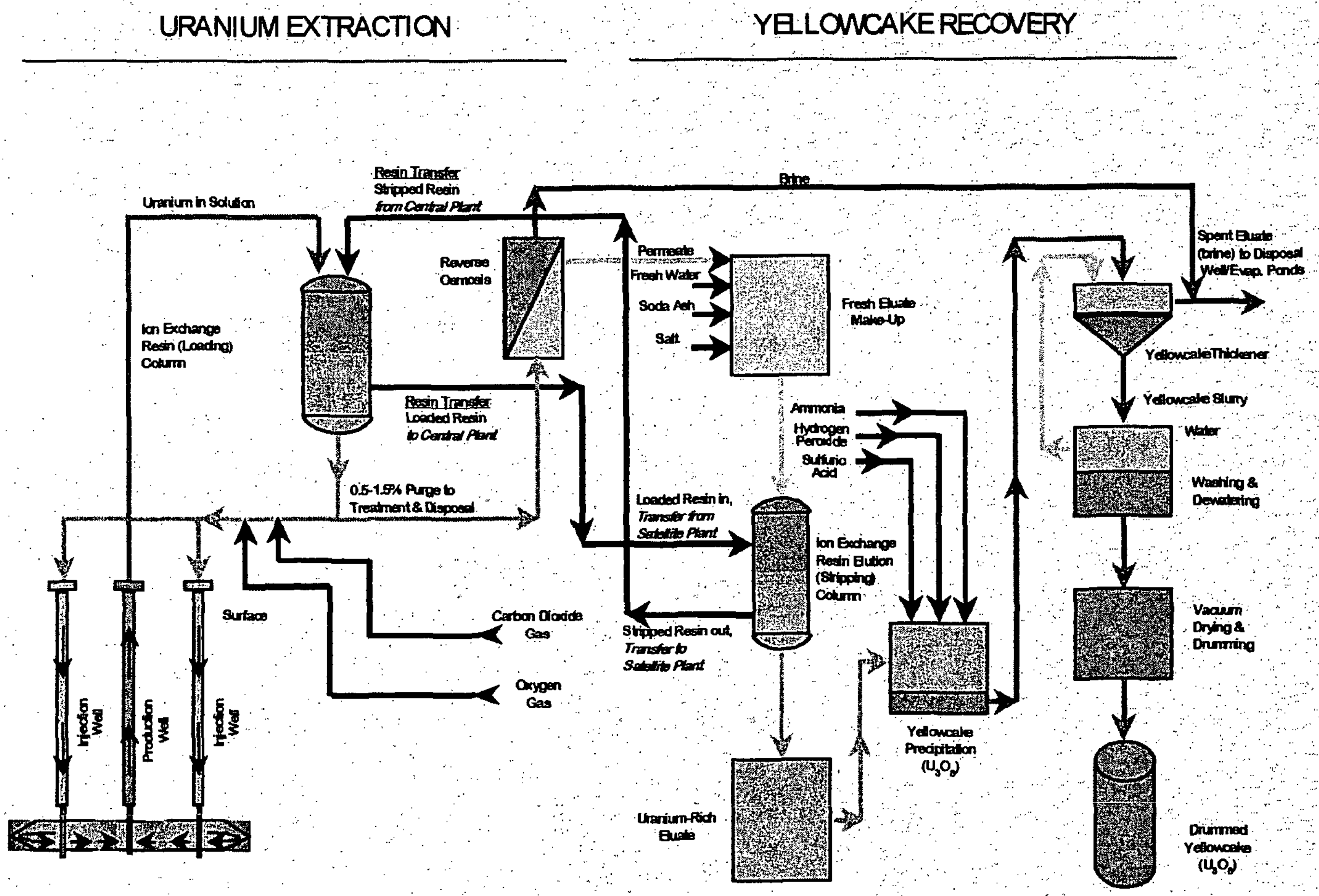

Figure 2.4-2. Flow Diagram of an ISL Uranium Recovery Process (Mackin, et al., 2001a)

solution is termed pregnant or rich eluant and typically contains 8 to 20 g/L [0.067 to 0.17 lb/gal] of uranium (Mackin, et al., 2001a). It is normally discharged to a holding tank. After enough pregnant eluant is obtained, it is moved to the precipitation, drying, and packaging circuit (Mackin, et al., 2001a).

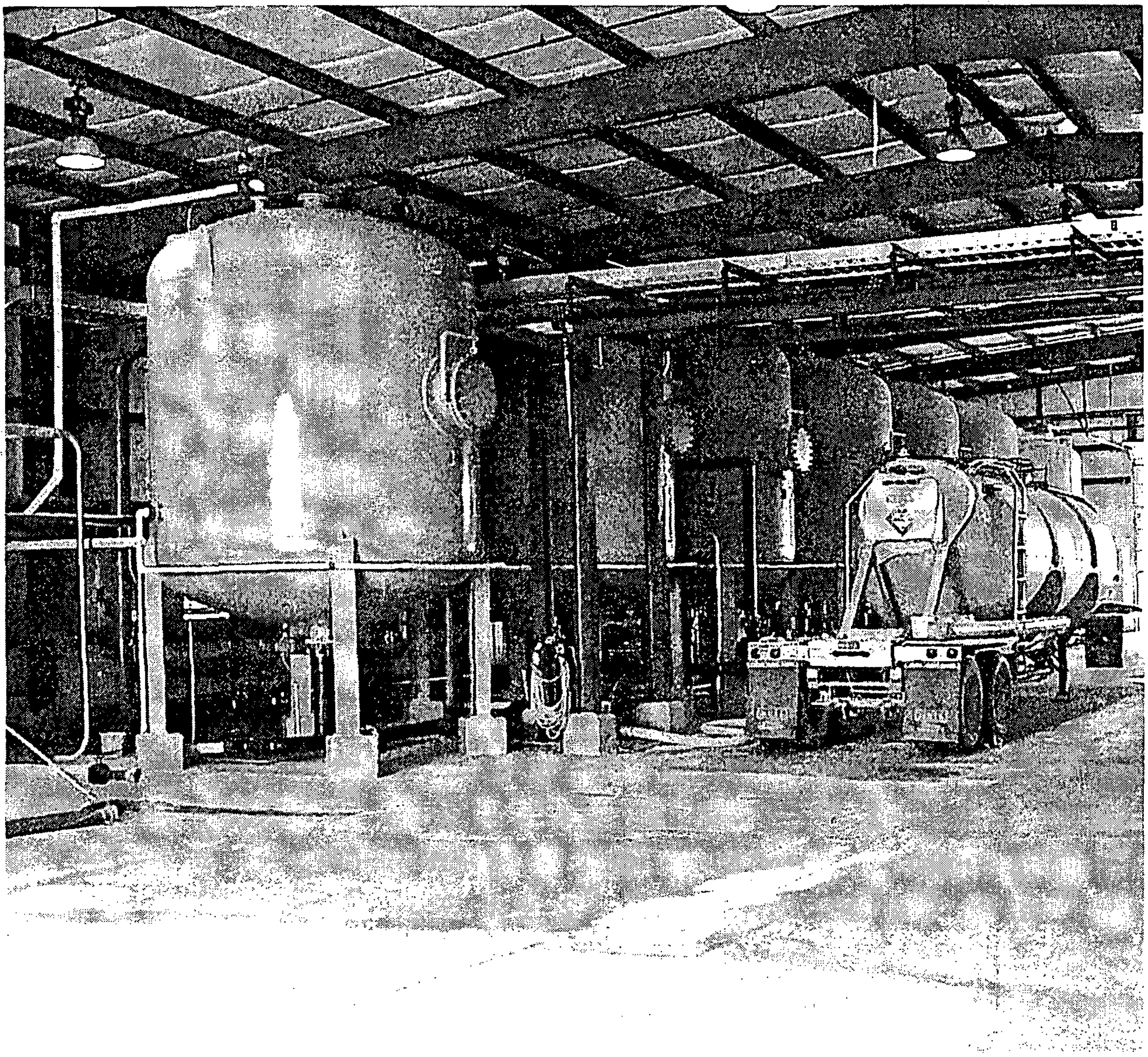

Figure 2.4-3. Typical Ion Exchange Vessels in an ISL Facility

2.4.2.3 Precipitation, Drying, and Packaging

In the precipitation and drying circuit, the pregnant eluant is typically acidified using hydrochloric or sulfuric acid to destroy the uranyl carbonate complex. Hydrogen peroxide (H_2O_2) is then added to precipitate the uranium as uranyl peroxide (UO_2O_2). Caustic soda (NaOH) or ammonia (NH_3) is also normally added at this stage to neutralize the acid remaining in the eluate. The (now barren) eluant is typically recycled. Water left over from these processes may be reused in the eluant circuit or may be disposed as 11e.(2) byproduct material. Effluent management is discussed in Section 2.7.2.

After the precipitation process, the resulting slurry is sent to a thickener where it is settled, washed, filtered, and dewatered (Figure 2.4-4). At this point, the slurry is 30 to 50 percent solids. This thickened slurry may be transported offsite to a uranium processing plant to produce yellowcake (U_3O_8), or it may be filter pressed to remove additional water, dried and packaged onsite.

