MODULE 2.0: URANIUM RECOVERY

Introduction

Welcome to Module 2.0 of the Fuel Cycle Processes Directed Self-Study Course! This is the second of nine modules available in this directed self-study course. The purpose of this module is to identify where uranium is geographically distributed, uranium mining methods, basic milling process steps, uranium extraction processes, hazards, controls, sampling and measurement activities, and the NRC regulatory authority for uranium recovery and mill tailings. The NRC does not regulate mining. This self-study module is designed to assist you in accomplishing the learning objectives listed at the beginning of the module. There are seven learning objectives in this module. The module has self-check questions to help you assess your understanding of the concepts presented in the module.

Before you Begin

It is recommended that you have access to the following materials:

- Trainee Guide

Complete the following prerequisites:

- Module 1.0: Overview of the Nuclear Fuel Cycle

How to Complete this Module

1. Review the learning objectives.
2. Read each section within the module in sequential order.
3. Complete the self-check questions and activities within this module
4. Check off the tracking form as you complete the self-check questions and/or activity within the module.
5. Contact your administrator as prompted for a progress review meeting.
6. Contact your administrator as prompted for any additional materials and/or specific assignments.
7. Complete all assignments related to this module. If no other materials or assignments are given to you by your administrator, you have completed this module.
8. Ensure that you and your administrator have dated and initialed your progress on the tracking form.
9. Go to the next assigned module.

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MODULE 2.0: URANIUM RECOVERY

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LEARNING OBJECTIVES

2.1 Upon completion of this module, you will be able to identify where uranium is geographically distributed, uranium mining methods, basic milling process steps, uranium extraction processes, hazards, controls, sampling and measurement activities, and the NRC regulatory authority for uranium recovery and mill tailings.

2.1.1 Identify the geographic distribution of uranium.

2.1.2 Identify uranium mining methods.

2.1.3 Identify basic milling process steps.

2.1.4 Identify uranium extraction processes.

2.1.5 Identify hazards, controls, and sampling and measurement activities associated with uranium recovery.

2.1.6 Identify NRC regulatory authority for uranium recovery and mill tailings.

MODULE 2.0: URANIUM RECOVERY

Learning Objective

When you finish this section, you will be able to:

2.1.1 Identify the geographic distribution of uranium.

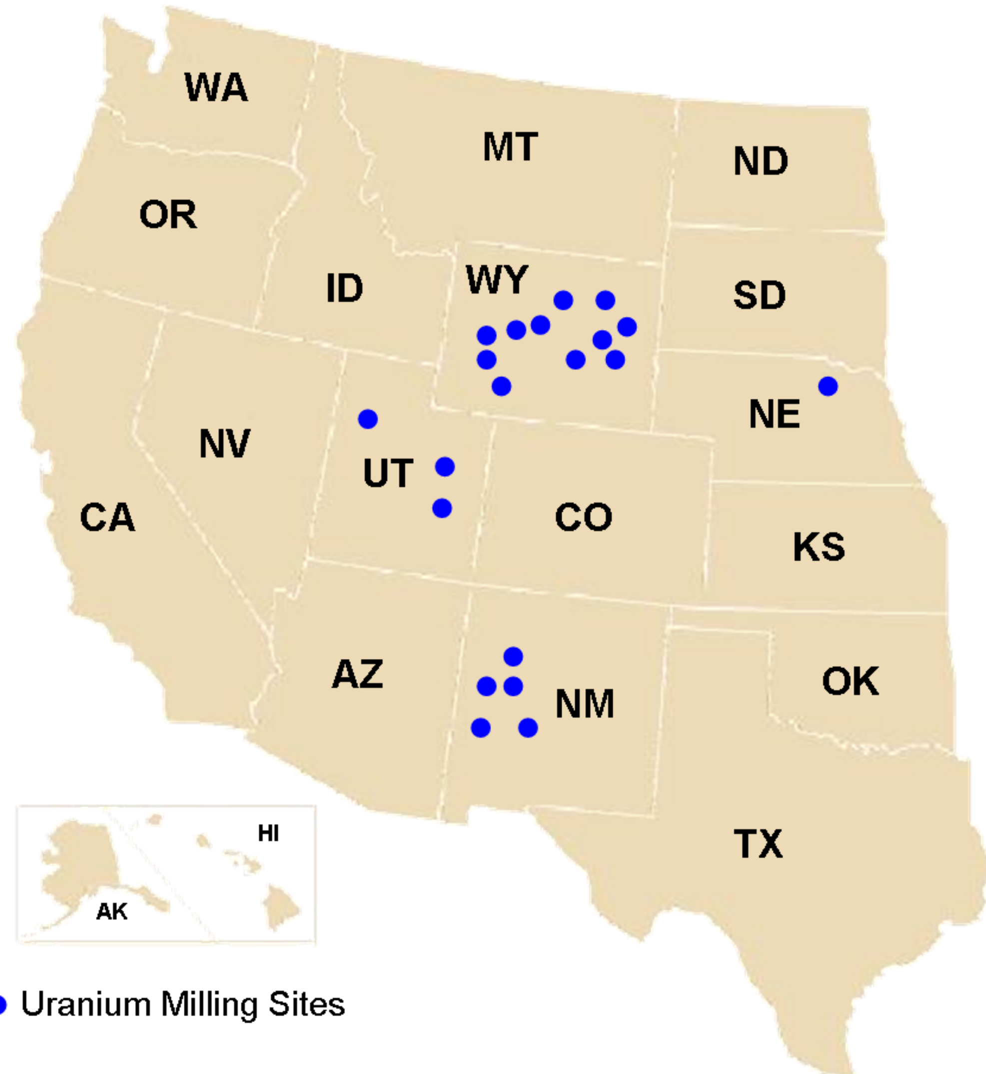
GEOGRAPHIC DISTRIBUTION OF URANIUM ORES

Uranium is present in the Earth's crust at an average concentration of 2 parts per million. Acidic rocks with high silicate, such as granite, have higher than average concentrations of uranium, while sedimentary rocks, on average, have lower levels. Uranite or pitchblende (U_3O_8), the most common uranium-containing ores, are mixtures of UO_2 (basic) and UO_3 (amphoteric) oxides. The major domestic deposits of uranium ores are found in the western United States. Historically, most uranium ore has been mined in Arizona, Colorado, New Mexico, Texas, Utah, Washington, and Wyoming. Lesser quantities have been mined in California, Idaho, Montana, Nebraska, Nevada, North Dakota, Oregon, and South Dakota. Figure 2-1 shows sites licensed by the NRC for uranium recovery operations. Table 2-1 lists the licensees.

About 95% of the uranium mined in the United States consists of uranium oxides in the form of uraninite or pitchblende. See Figure 2-2 for a conceptional model of a uranium roll front deposit.

Until 1975, import restrictions essentially prevented the importation of uranium from outside the United States. These restrictions were gradually removed between 1975 and 1985, resulting in a steady increase in uranium imports from countries having higher-grade uranium deposits. For the period 2003 to 2005, the leading suppliers (by country origin) of uranium to owners and operators of U.S. civilian nuclear power reactors were Canada, Russia, United States, Australia, Namibia, Uzbekistan, Kazakhstan, and South Africa. Owners and operators of U.S. civilian nuclear power reactors purchased a total of 66 million pounds U3O8 (uranium oxide equivalent) of deliveries from U.S. and foreign suppliers during 2005. Approximately 83 percent of all uranium purchased was foreign-origin uranium.