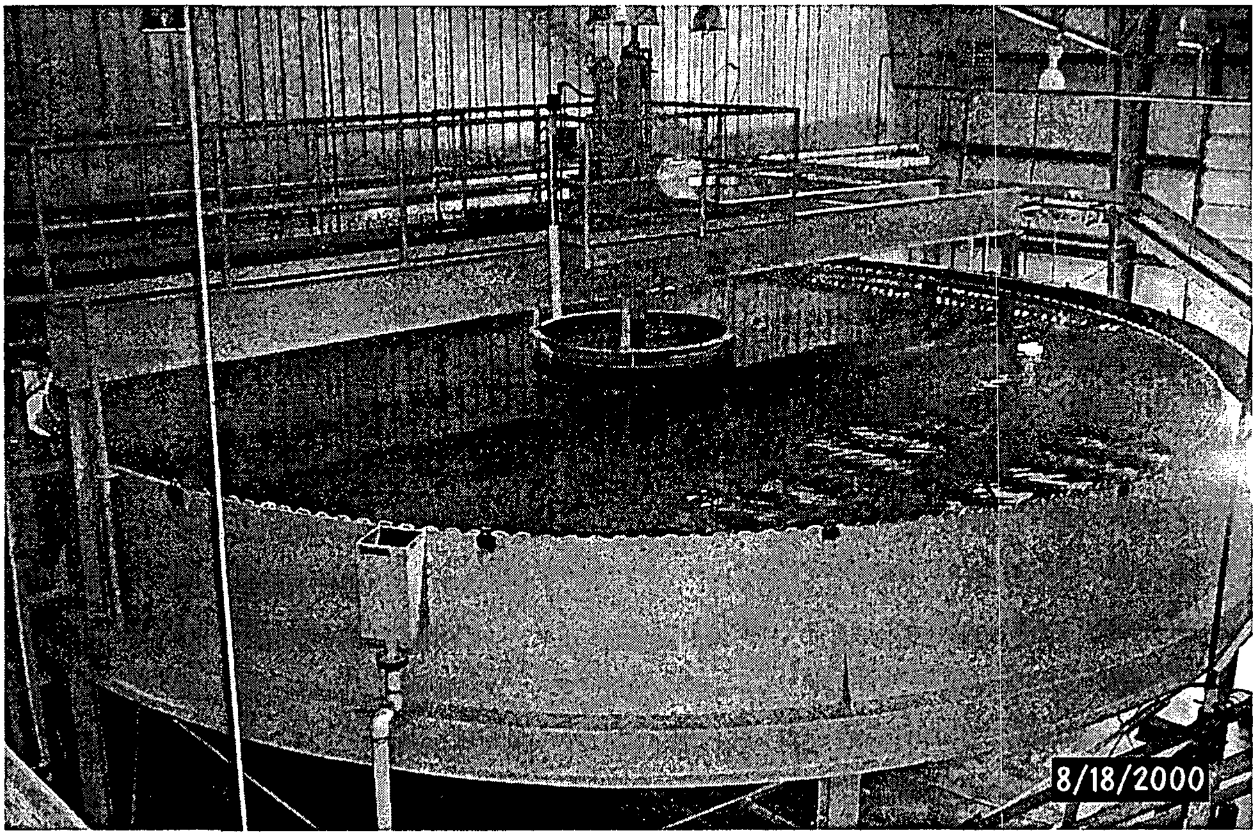

Figure 2.4-4. A Typical Thickener for an ISL Uranium Processing Facility

For onsite processing, the slurry is next dried in the yellowcake dryer. Two kinds of yellowcake dryers have been used: multihearth dryers and vacuum dryers. Older uranium ISL facilities used gas-fired multi-hearth dryers. These dryers typically dry the yellowcake at about 400 to 620 °C [750 to 1,150 °F]. Because of the high temperatures involved, any organic contaminants in the yellowcake (e.g., grease from bearings) will be completely burned and will exit the system with the dryer offgas. This is advantageous because leftover organic residues in the packaged yellowcake product may oxidize while in the drum, causing the drum to pressurize and burst due to the evolution of gases (primarily CO_2) inside it (NRC, 1999). The offgas discharge from the dryer is scrubbed with a high intensity venturi scrubber that is 95 to 99 percent efficient at removing uranium particulates before they are released to the atmosphere. Solutions from the scrubber are normally returned to the precipitation circuit and are processed to recover any uranium particulates. As a result, the stack discharge normally contains only water vapor and quantities of uranium fines that are managed to be below regulatory limits (see Sections 2.7.1 and Chapter 8).

Newer ISL facilities usually use vacuum yellowcake dryers. In a vacuum dryer (Figure 2.4-5), the heating system is isolated from the yellowcake so that no radioactive materials are entrained in the heating system or its exhaust. The drying chamber that contains the yellowcake slurry is under vacuum. Therefore, any potential leak would cause air to flow into the chamber, and the drying can take place at relatively low temperature {e.g., 149 °C [250 °F]}. Moisture in the yellowcake is the only source of vapor. Emissions from the drying chamber are normally treated in two ways. First, vapor passes through a bag filter to remove yellowcake particulates with an efficiency exceeding 99 percent. Any captured particulates are returned to the drying chamber. Then, any water vapor exiting the drying chamber is cooled and condensed. This process is designed to capture virtually all escaping particles (Mackin, et al., 2001a).

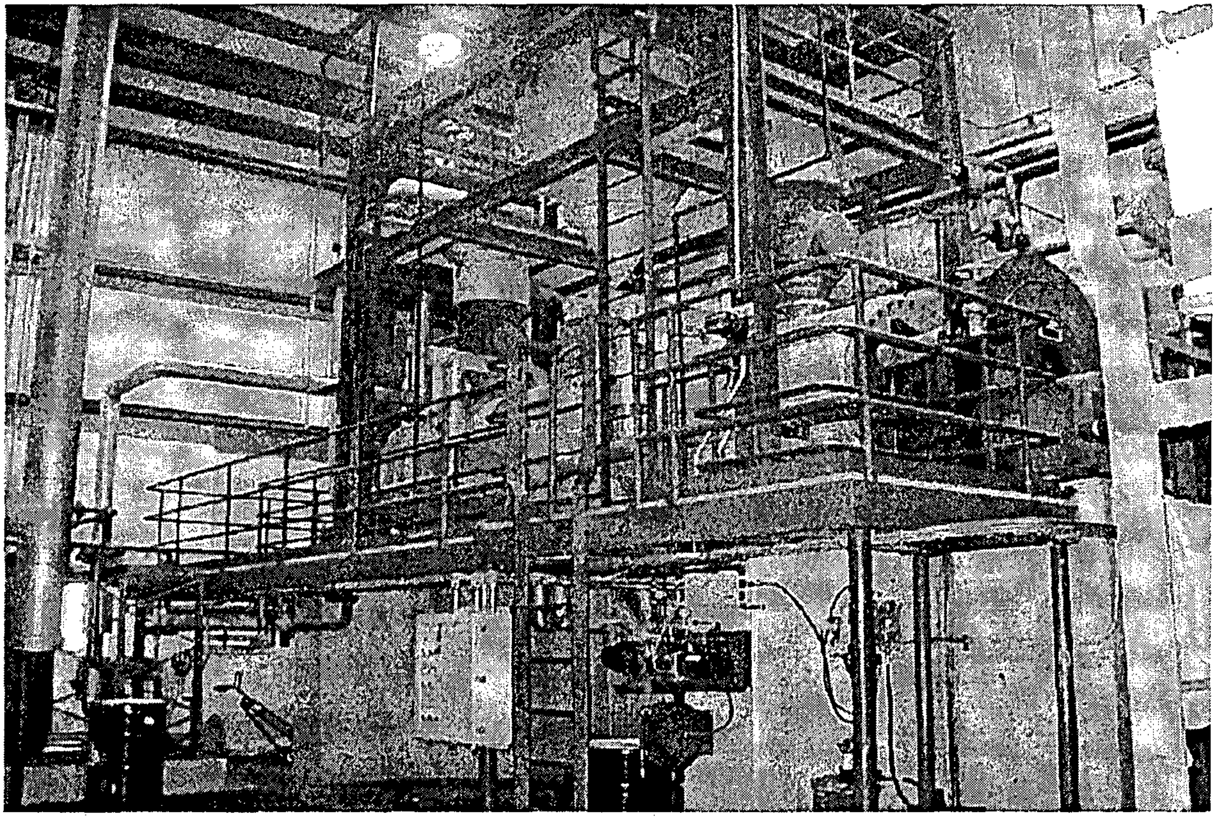

Figure 2.4-5. Typical Vacuum Dryer for Uranium Yellowcake Processing at an ISL Uranium Processing Facility

The dried product (yellowcake) is removed from the bottom of the dryer and packaged in drums for eventual shipping offsite. The packaging area normally has a baghouse dust collection system to protect personnel and to minimize yellowcake release. Air from the baghouse dust collection system is typically routed to the dryer offgas line and scrubber. During drum loading, the drum is normally kept under negative pressure via a drum hood with a suction line. The drum hood transports any released particulates to a baghouse dust collector. The filtered air from this baghouse joins the dryer offgas and is passed through the scrubber. Parameters important to the effective operation of the dryer must be monitored, and existing NRC regulations at 10 CFR Part 40, Appendix A, Criterion (8), prohibit dryer operations when these parameters are outside prescribed ranges. After the dried product is cooled, it is packaged and shipped in 208-L [55-gal] drums (Figure 2.4-6).

Figure 2.4-6. Labeled and Placarded 208-L [55-gal] Drum Used for Packaging and Shipping Yellowcake

2.4.3 Management of Production Bleed and Other Liquid Effluents

Uranium mobilization and processing produce excess water that must be properly managed. The production wells extract slightly more water than is re-injected into the host aquifer, which creates a net inward flow of groundwater in the well field. This production bleed is about 1 to 3 percent of the circulation rate, which can amount to an excess production of several tens to a hundred liters per minute (several tens of gallons per minute). As described in Section 2.4.1, the production bleed is diverted from the ISL circuit after the uranium is removed in the ion exchange resin system, but before the lixiviant is recharged. This water still contains lixiviant and minerals leached from the aquifer. The excess water can be discharged to an evaporation pond or a deep well injection for disposal, or treated further for discharge to the environment (Section 2.7.2). Other liquid waste streams produced during ISL operation can include spent eluant from the ion exchange system, and liquids from process drains. These are handled in the same manner as the production bleed.

2.5 Aquifer Restoration

Aquifer restoration within the well field ensures that the water quality and groundwater use in surrounding sources of drinking water will not be adversely affected by the uranium recovery operation. Before ISL operations can begin, the portion of the aquifer designated for uranium recovery must be exempted from U.S. Environmental Protection Agency (EPA) regulatory protection, in accordance with the Safe Drinking Water Act (see Section 1.7.2.1). Groundwater adjacent to the exempted portion of the aquifer, however, must still be protected. The states authorized to implement the EPA groundwater protection program as well as the NRC require well field restoration to protect human health and the environment.

After uranium is recovered, the groundwater in the well field contains constituents that were mobilized by the lixiviant. Licensees usually begin aquifer restoration in each well field as the uranium recovery operations end. Aquifer restoration criteria are determined on a site-specific, well field-by-well field basis. NRC's restoration standards are found in Appendix A to 10 CFR Part 40, and NRC historically has supplemented these regulatory standards through the use of guidance documents and conditions in NRC-issued licenses for ISL facilities. [NRC is currently engaged in a rulemaking that would clarify the requirements for groundwater protection at ISL facilities.]

Aquifer restoration programs typically use a combination of methods including (1) groundwater transfer, (2) groundwater sweep, (3) reverse osmosis with permeate injection, (4) groundwater recirculation, and (5) stabilization monitoring (Energy Information Administration, 1995; Mackin, et al., 2001a; Davis and Curtis, 2007).

2.5.1 Groundwater Transfer

Groundwater transfer involves moving groundwater between the well field entering restoration and another well field where uranium leach operations are beginning, or alternately, within the same well field, if one area is in a more advanced state of restoration than another (NRC, 2006). This technique displaces mining-affected waters in the restoration well field with baseline quality waters from the well field beginning leach operations. As a result, the groundwater in the two well fields becomes blended until the waters are similar in conductivity and therefore similar in the amount of dissolved constituents. Because water is transferred from one well field to another, groundwater transfer typically does not generate liquid effluents.

2.5.2 Groundwater Sweep

During the groundwater sweep phase, contaminated groundwater in the well field is removed by pumping. This pumping causes uncontaminated, native groundwater to flow into the ore body. The groundwater sweep process is depicted in Figure 2.5-1. During groundwater sweep, the licensee pumps water from the well field to the processing plant through all production and injection wells without reinjection. This draws native groundwater inward, flushing the contaminants from areas that have been affected by the horizontal spreading of the lixiviant in the affected zone during uranium recovery. Groundwater produced by the onsite wells will contain uranium and other contaminants released during uranium recovery and residual lixiviant. The initial concentrations of these substances would be similar to those during the uranium recovery operation phase, but would decline gradually with time (Davis and Curtis, 2007). The water removed from the aquifer during the sweep first is passed through the processing plant ion exchange system to recover the uranium and then disposed either in evaporation ponds or via deep well injection in accordance with the limits in the UIC permit.

Pore Volume and Flare

Pore volume is a term of convenience used by the *in situ* leach industry to describe the quantity of free water in the pores of a given volume of aquifer material. It provides a unit reference that an operator can use to describe the amount of lixiviant circulation needed to leach an ore body, or describe the unit number of treated water circulations needed to flow through a depleted ore body to achieve restoration. A pore volume provides a way for an operator to use relatively small-scale studies and scale the results to field-level pilot tests or to commercial well field scales. Typically, a "pore volume" is calculated by multiplying the surficial area of a well field (the area covered by injection and recovery wells) by the thickness of the production zone being exploited and the estimated or measured porosity of the aquifer material (NRC, 2003a).

A proportionality factor, known as "flare," is designed to estimate the amount of aquifer water outside of the pore volume that has been impacted by lixiviant flow during the extraction phase. The flare is usually expressed as a horizontal and vertical component to account for differences between the horizontal and vertical hydraulic conductivity of an aquifer material (NRC, 2003a).

The duration of the aquifer sweep and volume of water removed depend on the volume of the aquifer affected by the ISL process. The aquifer volume typically is described in terms of "pore volumes" (see text box). Based on operational data (see Section 2.11.5), it is likely that more than one pore volume would be removed during the sweep. At the Crow Butte ISL facility in Dawes County, Nebraska, the pore volumes for the first six well fields {3.8 to 16.3 ha [9.3 to 40.2 acres]} were estimated to range from 58.3 to 298.7 million L [15.4 to 78.9 million gal] (NRC, 1998b). In comparison, the total pore volume for the nine well fields at the Irigaray Project was estimated to be 232.8 million L [61.5 million gal] (Cogema Mining, 2005).

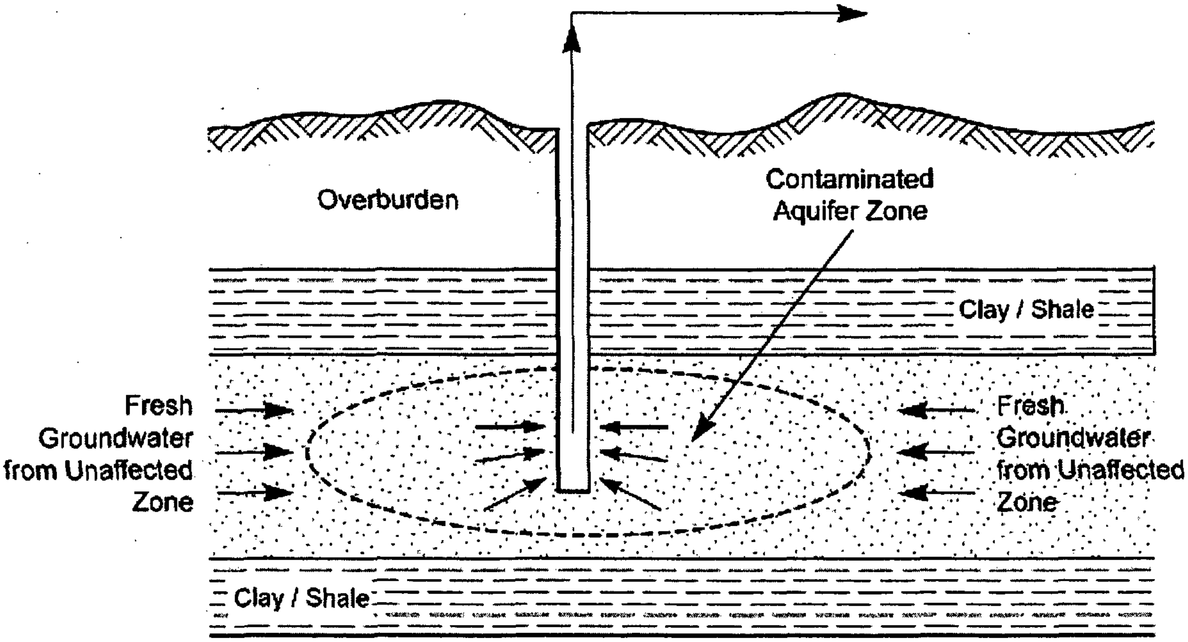

Figure 2.5-1. Schematic Diagram of Groundwater Sweep During Aquifer Restoration (after Energy Information Administration, 1995)

2.5.3 Reverse Osmosis, Permeate Injection, and Recirculation

Reverse osmosis and permeate injection are used after groundwater sweep operations. This phase returns total dissolved solids, trace metal concentrations, and aquifer pH to baseline values (Davis and Curtis, 2007; NRC, 2003a). During permeate injection and recirculation, uranium in the groundwater is removed by passing the water through the ion exchange circuit, as during operations. After that, other chemical constituents in the groundwater are removed by passing the groundwater through a reverse osmosis system consisting of pressurized, semi-permeable membranes.

The reverse osmosis process yields two fluids: clean water (permeate: about 70 percent) and water with concentrated ions (brine: about 30 percent). Water sent to the reverse osmosis system must be pre-treated so the semipermeable membranes used in the system are not fouled. The pH is lowered, and additives called antiscalants are added to the groundwater upstream of the reverse osmosis unit to prevent precipitation of minerals (particularly calcium carbonate). Typically, sodium hexametaphosphate or polycarboxylic acid are used as antiscalants and sulfuric acid is used for pH adjustment. After reverse osmosis, sodium hydroxide is added to readjust the pH of the groundwater to baseline levels.

The pumping and injection rates during the recirculation phase are likely to be similar to those during the sweep phase (hundreds of gallons per minute), but many pore volumes (often more than 10) must be circulated to achieve aquifer restoration goals (Davis and Curtis, 2007; Mackin, et al., 2001b). The net withdrawal from the aquifer depends on how the rejected liquid (reject) from the reverse osmosis system, which is about 30 percent of the pumping rate, is handled. Because the reject is a brine solution, it cannot be directly injected into the aquifer or discharged to the environment. The reject can be disposed directly in an evaporation pond or via a deep well injection in accordance with the discharge limits in the UIC permit. If the reject is sent directly to an evaporation pond or a deep disposal well, the net withdrawal from the aquifer could be about 30 percent of the pumping rate (tens of gallons per minute).

Alternatively, a brine concentrator can be used to treat the reject. The brine concentrator heats and evaporates the water, concentrating the brine, which then contains precipitated solids in the form of common salts. The brine concentration process typically results in about one part briny slurry and salts to 300 parts purified water. The purified water can be reintroduced into the aquifer and thus the net withdrawal from the aquifer would be only a small percentage of the recirculation rate. The briny slurry is disposed in an evaporation pond or via deep well injection (Section 2.7.2).

After completing the reverse osmosis/permeate injection phase, the well field water will have characteristics similar to the permeate, and the recirculation phase takes place. To homogenize the groundwater, well field water may be circulated using the original injection and production wells. The quantity of water that is recirculated depends on site-specific baseline parameters and contaminant levels.

2.5.4 Stabilization

The purpose of the stabilization phase of aquifer restoration is to establish a chemical environment that reduces the solubility of dissolved constituents such as uranium, arsenic, and selenium. An important part of stabilization during aquifer restoration is metals reduction (Davis and Curtis, 2007). During uranium recovery, if the oxidized (more soluble) state is allowed to persist after uranium recovery is complete, metals and other constituents such as arsenic, selenium, molybdenum, uranium, and vanadium may continue to leach and will remain at elevated levels. To stabilize metals concentrations, the pre-operational oxidation state in the ore production zone should be reestablished as much as is possible. This is achieved by adding an oxygen scavenger or reducing agent such as hydrogen sulfide (H_2S) or a biodegradable organic compound (such as ethanol) into the uranium production zone during the later stages of recirculation (Davis and Curtis, 2007). The need for an aquifer stabilization phase depends on how effectively the sweep and recirculation phases restore the affected aquifer to background water quality. The total volume and rate of net groundwater recovery during the stabilization phase will be similar to that during the restoration recirculation phase.

Following stabilization, the licensee monitors the groundwater by quarterly sampling to ensure that baseline or pre-operational class-of-use conditions have been permanently restored and that any adjacent nonexempt aquifers are unaffected. The licensee would reinitiate aquifer restoration if stabilization monitoring determines it is necessary. Both the state permitting agency and the NRC must review and approve the monitoring results before aquifer restoration is considered to be complete.

2.6 Decontamination, Decommissioning, and Reclamation

Decommissioning an ISL facility is based on an NRC-approved decommissioning plan. This section discusses activities based on previous summaries (Energy Information Administration, 1995; Mackin, et al., 2001a). The primary steps involved in decommissioning an ISL facility include

- Conducting radiological surveys of facilities, process equipment, and materials to evaluate the potential for exposure during decommissioning
- Removing contaminated equipment and materials for disposal at an approved facility or for reuse
- Decontaminating items to be released for unrestricted use
- Cleaning up areas used for contaminated equipment and materials
- Cleaning up evaporation ponds
- Plugging and abandoning wells
- Surveying excavated areas for contamination and removing contamination to meet cleanup limits
- Backfilling and recontouring disturbed areas
- Performing final site soil radiation background surveys
- Revegetating and reclaiming disturbed areas
- Monitoring the environment

Process buildings and equipment are surveyed to identify any radiation hazards. Alternatives for handling process buildings and equipment include reuse, removal, or disposal. Contaminated items are decontaminated if they are to be released for offsite unrestricted use; otherwise, they are disposed of as 11e.(2) byproduct material in a licensed disposal facility. Estimated volumes of building demolition and removed equipment wastes for an ISL facility are provided in Table 2.6-1.

Pond liners and leak detection systems are surveyed. If radiological contamination is found, the liners and detection systems are typically removed and disposed in a licensed disposal facility. Estimated volumes of pond reclamation wastes for an ISL facility are provided in Table 2.6-1.

Well fields are decommissioned after groundwater restoration has been completed. Proper well field decommissioning protects the groundwater supply and eliminates physical hazards. First, surface equipment (such as injection and production lines), electrical components, and well head equipment (such as valves, meters, or fixtures) are salvaged. Then buried piping is removed, and the wells are plugged and abandoned using accepted practices identified as part

Table 2.6-1. Estimated Decommissioning and Reclamation Waste Volumes (yd^3)* for Offsite Disposal, Smith Ranch *In-Situ* Leach Facility†

ISL Decommissioning Activity	Byproduct Radioactive Waste	Other Solid Waste
Processing Equipment Removal	342	0
Building Demolition	546	531
Well Field Equipment	1,361	404
Trunk Line Removal	2,263	0
Contaminated Soil Removed	1,428	0
Evaporation Pond Reclamation	68	0

*To convert yd^3 to m^3, multiply by 0.7646.

†Volumes were compiled and summed from an annual surety report. McCarthy, J. "Smith Ranch: 2007–2008 Surety Estimate Revision." Letter (June 29) to G. Janosko, NRC. Glenrock, Wyoming: Power Resources International. 2007.

of the EPA- or state-administered UIC program. Based on past experience, about 90 percent of the materials will be suitable for unrestricted release or disposal at an unrestricted area landfill. Estimated volumes of well field decommissioning wastes for an ISL facility are provided in Table 2.6-1. The well field area is decontaminated in accordance with NRC regulatory limits at 10 CFR Part 40, Appendix A, and surveys are performed to ensure compliance with standards. Surface reclamation is completed using an NRC-approved plan.

Contaminated soils are cleaned up as necessary for decommissioning. A gamma radiation survey is conducted to determine whether any contaminated areas exist. Criteria at 10 CFR Part 40, Appendix A, are used for identifying contaminated soils and for determining when cleanup is complete. The NRC reviews and approves survey and sampling results. In the well fields where gamma radiation surveys correlate strongly with actual radiation concentrations in soil, gamma surveys are conducted as each well field unit is decommissioned. Soil samples are obtained from any areas that have elevated gamma readings. Areas contaminated with Ra-226, Ra-228, or other radionuclides exceeding the limits specified at 10 CFR Part 40, Appendix A, Criterion 6-(6), are cleaned up. Contaminated soil is removed and disposed as 11e.(2) byproduct material at a licensed disposal facility. The estimated volume of contaminated soil removal for an ISL facility is provided in Table 2.6-1. The most likely areas for contaminated soils are well field surfaces, evaporation pond bottoms and berms, process building areas, storage yards, transportation routes for uranium recovery products or contaminated materials, and pipeline runs. Areas used for land application of treated water are also surveyed and decontaminated as necessary.

All radioactive wastes generated during ISL facility decommissioning (as well as radioactive wastes generated during construction, operation, and aquifer restoration) are considered 11e.(2) byproduct material that must be disposed at a licensed facility (Section 2.7).