Figure 2-1. Location of NRC Uranium Recovery Licensees

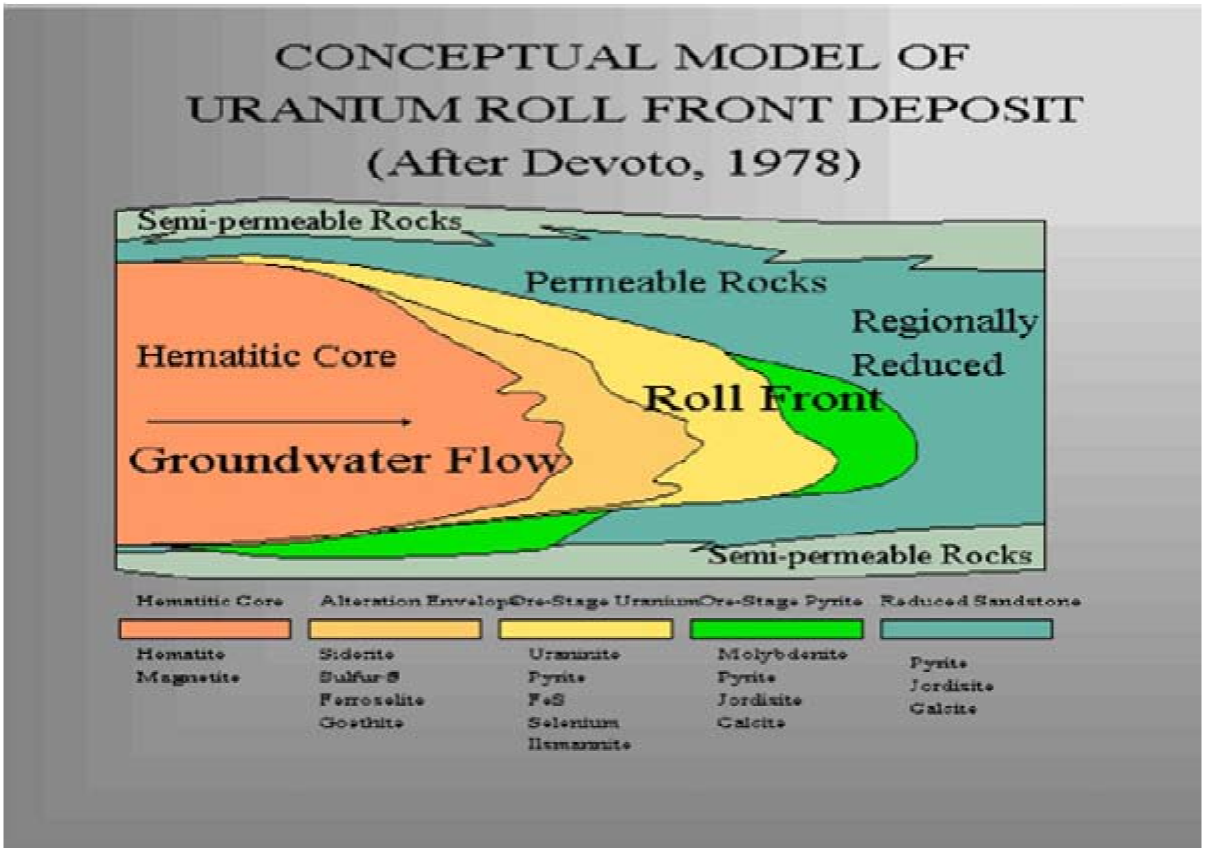


Note: Uranium mills are located in western states because the population density is lower

Table 2-1. NRC Uranium Recovery Licensees

Licensee	Site Name/Location
In Situ Leach Facilities	
AREVA, Inc.	Irigaray/Christensen Ranch, Wyoming
Power Resources, Inc.	Smith Ranch - Highland, Wyoming
Crow Butte Resources, Inc.	Crow Butte, Nebraska
Hydro Resources, Inc.	Crown Point, New Mexico
Conventional Uranium Milling Facilities*	
Umetco Minerals Corp.	Gas Hills, Wyoming
Western Nuclear, Inc.	Split Rock, Wyoming
Pathfinder Mines Corp.	Lucky Mc, Wyoming
American Nuclear Corp.	ANC, Wyoming
Pathfinder Mines Corp.	Shirley Basin, Wyoming
Exxon Mobil Corp.	Highlands, Wyoming
Bear Creek Uranium Co.	Bear Creek, Wyoming
Kennecott Uranium Co.	Sweetwater, Wyoming
Homestake Mining Co.	Grants, New Mexico
Rio Algom Mining, LLC	Ambrosia Lake, New Mexico
United Nuclear Corp.	Church Rock, New Mexico
* All but the Kennecott Uranium Company, Sweetwater, Wyoming mill are in decommissioning.	

Figure 2-2. Uranium Roll Front Deposit



Self-Check Questions 2-1

INSTRUCTIONS: Circle the correct response. Answers are located in the answer key section of the Trainee Guide.

1. The major domestic deposits of uranium ores are found in the __________ United States.

   A. Eastern
   B. Western
   C. Northern
   D. Southern

2. Historically, most uranium ore has been mined in Arizona, Colorado, New Mexico, Texas, Utah, Washington, and __________.