An NRC-approved surface reclamation plan ensures disturbed lands are returned to production or to planned post-operational land use. Baseline data on soils, vegetation, wildlife, and radiation are used as guidelines for the surface reclamation. Areas disturbed by the uranium recovery operations are restored as closely as possible to pre-operational conditions. Reclamation activities include replacing excavated soils, recontouring affected areas, reestablishing original drainage, and revegetation. The magnitude of reclamation activities vary, in part, with the size of the ISL facility. A large ISL facility, Smith Ranch (see Table 2.11-1) has estimated applying approximately 43,748 m^3 [57,221 yd^3] of topsoil to the ground surface during site reclamation (McCarthy, 2007). Because topsoil excavated during construction was stockpiled and reseeded to limit erosion (NRC, 1992), the net amount of topsoil needed to replace topsoil removed during decommissioning is approximated by the estimated volume of excavated soil destined for offsite disposal shown in Table 2.6-1 (1,092 m^3 [1,428 yd^3]). After reclamation is complete, lands are normally capable of supporting wildlife and land uses such as livestock grazing.

A financial surety (Section 2.10), established when an NRC license is granted, provides assurance that the costs of aquifer restoration and site decommissioning are covered when facility operations end. The surety also covers costs to close the site at any point during operations.

2.7 Effluents and Waste Management

ISL facilities generate airborne effluents, liquid wastes, and solid wastes that must be handled and disposed of properly. Effluents, waste streams, and waste management practices applicable to ISL facilities are described in this section.

2.7.1 Gaseous or Airborne Particulate Emissions

During construction, operations, aquifer restoration, and decommissioning, ISL facilities can produce airborne emissions including

- Fugitive dusts
- Combustion engine exhausts
- Radon gas emissions from lixiviant circulation and evaporation ponds
- Uranium particulate emissions from yellowcake drying

Fugitive dusts and engine exhausts are generated primarily during construction, transportation, and decommissioning activities. The fugitive dust is generated by travel on unpaved roads and from disturbed land associated with the construction of well fields, roads, and support facilities. Vehicles workers use to commute to the facility, to support onsite activities, or to transport supplies to the site emit fuel combustion products. Diesel emissions originate from drill rigs, diesel-powered water trucks, and other equipment used during the construction phase. Table 2.7-1 provides information from a previously licensed ISL satellite facility on the nature and duration of nonradiological emission-generating activities during construction, operation, and decommissioning. Table 2.7-2 contains the annual total releases and average air concentrations of particulate (fugitive dust) and gaseous (diesel combustion products) emissions estimated for the construction phase of the ISL facility near Crownpoint, New Mexico.

Table 2.7-1. Combustion Engine Exhaust Sources for the Gas Hills In-Situ Leach Satellite Facility During Construction, Operations, Reclamation, and Decommissioning*

Period	Activity	Equipment Type	Number of Units	Frequency of Operation	Duration of Operation
Construction	Initial Construction/ Well Field Road Construction	Scraper	1	8 hr/day, 5 day/wk	2 months
		Bulldozer	1	"	"
		Motor Grader	1	"	"
	Well Preparation	Truck Mount Rotary Drill Rig, Diesel Truck	4-8	8 hr/day, 5 day/wk	12 mo/yr
		Pump Pulling Vehicle 1-ton gas or diesel	2	"	"
		Motor Grader	1	"	3 mo/yr
		Backhoe	3	"	12 mo/yr
		Forklift	2	"	"
		Cementer (gas)	4	"	"
		Light Duty Truck	8-10	8 hr/day, 7 day/wk	"
	Construction Material Transport	Heavy Duty Water Truck (1,500 gal)	4-8	"	"
		Heavy Duty Diesel Truck	1	1 trip/day	2 mo/yr
	Commuting	Light Duty Vehicles	30	"	6 mo/yr
Operation	Satellite Facility	Gas or Propane Heater	6	24 hr/day	6 mo/yr
	Product Transport	Truck to Highland Site Diesel Semi with Trailer	2	1 trip/day	12 mo/yr
	Commuting	Light Duty Vehicles	30	"	"
Decommissioning	Reclamation	Scraper	1	2 × 8 hr shift/day*	2-3 yr
		Motor Grader	1	"	"
		Backhoe	2	"	"
		Heavy Duty Truck (Diesel)	3	"	"
		Light Duty Truck	15	"	"
		Light Duty Vehicles	20	1 trip/day	"

*NRC. "Environmental Assessment for the Operation of the Gas Hills Project Satellite In-Situ Leach Uranium Recovery Facility." Docket No. 40-8857. Washington, DC: NRC. January 2004.

Table 2.7-2. Estimated Particulate (Fugitive Dust) and Gaseous (Diesel Combustion Products) Emissions for the Crownpoint, New Mexico, *In-Situ* Leach Facility Construction Phase*

Emission Type	Annual Total (metric tons)†	Annual Average Concentration ($\mu g/m^3$)‡
Particulates	10.0	0.28
Sulfur dioxides (SO_x)	6.4	0.18
Nitrous oxides (NO_x)	76.2	2.1
Hydrocarbons	9.8	0.27
Carbon monoxide	63.7	1.8
Aldehyde	1.4	0.04

*Modified from U.S. Nuclear Regulatory Commission. NUREG–1508, "Final Environmental Impact Statement To Construct and Operate the Crownpoint Uranium Solution Mining Project, Crownpoint, New Mexico." Washington, DC: U.S. Nuclear Regulatory Commission. February 1997.

†Multiply metric ton value by 1.1023 to convert units to short ton.

‡Multiply $\mu g/m^3$ value by 2.74×10^{-8} to convert units to oz/yd^3.

Radon gas is released during operation and aquifer restoration. Pressurized processing systems may contain most of the radon in solution; however, radon may escape from the processing circuit in the central uranium processing facility through vents or leaks, during well field operations, or during resin transfer when remote ion exchange is used. For open air activities, the gas quickly disperses into the air. In closed processing areas, the building ventilation systems are designed to limit indoor radon concentrations. Radon detectors are placed in appropriate locations to ensure compliance with worker protection regulations in 10 CFR Part 20. Airborne particulate emissions from yellowcake drying and packaging and the filling of sodium bicarbonate storage containers are controlled by using vacuum drying equipment and baghouse dust collection systems.

Both radon releases and uranium particulate emissions can migrate downwind from processing facilities and well fields. Downwind radiation dose from such ISL facility emissions varies due to the effects of dispersion as a function of distance. Particulate emissions are further reduced by the effect of dry deposition during airborne transport. Calculations of downwind dose are based on estimating the relative air concentration of released radionuclides (which is proportional to dose). Figure 2.7-1 shows relative air concentration for particulate matter as a function of distance estimated for the Bison Basin ISL facility (NRC, 1981, Table D.3). These results apply to the downwind area with the highest relative air concentrations. As shown, relative air concentration of uranium particulates, and therefore dose, drops by about a factor of 10 from the first data point {500 m [1,640 ft]} to the second {1,500 m [4,920 ft]}. The reduction in relative air concentration, and therefore dose, becomes less significant as downwind distance increases. The effect of distance on air concentration estimates is less pronounced for transport of gases (e.g., radon) due to the absence of dry deposition, which does not apply to gaseous transport. Airborne transport and dose modeling results for ISL facility releases to air (including both radon and uranium particulate releases, where applicable) are provided in Sections 4.2.11.2, 4.3.11.2, 4.4.11.2, and 4.5.11.2.

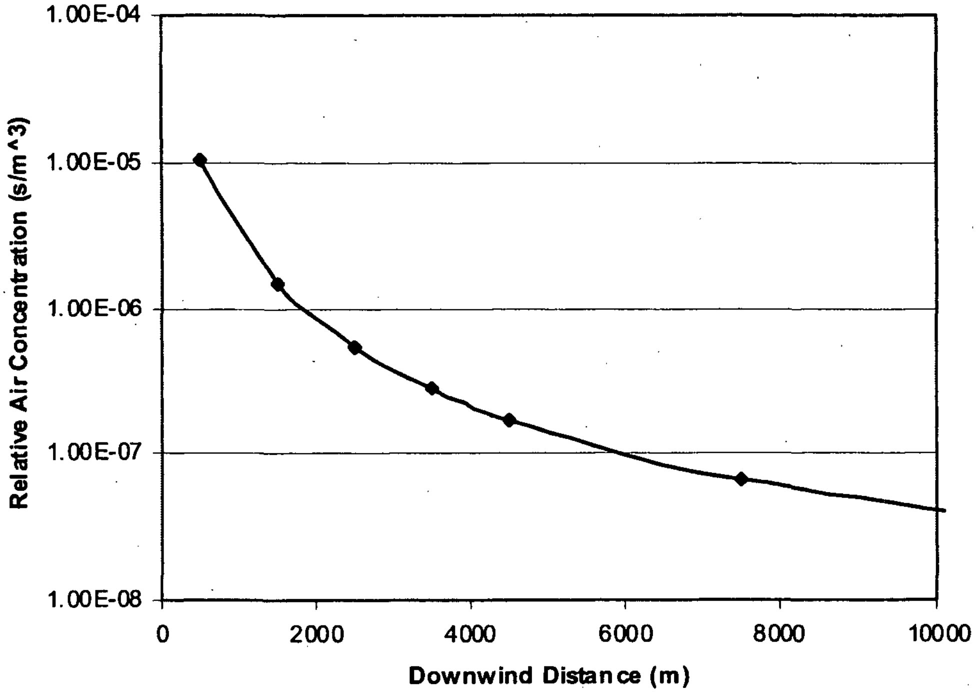

Figure 2.7-1. Downwind Distance Versus Relative Air Concentration (Which Is Proportional to Dose) [Bison Basin ISL Facility (NRC, 1981, Table D.3)]

2.7.2 Liquid Wastes

Liquid wastes from ISL facilities are generated during all phases of uranium recovery; construction, operations, aquifer restoration, and decommissioning. Liquid wastes may contain elevated concentrations of radioactive and chemical constituents. Table 2.7-3 shows estimated flow rates and constituents in liquid waste steams for the Highland ISL facility (NRC, 1978). Liquid waste streams are predominantly production bleed (1 to 3 percent of the process flow rate) and aquifer restoration water (NRC, 1997a). Additional liquid waste streams are generated from well development, flushing of depleted eluant to limit impurities, resin transfer wash, filter washing, uranium precipitation process wastes (brine), and plant wash down water. ISL facilities have concrete curbed floors with drains and a sump to control and retain water from spills and wash downs. Sumps direct water to treatment facilities, to evaporation ponds, or back to the process circuit. Chemical tanks have berms that can hold tank contents if tanks rupture.

Table 2.7-3. Estimated Flow Rates and Constituents in Liquid Waste Streams for the Highland *In-Situ* Leach Facility*

	Water Softener Brine	Resin Rinse	Elution Bleed	Yellowcake Wash Water	Restoration Wastes
Flow Rate, gal/min	1	<3	3	7	450
As, ppm					0.1–0.3
Ca, ppm	3,000–5,000				
Cl, ppm	15,000–20,000	10,000–15,000	12000–15000	4,000–6,000	
CO_3, ppm		500–800			300–600
HCO_3, ppm		600–900			400–700
Mg, ppm	1,000–2,000				
Na, ppm	10,000–15,000	6,000—11,000	6,000–8,000	3,000–,000	380–720
NH_4, ppm			640–180		
Se, ppm					0.05–0.15
Ra-226, pCi/L	<5	100–00	100–300	20–50	50–100
SO_4, ppm					100–200
Th-230, pCi/L	<5	50–100	10–30	10–20	50–150
U, ppm	<1	1–3	5–10	3–5	<1
Gross Alpha, pCi/L					2,000–3,000
Gross Beta, pCi/L					2,500–3,500

*NRC. NUREG–0489, "Final Environmental Statement Related to Operation of Highland Uranium Solution Mining Project, Exxon Minerals Company, USA." Washington, DC: NRC. November 1978.