   A. Florida
   B. Idaho
   C. Kansas
   D. Wyoming

3. By 2005, imports provided about __________ percent of the U.S. requirement for uranium.

   A. 74
   B. 22
   C. 44
   D. 83

4. The principal sources of uranium imports have been Canada, Russia,___________, and Australia.

   A. France
   B. Germany
   C. New Zealand
   D. South Africa

You have completed this section.
Please check off your progress on the tracking form.
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Learning Objective

When you finish this section, you will be able to:

2.1.2 Identify uranium mining methods.

MINING

Uranium mining is the process of removing uranium ore from the earth. There are three primary types of mining operations for uranium:

- Open-pit mining
- Underground mining
- In-situ solution techniques

Open-Pit Mining

Surface or open-pit mining is used for removing ores near the surface of the earth (within 400 feet). The topsoil and overburden are removed to expose the ore, which is then mined. The location of the ore is determined using Geiger-Müller counters that are calibrated to indicate the uranium content of the rock. The ore is removed using large backhoes or front-end loaders. It is then loaded into ore trucks for transport to a stockpile at a mine or mill. Overburden is backfilled into previously mined areas for reclamation. When an area is completely backfilled, it is graded to conform to the surrounding topography, covered with topsoil, and seeded. See Figure 2-3, Sweetwater Open-Pit Mining and Milling Facility.

Note: Most uranium deposits lie below the water table, and groundwater must be prevented from flooding the pit during mining operations.

Figure 2-3. Sweetwater Open-Pit Mining and Milling Facility

Open-Pit Mining Hazards

The removal of the topsoil and overburden from an open-pit mine is accomplished by blasting and heavy equipment. The operation of the heavy equipment causes potential safety risks for the workers, as well as noise and fumes from the operation of the equipment. The redistribution of the topsoil results in inhalation hazards for the miners due to the silica in the soil and heavy metal and radionuclides from the ore.

Radiological protection issues associated with open-pit mining include not only inhalation of dust generated in the mining process, but also redistribution of radionuclides, which can cause surface contamination on the ground and on equipment and personnel. Historically, open-pit mining has caused the least concern for the radiological protection of workers. A well-operated open-pit uranium mining operation should not expose workers to any significant radiation dose. See Table 2-2 for a list of common open-pit mining hazards.

Table 2-2. Open-Pit Mining Hazards

Type	Hazard
Chemical	Silica
	Heavy metals
	Diesel and gasoline fumes from heavy equipment
Physical/Mechanical	Noise from equipment and/or blasting
	Ergonomic
	Explosions
	Falls of ground or slides
Radiological	Redistribution of radionuclides

Underground Mining

In underground mining, shafts and tunnels are used to gain access to the ore. The ore is moved to the surface and stored for transport to a uranium mill.

Underground Mining Hazards

Underground mining operations provide greater hazards because of the reduced ventilation rates. The short-lived radon progeny must be cleared from the air of the work area before unacceptable levels are reached. Protection from the radioactive dust must be achieved by preventing the dust from becoming airborne. Additional occupational hazards include noise, fire, ergonomic concerns, and falls of ground due to the confining nature of the work area. Conventional mining and milling also create a much larger cumulative environmental impact than in-situ leaching operations. See Table 2-3 for a list of common underground mining hazards.

Table 2-3. Underground Mining Hazards

Type	Hazard
Chemical	Silica
	Heavy metals
	Diesel and gasoline fumes from heavy equipment
Physical/Mechanical	Noise from equipment and/or blasting
	Ergonomic
	Explosions—includes spontaneous ignition due to dust
	Falls of ground or slides
Radiological	Fire—due to dust or fuel
	Electrical
	Redistribution of radionuclides
	Radon progeny

Radiological Hazards

The radiological hazards of uranium mining and milling are due to the ionizing radiation emitted by the radionuclides in uranium ore. The primary radiological hazard is the presence of radium isotopes of the radioactive decay series of U-238 and U-235 (Ra-226 and Ra-228). Exposure to radon and radon progeny has been a significant source of radiation exposure to uranium miners. The uranium mill tailings, which contain most of the progeny of uranium, are a significant source of release of radon and radon progeny to the surrounding environment.