Some liquid wastes are treated at the processing facility to remove or reduce contaminants prior to disposal. Reverse osmosis is commonly used to segregate contaminants from liquid waste streams (e.g., Section 2.5.3). Radium concentrations are also selectively reduced when water is treated with barium chloride. The barium chloride chemically binds to radium in solution and deposits as a sludge that is sent to a licensed disposal facility. Results from Hydro Resources, Inc. reported in NRC (1997a) show radium concentrations of 74 pCi/l were reduced to less than 1 pCi/L following treatment with barium chloride.

Byproduct Material

11e.(2) byproduct materials are tailings or waste generated by extraction or concentration of uranium or thorium processed ores, as defined under Section 11e.(2) of the Atomic Energy Act.

Liquid effluent disposal practices that NRC previously has approved for use at specific sites include evaporation ponds, land application, deep well injection, and surface water discharge.

Evaporation ponds are used to retain the process-related liquid effluents that cannot be discharged directly to the environment. These effluents are 11e.(2) byproduct material. The residual solid waste materials normally remain in ponds until the ponds are decommissioned, when sludges are disposed of as 11e(2) material at a licensed disposal facility (Section 2.6). Guidance for the construction, operation, and monitoring of evaporation ponds is found in NRC

Regulatory Guide 3.11 (NRC, 1977, 2008). Typical evaporation ponds have surface areas ranging from 0.04 to 2.5 ha [0.1 to 6.2 acres] (NRC, 1998a; Crow Butte Resources, 2007). Evaporation ponds at NRC-licensed ISL facilities are designed with leak detection systems to detect liner failures. The licensee also must maintain sufficient reserve capacity in the retention pond system so that the contents of a pond can be transferred to other ponds in the event of a leak and subsequent corrective action and liner repair. Licensee and applicants can minimize the likelihood of impoundment failure by designing the pond embankments in accordance with the criteria found in NRC Regulatory Guide 3.11 (NRC, 1977, 2008). Sufficient freeboard height above the liquid level ensures containment during wind and rain events.

Land application uses agricultural irrigation equipment to apply treated water to land where the water can evaporate directly or be transpired by plants. Uranium and radium levels are reduced in the effluents disposed of by land application so as to limit contamination of surface soils and plants. Areas of a site where land application of treated water has been used are included in decommissioning surveys to ensure soil concentration limits are not exceeded. Land application may also require approval and permitting by other applicable State agencies.

NRC staff may also review and approve deep well injection for a specific ISL site as a method to dispose of particular process fluids such as reverse osmosis brine. [EPA or the state give the final approval, though, for the use of this method of waste disposal.] Deep well injection involves pumping the waste fluids into a deep confined aquifer at depths typically greater than 1,524 m [5,000 ft] below the ground surface (NRC, 1997a). Aquifer water quality in the deep confined aquifer is often poor (e.g., high salinity or total dissolved solids) and below drinking water standards. The approval process verifies that site-specific and regional characteristics limit the potential for contamination of local drinking water sources. Licensees must obtain an UIC permit from EPA or the appropriate state agency (Section 1.7).

The National Pollutant Discharge Elimination System (NPDES) permitting process (Section 1.8) allow for surface discharge of treated liquid effluents to local waterways including ephemeral stream channels. Water discharged in this way must be treated to remove contaminants to meet state and federal water quality standards.

2.7.3 Solid Wastes

All phases of the ISL facilities lifecycle generate solid wastes. These wastes include spent resin, empty chemical containers, pipes and fittings, pond sludge, tank sediments, contaminated soil from leaks and spills, and municipal waste. Solid wastes are classified as radioactive or nonradioactive prior to disposition. Radioactive wastes are disposed of as 11e(2) byproduct material at a licensed facility. Contaminated equipment and buildings may be similarly disposed or decontaminated and released according to NRC requirements. Nonradioactive hazardous wastes are segregated and disposed of at a hazardous waste disposal facility. Nonradiological uncontaminated wastes are disposed of at as ordinary solid waste at a municipal solid waste facility. The largest volumes of solid wastes requiring disposal are generated during facility decommissioning (EPA, 2007a,b). Table 2.6-1 provides estimated volumes of radioactive and noncontaminated ISL facility decommissioning wastes designated for offsite disposal.

2.8 Transportation

Trucks transport construction equipment and materials, operational processing supplies, ion exchange resins, yellowcake product, and waste materials during all phases of the ISL facility lifecycle.

Trucks transport construction equipment and materials to the site to support facility and well field construction activities along local roads. Because ISL facilities are small magnitude construction projects and well field construction is phased over a period of years, the magnitude of trucking activity to support construction is small relative to other industrial activities. The estimated frequency of truck shipments for construction of an ISL facility is provided in Table 2.8-1.

During the operational period, trucks supply an ISL facility with materials needed to support processing operations. Shipments involve hazardous chemicals such as ammonia, sulfuric acid, liquid and gaseous oxygen, hydrogen peroxide, sodium hydroxide, barium chloride, carbon dioxide, hydrochloric acid, sodium carbonate, sodium chloride, hydrogen sulfide, and sodium sulfide. These chemicals are commonly used in a variety of industrial applications, and the U.S. Department of Transportation regulates their transport. The estimated frequency of truck shipments to support ISL facility operation is provided in Table 2.8-1.

In areas where ore deposits are smaller and more spread out, a producer may construct a series of small satellite plants at the well field where ion exchange processing is conducted remotely rather than at the central uranium processing facility (NRC, 2004, 2006). The products of ion exchange processing are then transported by truck to a central uranium processing facility (Section 2.4). Uranium production using these types of satellite facilities is sometimes known as satellite remote ion exchange (Finch, 2007). Facilities that incorporate remote ion exchange operations will transport loaded ion exchange resins or uranium slurry from well fields to centralized processing facilities by truck. These trucks are typically modified three-compartment cement trailers. The carbon steel compartments are pressurized and rubber lined. The first compartment carries the uranium-loaded resin, the second is empty, and the third compartment holds unloaded resins (Finch, 2007). Each shipment can contain about 900–1,350 kg [2,000–3,000 lb] of uranium-loaded resin, although the actual amount depends on the size of the trailer. These trucks are generally sole-use vehicles that are labeled for this purpose in accordance with U.S. Department of Transportation requirements at 49 CFR 171–189 and NRC regulations at 10 CFR Part 71. In accordance with these regulations, no liquids are permitted in the truck during transport of uranium resins. The estimated frequency of remote ion exchange truck shipments to support ISL facility operation is provided in Table 2.8-1.

The refined yellowcake product is packed in 208-L [55-gal], 18-gauge drums holding an average of 430 kg [950 lb] and classified by the U.S. Department of Transportation as Type A packaging (49 CFR Parts 171–189 and 10 CFR Part 71). The yellowcake is shipped by truck to a remote conversion plant that transforms the yellowcake to uranium hexafluoride (UF_6) for the enrichment step of the reactor fuel cycle. An average truck shipment contains approximately 40 drums or 17 metric tons [19 short tons] of yellowcake (NRC, 1980). The annual number of shipments from a given ISL facility depends on the yellowcake production rate of the facility. A range of estimated annual shipment totals based on prior ISL facility production limits is provided in Table 2.8-1.

Table 2.8-1. Estimated Annual Vehicle Trips for Phases of ISL Facility Lifecycle

Cargo	Estimated Number of Truck Shipments	Remarks
Construction Equipment/Supplies	62*	1 per day for 2 months
Remote IX Shipments	365*	1 per day annually
Processing Chemicals	272†	Less than 1 per day annually
Processing Wastes	Range: 2.5–15*	Less than 1 per month annually
Yellowcake	Range: 21–145‡§‖¶#	Maximum is based on production assumed at the permitted limit at the largest facility
Decommissioning Nonhazardous Solid Waste	44**	Based on waste volumes from Smith Ranch (Table 2.6-1) and truck volume of 20 yd^3/shipment
Decommissioning Byproduct Waste	100**	Based on waste volumes from Smith Ranch (Table 2.6-1) and truck volume of 20 yd^3/shipment
Decommissioning Hazardous Waste	To be determined	To be determined
Employee Commuting	5,200–52,000 trips*	20 to 200 employees per day assumed for 12 months/yr. Maximum in range is expected to depend on timing of construction, drilling, and operational activities (Section 2.11.6)

*NRC. "Environmental Assessment for the Operation of the Gas Hills Project Satellite *In-Situ* Leach Uranium Recovery Facility." Docket No. 40-8857. Washington, DC: NRC. January 2004.

†NRC. "Environmental Assessment for Renewal of Source Material License No. SUA–1534—Crow Butte Resources Inc., Crow Butte Uranium Project Dawes County, Nebraska." Docket No. 40-8943. Washington, DC: NRC. 1998.

‡NRC. NUREG–0489, "Final Environmental Statement Related to Operation of Highland Uranium Solution Mining Project, Exxon Minerals Company, USA." Washington DC: NRC. November 1978.

§NRC. "Final Environmental Statement Related to the Operation of Bison Basin Project." Docket No. 40-8745. Washington, DC: NRC. 1981.

‖NRC. NUREG–1508, "Final Environmental Impact Statement To Construct and Operate the Crownpoint Uranium Solution Mining Project, Crownpoint, New Mexico." Washington, DC: NRC. February 1997.

¶NRC. "Environmental Assessment for Renewal of Source Material License No. SUA–1534—Crow Butte Resources Inc., Crow Butte Uranium Project Dawes County, Nebraska." Docket No. 40-8943. Washington, DC: NRC. 1998.

#NRC. "Environmental Assessment Construction and Operation of In Situ Leach Satellite SR-2 Amendment No. 12 to Source Material License No. SUA-1548—Power Resources, Inc., Smith Ranch-Highland Uranium Project (SR-HUP) Converse County, Wyoming." Docket No. 40-8964. Washington DC: NRC. December 2007.

**Waste volumes compiled and summed from estimates reported in McCarthy, J. "Smith Ranch: 2007–2008 Surety Estimate Revision." Letter (June 29) to G. Janosko, NRC. Glenrock, Wyoming: Power Resources International. 2007.

Waste materials generated by construction, operation, aquifer restoration, and decommissioning activities including hazardous chemical, radioactive, and ordinary municipal waste streams are segregated by waste type and transported by truck to approved disposal facilities. The estimated frequency of waste shipments for operation and decommissioning an ISL facility is provided in Table 2.8-1. Section 2.7 provides additional information on waste streams and waste management activities.

2.9 Radiological Health and Safety

NRC regulations at 10 CFR Part 20 address the health and safety of workers and the public in the event of exposure to radiation from all phases of the ISL facility lifecycle. These regulations require ISL facility operators to develop and implement an NRC-approved radiation protection program. During NRC inspections and other oversight activities, including reviews of monitoring and incident reports, NRC checks compliance with this program. This section briefly summarizes basic elements of a 10 CFR Part 20 radiation protection program. More detailed descriptions of radiological safety requirements and programs are found in the regulations at 10 CFR Part 20 and applicable NRC guidance documents summarized in the NRC Standard Review Plan for ISL facilities (NRC, 2003a).

A radiological protection program includes plans and procedures addressing the following topics:

- **Effluent Control**. Effluents to air (e.g., radon, uranium particulates) and surface water (e.g., permitted wastewater discharges) must meet NRC limits in 10 CFR Part 20 for radioactive effluents and worker and public doses. To ensure proper performance to specifications, plans and procedures include minimum performance specifications for control technologies (e.g., yellowcake dryer emission controls) and frequencies of tests and inspections.

- **External Radiation Exposure Monitoring Program**. This program specifies survey methods (including monitoring locations), instrumentation, and equipment for measuring worker exposures to external radiation during routine and nonroutine operations, maintenance, and cleanup activities. The program is designed to ensure worker dose levels are as low as reasonably achievable and comply with NRC requirements in 10 CFR Part 20.

- **Airborne Radiation Monitoring Program**. This program determines concentrations of airborne radioactive materials (including radon) in the workplace during routine and nonroutine operations, maintenance, and cleanup. This program is designed to ensure airborne radiation releases and worker exposures are as low as reasonably achievable and meet requirements specified in 10 CFR Part 20.

- **Exposure Calculations**. Procedures document the methodologies used to calculate intake of airborne radioactive materials in the workplace during routine and nonroutine operations, maintenance, and cleanup activities.

- **Bioassay Program**. A bioassay program assesses biological intake of uranium by workers routinely involved in operations where radioactive material can be inhaled (e.g., yellowcake dust from dryer operations or baghouse maintenance). Programs include collection and analysis of urine samples that are assessed for the presence of uranium. Action levels are set to maintain exposures as low as reasonably achievable and within worker requirements in 10 CFR Part 20.

- **Contamination Control Program.** A contamination control program includes standard operating procedures to prevent employees from entering clean areas or leaving the site while contaminated with radioactive materials. Such programs involve radiation surveys of personnel and surfaces, housekeeping requirements, specifications to control contamination in processing areas, and controls for the release of contaminated equipment.

- **Airborne Effluent and Environmental Monitoring Program.** This program measures concentrations and quantities of radioactive and nonradioactive materials released to the environment surrounding the facility. Such programs measure concentrations of constituents in stack effluents at the facility and in the environment near and beyond the site boundary emphasizing surface water, groundwater, vegetation, food and fish, and soil and sediment. Direct radiation and radon flux are also measured. Offsite radiological and environmental monitoring is detailed in Chapter 8.

2.10 Financial Surety

NRC regulations [10 CFR Part 40, Appendix A, Criterion (9)] require that applicants or licensees cover the costs for a third party to conduct decommissioning, reclamation of disturbed areas, waste disposal, and groundwater restoration (Mackin, et al., 2001b). NRC annually reviews a licensee's financial surety to assess expansions in operations, changes in engineering design, completion of decommissioning activities, actual experience in aquifer restoration, and inflation. Specific considerations for estimating these costs are detailed in Appendix C of NRC, 2003a, and financial surety arrangements are discussed only briefly here.

Each licensee establishes financial surety arrangements before uranium recovery operations begin to assure there will be sufficient funds to carry out the activities described in Sections 2.5 and 2.6. The surety funds also must be sufficient for monitoring and control required as part of the license termination. Acceptable financial surety arrangements include surety bonds, cash deposits, certificates of deposit, deposits of government securities, parent company guarantees (subject to specific NRC criteria), trusts and standby trusts, irrevocable letters or lines of credit, and combinations of these instruments. Self-insurance is not an acceptable form of surety for NRC, although it may be accepted by individual states. The term of the surety mechanism must be open ended so that it will not expire before cleanup is complete. [NRC is currently engaged in a rulemaking that may change the list of NRC-approved surety instruments and conditions for other approved forms of financial assurance. The final rule may be issued in late 2008 or early 2009.]

As required under 10 CFR Part 40, Appendix A, Criterion 9, the licensee must supply enough information for NRC to verify that the amount of financial coverage will allow all decontamination and decommissioning and reclamation of sites, structures, and equipment used in conjunction with facility operation to be completed. Cost estimates for the following activities (where applicable) should be submitted to NRC with the initial license application or reclamation plan and should be updated annually as specified in the operator's NRC license. A third party (an independent contractor or operator who is not financially affiliated with the licensee) must calculate cost estimates based on completion of all activities. Unit costs, calculations, references, assumptions, equipment and operator efficiencies, and other breakdown details must be provided.

In the required annual surety estimate, the licensee must provide estimated costs for all decommissioning, reclamation, and groundwater restoration work remaining to be performed at the site—not simply deduct the cost of work already performed from the previous surety estimate (see NRC, 1997b). For each activity, estimates should include costs for equipment; materials; labor and overhead; licenses, permits, and miscellaneous site-specific costs; and any other activity or resource that will require spending funds. The licensee should add a contingency amount to the total cost estimate for the final site closure. NRC typically considers a 15 percent contingency to be an acceptable minimum amount (NRC, 2003a, Appendix C). The licensee is required by 10 CFR Part 40, Appendix A, Criterion 9, to adjust cost estimates annually to account for inflation and changes in reclamation plans. In addition, all costs are to be estimated based on third party, independent contractor costs (including overhead and profit in unit costs or as a percentage of the total). Licensee-owned equipment and the availability of licensee staff should not be considered in the financial surety estimate, because this can reduce cost calculations.

To avoid unnecessary duplication and expense, NRC also takes into account surety arrangements that other federal, state, or other local agencies may require. However, NRC is not required to accept such sureties if they are insufficient. NRC reviews the licensee's surety analysis annually to ensure that the funding reflects ongoing aquifer restoration and decommissioning/reclamation activities. The surety remains in place until the final NRC decommissioning surveys are complete and the license is terminated.

2.11 Information From Historical Operation of ISL Uranium Milling Facilities

2.11.1 Area of ISL Uranium Milling Facilities

The permitted areas for past and current ISL uranium recovery operations have varied in size. As shown in Table 2.11-1 facilities range from about 1,034 ha [2,552 acres] for the proposed Crownpoint facility in McKinley County, New Mexico, to over 6,480 ha [16,000 acres] for the Smith Ranch property in Converse County, Wyoming. However, much of the permitted area of a site is undisturbed, and surface operations (wells, processing facilities) affect only a small portion of it. For example, the well fields and excursion monitoring wells that go along with them occupy between 40 and 2,500 ha [100 and 6,000 acres], although most occupy less than about 1,000 ha [2,500 acres]. The central processing facility may occupy only 1 to 6 ha [2.5 to 15 acres], and satellite plants would be even smaller (NRC, 2006).

Surface facilities are considered controlled areas where security fencing limits access. The well fields, which consist of injection and recovery (production) wells, are the areas where most activities that disturb the surface and subsurface take place. Select areas around header houses and well heads are fenced to prevent livestock grazing. Lands near surface operations and in active uranium recovery are excluded from agricultural production for the duration of the project. Despite the large permitted area of a typical ISL facility, the amount of land that is disturbed by earthmoving activities at any one time is relatively small. For example, while the total area disturbed by construction activities between 1987 and 2007 is about 530 ha [1,310 acres] for the Crow Butte ISL facility in Dawes County, Nebraska, only about 50 ha [120 acres] is estimated to be the total disturbed area at any one time (Crow Butte Resources, Inc., 2007). After the surface operations are complete and well fields are restored, the final steps of decommissioning and surface reclamation are intended to return the land to its pre-operational conditions.

Table 2.11-1. Size of Permitted Areas for ISL Facilities

Name	Permitted Area in Hectares [acres]	Status of Facility as of February 2008
Crownpoint, New Mexico	1,034 [2,552]†	Partially permitted and licensed
Crow Butte, Nebraska	1134 [2,800] ‡	Operating
Gas Hills, Wyoming (Satellite)	3,442 [8,500]*	Under development as a satellite of Smith Ranch/Highland, intend to expand
Reynolds Ranch, Wyoming (Satellite	3,525 [8,704]§x	Under development as satellite of Smith Ranch/Highland
Highland, Wyoming	6,075 [15,000] ‡	Operating, combined with Smith Ranch
Irigaray, Christensen Ranch	6,075 [15,000]¶	Previously issued license, intend to restart
Smith Ranch, Wyoming	6,480 [16,000]#	Operating, combined with Highland, Gas Hills, North Butte, and Ruth, intend to expand

*NRC. NUREG–1508, “Final Environmental Impact Statement To Construct and Operate the Crownpoint Uranium Solution Mining Project, Crownpoint, New Mexico.” Washington, DC: NRC. February 1997.

†NRC. “Environmental Assessment for Renewal of Source Material License No. SUA–1534—Crow Butte Resources Inc., Crow Butte Uranium Project Dawes County, Nebraska.” Docket No. 40-8943. Washington, DC: NRC. 1998.

‡NRC. “Environmental Assessment for the Operation of the Gas Hills Project Satellite *In-Situ* Leach Uranium Recovery Facility.” Docket No. 40-8857. Washington, DC: NRC. January 2004.

§NRC. “Environmental Assessment for the Addition of the Reynolds Ranch Mining Area to Power Resources Inc., Smith Ranch/Highlands Uranium Project Converse County Wyoming, Source Material License No SUA–1548.” Docket No. 40-8964. Washington, DC: NRC. November 2006.

‖NRC. “Environmental Assessment for Renewal of Source Material License No. SUA-1511 Power Resources Inc., Highland Uranium Project Converse County, Wyoming.” Docket No. 40-8857. Washington DC: NRC. August 18, 1995.

¶NRC. “Environmental Assessment for Renewal of Source Material License No. SUA–1341, Cogema Mining, Inc. Irigaray and Christensen Ranch Projects, Campbell and Johnson Counties, Wyoming.” Docket No. 40-8502. Washington, DC: NRC. June 1998.

#NRC. “Environmental Assessment for Rio Algom Mining Corporation Smith Ranch *In-Situ* Leach Mining Project, Converse County, Wyoming in Consideration of a Source and Byproduct Material License Application.” Docket No. 40-8964. Washington, DC: NRC. January 1992.

2.11.2 Spills and Leaks

During ISL operations and aquifer restoration, barren and pregnant uranium-bearing process solutions are moved through pipelines to and from the well field and among different surface facilities (e.g., processing circuit, evaporation ponds). If a pipeline ruptures or fails, process solutions can be released and (1) pond on the surface, (2) run off into surface water bodies, (3) infiltrate and adsorb in overlying soil or rock, or (4) infiltrate and percolate to groundwater. For example, from 2001 to 2005, the operators of the Smith Ranch-Highland uranium ISL facility in Converse County, Wyoming, reported 24 spills of uranium recovery solutions, and the WDEQ identified more than 80 spills during commercial operations (WDEQ, 2008). This is the largest NRC-licensed ISL uranium recovery facility. The size of the spills at Smith Ranch-Highland has ranged from a 190- to 380-liter [50- to 100-gallon] spill in February 2004 to a 751,400-L [198,500-gal] spill of injection fluid in June 2007 (WDEQ, 2007; NRC, 2006). The spills most commonly involved injection fluids {0.5 to 3.0 mg/l uranium [0.5 to 3.0 parts per million]}, although spills of production fluids {10.0 to 152 mg/l uranium [10.0 to 152 parts per million]} also have occurred (NRC, 2007). These spills have been predominantly caused by the failure of joints, flanges, and unions of pipelines and at wellheads (NRC, 2006, 2007). The large June 2007 spill at Highland was the apparent result of a failed fitting. The spilled fluids flowed into a drainage and continued downstream for about 700 m [2,300 ft]. The WDEQ Land Quality Division estimated the affected area at 0.44 ha [1.08 acres] (WDEQ, 2007).

Reporting requirements for spills differ from State to State. NRC's requirements for spill reporting are found in Subpart M of 10 CFR Part 20 and at 10 CFR 40.60. Additionally, NRC may incorporate reporting requirements as conditions in the issued operating license. Generally, such NRC and State requirements include a more immediate report (e.g., notifications within 24 to 48 hours of the spill) followed by a later written report addressing items such as, the conditions leading to the spill, the corrective actions taken, and the results achieved. A licensee's documentation of its spills helps in final site decommissioning activities.

For hazardous chemicals stored at the processing facility, spill responses would be similar to those described previously for yellowcake transportation, although nonradiological material spills are primarily reportable to the appropriate state agency and EPA. Concrete berms with at least the volume of the tank are used to contain spills from process chemical storage tanks and simplify cleanup (e.g., NRC, 1998a,b). The Occupational Safety and Health Administration sets worker exposure limits to process chemicals at the ISL surface facilities. Typical onsite quantities of process chemicals used at ISL facilities are included in Tables 2.11-2 and 2.11-3.

Table 2.11-2. Common Bulk Chemicals Required at the Project Processing Sites*†

Shipped as Dry Bulk Solids	Shipped as Liquids and Gases
Salt (NaCl)	Hydrochloric acid (HCl)
Sodium bicarbonate ($NaHCO_3$)	Sulfuric acid (H_2SO_4)
Sodium carbonate (Na_2CO_3)	Hydrogen peroxide (H_2O_2)
Sodium hydroxide (NaOH)	Oxygen (O_2)
—	Carbon dioxide (CO_2)
—	Anhydrous ammonia (NH_3)
—	Diesel oil
—	Bottled gases
—	Liquified petroleum gas (LPG)

*NRC. NUREG–1508, "Final Environmental Impact Statement to Construct and Operate the Crownpoint Uranium Solution Mining Project, Crownpoint, New Mexico." Washington, DC: NRC. February 1997.
†Energy Metals Corporation, U.S. "Application for USNRC Source Material License Moore Ranch Uranium Project, Campbell County, Wyoming: Environmental Report." ML072851249. Casper, Wyoming. Energy Metals Corporation, U.S. September 2007.

Table 2.11-3. Onsite Quantities of Process Chemicals at ISL Facilities*

Chemical	Typical Onsite Quantity	Use in Uranium ISL Process
Ammonia (NH_3)	40,820 kg [90,000 lb]	pH adjustment
Sulfuric acid (H_2SO_4)	37,850 L [10,000 gal]	pH control during lixiviant processing, and splitting uranyl carbonate complex into CO_2 gas and uranyl ions in preparation for their precipitation
Liquid and gaseous oxygen	No specific typical quantities available	Oxidant in lixiviant, and precipitation of uranium as an insoluble uranyl peroxide compound
Hydrogen peroxide (H_2O_2)	26,500 L [7,000 gal]	Uranium precipitation and oxidant in lixiviant
Sodium hydroxide (NaOH)	Typically stored in 208-L [55-gal] drums	pH adjustment
Barium chloride ($BaCl_2$)	No specific typical quantities available	Precipitation of radium during groundwater restoration, and wastewater treatment
Carbon dioxide (CO_2)	*No specific typical quantities available*	*Carbonate complexing*
Hydrochloric acid (HCl)	37,850 L [10,000 gal]	pH adjustment
Sodium carbonate (Na_2CO_3)	64,350 L [17,000 gal]	Carbonate complexing and resin regeneration
Sodium chloride (NaCl)	127,000 kg [280,000 lb]	Resin regeneration
Hydrogen sulfide (H_2S)	No specific typical quantities available	Groundwater restoration
Sodium sulfide (Na_2S)	No specific typical quantities available	Groundwater restoration

*Mackin, P.C., D. Daruwalla, J. Winterle, M. Smith, and D.A. Pickett. NUREG/CR–6733, "A Baseline Risk-Informed Performance-Based Approach for *In-Situ* Leach Uranium Extraction Licensees." Washington, DC: NRC. September 2001.

Evaporation ponds are typically constructed in accordance with NRC staff guidance in NRC (1977, 2008), and license conditions require that these ponds be periodically monitored. Pond leaks have, however, occurred at active ISL facilities. For example, at the Crow Butte ISL facility in Dawes County, Nebraska, seven leaks were identified for three different commercial evaporation ponds from 1991 through 1997 (NRC, 1998b). The volumes of the leaks ranged from about 257.4 to 1,135.6 L [68 to 300 gal], but in all cases, the leaks involved only the upper liner of the double-lined system. To repair the leaks, the licensee exposed the liner by transferring water to other ponds to lower the water level, patched the holes, and pumped the water from the underdrain system (NRC, 1998b). Since, 1997, the Crow Butte facility has reported and repaired an additional eight pond leaks, with the most recent leak identified and the pond liner repaired in May 2006 (Teahon, 2006). From 1988 to 1997, one pond leak was reported in 1992 at the Irigary/Christensen Ranch ISL facility in Campbell and Johnson Counties, Wyoming (NRC, 1998a). The licensee's corrective actions included temporarily transferring water to expose the liner and repair the leak.

The EPA- or state-issued UIC permit requires monitoring and testing the mechanical integrity of production and injection wells, reducing the potential for these types of failures. At the proposed Reynolds Ranch expansion of the Smith Ranch-Highland ISL facility in Converse County, Wyoming, the applicant established immediate spill responses through onsite standard operating procedures. These include shutting down the affected well or pipeline; recovering as much of the spilled fluid as possible; collecting samples of the affected soil so it can be compared to background values for uranium, radium-228, and selenium; and cleaning it up if necessary (NRC, 2006).

2.11.3 Groundwater Use

During construction, groundwater use is limited to routine activities such as dust suppression, mixing cements, and drilling support. Although large amounts of groundwater are moved and processed during ISL facility operations, most of the water is reinjected maintaining the overall water balance. A production bleed of about 1–3 percent, as discussed earlier, means that about 97–99 percent of the water produced from a well field is reinjected for additional uranium recovery. For example, for the proposed Reynolds Ranch addition to the Smith Ranch ISL facility in Converse County, Wyoming, the NRC staff estimated that the amount of water used in the ion exchange columns at the satellite facilities or discharged to a deep disposal well could be as much as 1,480,000,000 L [391 million gal] over the course of an assumed operating period of 15 years (NRC, 2006). For the Crow Butte ISL facility in Dawes County, Nebraska, the average operating flow rate in 2007 was about 16,200 L/min [4,279 gal/min] (Cameco Resources, Inc., 2008). The total net volume of groundwater produced for 2007 (volume produced–volume injected) was 346,900,000 L [91,640,000 gal], and the production bleed ranged from about 1.1 to 1.6 percent. During the last six months of 2007, about 76,200,000 L [20,130,000 gal] was disposed in the licensed Class I UIC deep disposal well and about 14,370,000 L [3,800,000 gal] was discharged to the evaporation pond system (Cameco Resources, 2008).

2.11.4 Excursions

As discussed in Section 2.4, ISL operations may affect the groundwater quality near the well fields or in over- or underlying aquifers when lixiviant travels from the production zone and beyond the well field boundaries. Monitoring wells are designed and placed to capture any lixiviant that moves out of the production zone. A monitoring well is placed on excursion status when two or more excursion indicators exceed their respective upper control limits (UCLs) (NRC, 2003a). NRC licensees are required by license conditions to identify reporting, monitoring, and response measures to be taken to determine the extent and cause of the excursion, as well as measures to recover the excursion into the well field and remove the well from excursion status.

Historical information for several facilities indicates that excursions can and do occur at ISL operations (NRC, 2006, 1998a,b, 1995; Crow Butte Resources, Inc., 2007; Cameco Resources, 2008; Arbogast, 2008). For example, from 1987 to 1998, 49 different wells were placed on excursion status at the Irigary and Christensen Ranch uranium recovery facility in Campbell and

Johnson Counties in the Wyoming East Uranium Milling Region (NRC, 1998a). Most of these excursions were recovered within a period of weeks to months, but six vertical excursions proved more difficult to return to baseline, with two wells remaining on excursion status for at least 8 years. These excursions were believed to be due to improperly abandoned wells from earlier exploratory programs prior to regulation by a UIC program. In 2007, three wells were on excursion status at the Christensen Ranch project, with only one, originally identified in 2004, remaining on excursion status at the end of 2007 (Arbogast, 2008a). None of the earlier wells identified in NRC (1998a) were still on excursion status. An additional well at the Christensen Ranch project was placed on excursion status in 2008 (Arbogast, 2008b).

From 1988 through 1995, 22 monitoring wells (11 vertical and 11 horizontal) were placed on excursion status for the Highland Uranium Project located in Converse County in the Wyoming East Uranium Milling Region (NRC, 1995). Most of the excursions were recovered within less than 1 year, but four horizontal excursions lasted up to at least five years. In two of these wells, the excursions were due to a thinning of the confining layer that separated two different production zones. Groundwater pumping during restoration of the underlying production zone resulted in establishing a hydraulic gradient that brought production fluids down from the overlying aquifer. One of the other excursions was believed to be the result of fluids migrating from an upgradient abandoned uranium mine (NRC, 1995). No cause was identified for the final long-term excursion at the Highland Uranium Project. Only one horizontal excursion was reported between 2001 and 2005 at the Smith Ranch-Highland uranium recovery facility, and corrective action brought the well back below the UCLs within less than one month (NRC, 2006).

At the Crow Butte ISL facility located in Dawes County, Nebraska (Nebraska-South Dakota-Wyoming Uranium Milling Region), the operator reported five vertical excursions into the overlying aquifer from the start of commercial operations in 1989 through the license renewal in 1998 (NRC, 1998b). In two cases, these excursions resulted from well integrity problems (borehole cement contamination and a failed casing coupling). One excursion resulted from a leak in a plugged and abandoned injection well, and the remaining two were believed to result from natural fluctuations in the groundwater quality (NRC, 1998b). Between 1999 and 2006, 17 wells at the Crow Butte facility were placed on excursion status (7 vertical and 10 horizontal) Most of these wells were restored below the UCLs within 1 to 6 months, although one vertical well took almost four years to restore (Crow Butte Resources, Inc., 2007). In the second half of 2007, three horizontal monitoring wells were on excursion status (Cameco Resources, 2008). These excursions were first identified in April 2000, December 2003, and September 2006 (Crow Butte Resources, Inc., 2007). The licensee believes that these longer term excursions resulted from well field geometry and well field flare as a result of ongoing groundwater transfer and well field restoration activities.

Operational experience at these facilities indicates that lixiviant excursions can result from

- Thinning or discontinuous confinement
- Improperly abandoned wells that may provide vertical flow pathways
- Casing failure or other well leaks
- Natural fluctuations in groundwater quality
- Improper balance of well field hydrologic gradients

Most horizontal excursions could be recovered quickly (weeks to months) by fixing and reconditioning wells and adjusting pumping rates in the well field, consistent with the findings of

Mackin, et al. (2001a). Vertical excursions tended to be more difficult to recover than horizontal excursions, and in a few cases, a well could remain on excursion status for a period of as much as 8 years.

2.11.5 Aquifer Restoration

Operational history at NRC-licensed ISL facilities is available to examine aquifer restoration at the well-field scale. In preparing the environmental report for the proposed Moore Ranch facility in Campbell County, Wyoming, Energy Metals Corporation, U.S., (2007) summarized mean groundwater quality conditions at the end of uranium recovery operations for a 12-ha [30-acre] area covered by Production Units 1–9 at the nearby COGEMA Irigaray ISL facility (Table 2.11-4). Before May 1980, the uranium recovery operations at Irigaray used an ammonium bicarbonate-hydrogen peroxide lixiviant. In May 1980, the facility was converted to a sodium bicarbonate-gaseous oxygen lixiviant. A comparison of the baseline and past recovery groundwater analytical data indicates that the water quality in the production zone is degraded for elements that make up part of the lixiviant (e.g., ammonia, bicarbonate, sodium) and for other elements (e.g., calcium and chloride).

Table 2.11-4. Irigaray Post-Uranium Recovery Water Quality*

Parameters (units)	Irigaray Baseline Range	Irigaray Post-Uranium Recovery Mean
Dissolved aluminum (mg/L†)	<0.05–4.25	<1.037
Ammonia nitrogen as N (mg/L)‡	<0.05–1.88	23
Dissolved arsenic (mg/L)	<0.001–0.105	<0.601
Dissolved barium (mg/L)	<0.01–0.12	<1.067
Boron (mg/L)	<0.01–0.225	<0.442
Dissolved cadmium (mg/L)	<0.002–0.013	<0.979
Dissolved chloride (mg/L)†	5.3–15.1	277
Dissolved chromium (mg/L)	<0.002–0.063	<1.018
Dissolved copper (mg/L)	<0.002–0.04	<0.828
Fluoride (mg/L)	0.11–0.66	<1
Total and dissolved iron (mg/L)	0.02–11.8	<1.098
Dissolved mercury (mg/L)	<0.0002–<0.001	<0.971
Dissolved magnesium (mg/L)	0.02–9.0	45.7
Total manganese (mg/L)	<0.005–0.190	1.249
Dissolved molybdenum (mg/L)	<0.02–<0.1	<1.067
Dissolved nickel (mg/L)	<0.01–<0.2	<1.018
Nitrate + nitrite as N (mg/L)	<0.2–1.0	<3
Dissolved lead (mg/L)	<0.002–<0.050	<1.018
Radium-226 (pCi/L)	0–247.7	200.5
Dissolved selenium (mg/L)	<0.001–0.416	0.247
Dissolved sodium (mg/L)	95–280	827
Sulfate (mg/L)	136–824	639

Table 2.11-4. Irigaray Post-Uranium Recovery Water Quality* (continued)

Parameters (units)	Irigaray Baseline Range	Irigaray Post-Uranium Recovery Mean
Uranium (mg/L)	<0.0003–18.8	7.411
Vanadium (mg/L)	<0.05–0.55	<1.067
Dissolved zinc (mg/L)	<0.01–0.200	<0.065
Dissolved calcium (mg/L)†	1.6–33.5	199.2
Bicarbonate (mg/L)†	5–144	1,343
Carbonate (mg/L)	0–96	<2
Dissolved potassium (mg/L)	0.4–17.5	9
Total dissolved solids at 180 °F (mg/L)	308–1,054	2,451

*Energy Metals Corporation, U.S. "Application for USNRC Source Material License Moore Ranch Uranium Project, Campbell County, Wyoming: Environmental Report." ADAMS ML072851249. Casper, Wyoming: Energy Metals Corporation U.S. 2007.
†1 mg/L = 1 ppm
‡Parameters with restoration value other than baseline.

Catchpole, et al. (1992a,b) provide an early discussion of small-scale restoration efforts for research and development (R&D) of ISL uranium recovery facilities in Wyoming. These include the Bison Basin facility in Fremont County (described in NRC, 1981), the Reno Creek project in Campbell County, and the Leuenberger Project in Converse County. Restoration activities required treatment of water from nine pore volumes at Bison Basin and five pore volumes at Reno Creek. In all cases, most water quality parameters were returned to within a statistical range of baseline values with the exception of uranium (Bison Basin and Reno Creek) and radium-226 (Leuenberger). For these parameters, Catchpole, et al. (1992a,b) report that water in the well field was returned to the same class of use.

Davis and Curtis (2007) detailed available information on aquifer restoration at ISL uranium recovery facilities. These include a pilot scale study by Rio Algom for the Smith Ranch facility in Converse County, Wyoming (Rio Algom Mining Corporation, 2001); the proposed Crownpoint ISL facility near Crownpoint, New Mexico (NRC, 1997); the A-Well Field at the Highland Uranium Project in Converse County, Wyoming (Power Resources, Inc., 2004a); and the Crow Butte Mine Unit No. 1 in Dawes County, Nebraska (NRC, 2002, 2003c). Rock core laboratory studies that Hydro Resources Inc. conducted for the Crownpoint facility (NRC, 1997a) also provide useful insights to water quality parameters that may present challenges for aquifer restorations.

Davis and Curtis (2007) generally concluded that for the sites and data they examined, aquifer restoration took longer and required more pore volumes than originally planned. For example, at the A-Well Field at the Highland Uranium Project, the licensee's original plan anticipated that restoration would last from four to seven years and require treating 5–7 pore volumes of groundwater. When uranium recovery in the well field ended in 1991, the baseline and class of use were not restored in the well field until 2004 (Table 2.11-5), and more than 15 pore volumes of water were involved (NRC, 2006, 2004). Similarly, WDEQ has noted that the C-Well field at Smith-Ranch-Highland has been undergoing restoration for 10 years (WDEQ, 2008). At the Crow Butte Mine Unit No. 1, more than 9.85 pore volumes of groundwater were used in all the stages of aquifer restoration over approximately 5 years as compared to the 8 pore volumes estimated before restoration (NRC, 2002, 2003c). CBR extracted uranium from an additional 26 pore volumes using ion exchange, without lixiviant injection, prior to active restoration.

Table 2.11-5. Baseline Groundwater Conditions, Aquifer Restoration Goals, and Actual Final Restoration Values NRC Approved for the Q-Sand Pilot Well Field, Smith Ranch, Wyoming*†

Parameter (units)	Range	Mean	Restoration Goal	Actual Restoration
Arsenic (mg/L‡)	0.001–.0013	0.004	0.05	0.008
Boron (mg/L)	0.002–0.70	0.15	0.54	0.14
Calcium (mg/L)	24–171	72	120	78
Iron (mg/L)	0.01–0.27	0.025	0.3	0.24
Magnesium (mg/L)	3–22	16	0.092	0.06
Manganese (mg/L)	0.01–0.077	0.023	Not applicable	0.1
Selenium (mg/L)	0.001–0.024	0.004	0.029	0.003
Uranium (mg/L)	0.001–3.1	0.28	3.7	1.45
Chloride (mg/L)	4–65	18	250	15
Bicarbonate (HCO_3) (mg/L)	129–245	199	294	254
Carbonate (CO_3) (mg/L)	Nondetectible–75	18	15	Nondetectible
Nitrate (mg/L)	0.1–1.0	0.4	Not applicable	0.13
Potassium (mg/L)	7–34	12	23	8
Sodium (mg/L)	19–87	28	41	38
Sulfate (mg/L)	100–200	124	250	128
Total dissolved solids (mg/L)	155–673	388	571	443
Specific conductivity (μmhos/cm)	518–689	582	827	642
pH (standard units)	7.5–9.4	8.0	6.5–8.6	7.0
Radium-226 (pCi/l)	6–1132	340	923	477
Thorium-230 (pCi/l)	0.027–4.65	1.03	5.62	3.4

*NRC. "Environmental Assessment for the Addition of the Reynolds Ranch Mining Area to Power Resources, Inc.'s Smith Ranch/Highlands Uranium Project Converse County, Wyoming." Source Material License No. SUA–1548. Docket No. 40-8964. Washington, DC: NRC. 2006.

†Sequoyah Fuels Corporation. "Re: License Application, Smith Ranch Project, Converse County, Wyoming." ML8805160068. Glenrock, Wyoming: Sequoyah Fuels Corporation. 1988.

‡1 mg/L = 1 ppm

As a field test of groundwater stabilization during aquifer restoration, hydrogen sulfide gas was injected as a reductant into the Ruth ISL research and development facility in Campbell County, Wyoming. After 6 weeks of hydrogen sulfide injection, pH dropped relatively quickly from 8.6 to 6.3, and sulfate concentration increased from 28 ppm to 91 ppm indicating a more reducing environment (Schmidt, 1989; Davis and Curtis, 2007). Concentrations of dissolved uranium, selenium, arsenic, and vanadium decreased by at least one order of magnitude. After one year of monitoring, however, reducing conditions were not maintained, and uranium, arsenic, and radium concentrations began to increase.

Based on the available field data from aquifer restoration, Davis and Curtis (2007) concluded that aquifer restoration is complex and results could be influenced by a number of site-specific hydrological and geochemical characteristics. As discussed previously, in some cases, such as at Bison Basin and Reno Creek, the aquifer was restored in a relatively short time. In other cases, restoration required much more time and treatment than was initially estimated (e.g., the A- and C- Well Fields at the Highland ISL facility.

2.11.6 Socioeconomic Information

Because they are generally located in remote areas, uranium ISL facilities tend to be important employers in the local economy. The total number of full-time, permanent employees and local contractors varies during an operational life that may span several decades. Based on employment levels at existing operations and projected employment for proposed projects, staff levels at ISL facilities range from about 20 to 200, with peak employment depending on the scheduling of construction, drilling, and operational activities (Crow Butte Resources, Inc., 2007; Power Resources, Inc., 2004a; NRC, 1997a).

Another economic effect from ISL facilities is contributions to the local economy through purchases and through tax revenues from the uranium produced at the facility. For example, at the Crow Butte ISL facility in Dawes County, Nebraska, local purchases of goods and services in 2006 were estimated at about $5,000,000 (Crow Butte Resources, Inc., 2007). Annual tax revenues depend on uranium prices and the amount of uranium produced at a given facility. For example, for a 272,155-kg [600,000-lb] increase in annual yellowcake production at the Crow Butte facility at a price of $80/lb, an incremental contribution to federal, state, and local taxes on the order of $1 million to $1.4 million would result (Crow Butte Resources, Inc., 2007).

2.12 Alternatives Considered and Included in the Impact Analysis

The NRC's environmental review regulations in 10 CFR Part 51 that implement the National Environmental Policy Act (NEPA) require the NRC to consider reasonable alternatives, including the no-action alternative, to a proposed action before acting on a proposal. The intent is to enable the agency to consider the relative environmental consequences of an action given the environmental consequences of other activities that also meet the need for the action, as well as the environmental consequence of taking no action at all. The information in this section does not constitute NRC's final consideration of reasonable alternatives for the site-specific environmental reviews of ISL license applications.

2.12.1 The No-Action Alternative

As defined in Chapter 1, the proposed action is to identify and evaluate the potential environmental impacts associated with the construction, operation, aquifer restoration, and decommissioning of ISL facilities in designated regions of the western U.S. In the No-Action Alternative, no additional ISL activity would take place in the four geographic regions considered in this Draft GEIS. As a result, the regions would not see additional ISL activities as described in Chapter 2 nor the associated potential environmental impacts discussed in Chapter 4. Ongoing and reasonably foreseeable future activities as described in Chapter 5 would still impact the regions.

2.13 Alternatives Considered and Excluded From the Impact Analysis

Alternative methods for uranium recovery include conventional mining/milling methods and heap leaching. Heap leaching (i.e., use of chemical solutions to leach uranium from a pile of crushed ore) may be used for low grade or small ore bodies, but mining and some crushing and grading is necessary to build up the ore pile (EPA, 2007a; NRC, 1980). The heap leach process is a technology that is considered to be part of the conventional mining and milling industry; NRC regulates this technology using the criteria in 10 CFR 40, Appendix A, that are deemed applicable to such operations (NRC, 1980, Appendix B). These two alternative uranium recovery technologies are discussed further in Appendix C.

Because the Draft GEIS focuses on the future licensing of ISL facilities and does not evaluate available technologies for uranium recovery, conventional mining/milling and heap leaching were not included in the impact analysis. However, such uranium recovery methods may be among the reasonable alternatives evaluated in a site-specific review of an ISL license application. As described in Section 2.1, there are particular types of uranium deposits that are amenable to ISL uranium recovery technology. In certain cases (e.g., the ore body is located near the surface), these deposits may also be accessible by conventional mining techniques, with the uranium in the mined ore recovered by conventional milling methods or by heap leaching. Therefore, the alternatives to be considered will be addressed in the site-specific environmental reviews.

2.14 References

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