Radon

Radon (Rn-222) is an inert gas with a radiological half-life of 3.8 days; it is a product of the natural decay of radium-226. When radon decays, alpha particles and gamma particles are emitted, and an isotope of polonium-218 is formed. Polonium-218 and its decay products—lead-214, bismuth-214, and polonium-214—are commonly referred to as short-lived radon progeny because they have half-lives of 27 minutes or less.

Radon diffuses continuously from surrounding rock and broken ore into the air of underground mines and from groundwater containing dissolved radon. Radon gas may be inhaled and immediately exhaled without noticeably affecting the respiratory tissues. However, when attached to dust particles or unattached, radon progeny may be inhaled and deposited in the lower respiratory tract. Alpha radiation may subsequently be emitted into those tissues from polonium-218 and polonium-214 and pose a cancer risk to workers who inhale radon progeny. Beta particles and gamma radiation emitted by radon progeny make a negligible contribution to the radiation dose in the lung.

The Mining Safety and Health Administration (MSHA) regulates radiation protection standards for workers in underground metal and nonmetal mines (Title 30 Code of Federal Regulations [CFR], Parts 57.5037 through 57.5047). Because it is not feasible to routinely measure the individual radon exposure, the concept of the working level (WL) is used. The WL represents any combination of short-lived radon progeny in 1 liter of air that will result in the ultimate emission of 1.3 x 10 5 MeV of potential alpha particle energy during decay to lead-210. The WL unit represents the amount of alpha radiation emitted from the short-lived radon progeny. A working level month (WLM) is the product of radon progeny concentration in WL and the exposure duration in months. In 10 CFR 20, Appendix B, worker DAC limit is 33 WL based on 170 hours.

A National Institute of Occupational Safety and Health (NIOSH) risk assessment, based on a study of uranium miners, demonstrated a significant link between lung cancer and radon exposure. This analysis indicates that exposure to radon progeny at four WLMs over a working lifetime will result in 42 additional lung cancers per 1,000 miners.

In-Situ Leach

A Nuclear Regulatory Commission source and by-product license is required under the provisions of 10 Code of Federal Regulations (CFR) Part 40, Domestic Licensing of Source Material, to recover uranium by in-situ solution techniques (in-situ leach). Recovery of uranium in place, or ISL recovery, is considered mining by several states, but is milling as defined in Part 40, Appendix A. See ISL Process description in next section on Recovery.

Self-Check Questions 2-2

INSTRUCTIONS: Circle the correct response. Answers are located in the answer key section of the Trainee Guide.

1. This mining method is used for ores that lie near the surface (within 400 feet).

   A. Modified Room and Pillar
   B. Open-Pit
   C. Solution
   D. Vein Structure

For questions 2 through 7, fill in the missing word(s) in each statement.

ALARA	cancer	groundwater	ionizing	progeny
radium	radon	remote control	working level	

2. The radiological hazards of uranium milling are due to the __________________ radiation emitted by the radionuclides in uranium ore.

3. The primary radiological hazard in uranium milling is the presence of _________________ isotopes of the radioactive decay series of U-238.

4. Exposure to __________________ and radon __________________ can be a significant source of radiation exposure to uranium workers.

5. The _________________ unit represents the amount of alpha radiation emitted from the short-lived radon progeny.

You have completed this section.
Please check off your progress on the tracking form.
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MODULE 2.0: URANIUM RECOVERY

Learning Objective

When you finish this section, you will be able to:

2.1.3 Identify basic milling process steps.

2.1.4 Identify uranium extraction processes.

2.1.5 Identify hazards, controls, and sampling and measurement activities associated with uranium recovery.

RECOVERY

Uranium mills extract uranium from ores and recover it in a concentrated form. The ores are transported from the mine to a uranium mill for processing. Usually, the two activities occur in the same geographical area.

Generally, 90% to 95% of the uranium is extracted from the ore during convention milling. The in-situ leaching recovery rate is significantly less. The resulting purified form of uranium concentrate is called yellowcake (U_3O_8).

Uranium Recovery Facilities

A conventional mill uses uranium ore extracted by either open-pit or deep mining. The rock is then crushed and sent through a mill, where extraction processes concentrate the uranium into a uranium oxygen compound called yellowcake. The remainder of the crushed rock is placed in a tailings pile.

<u>Conventional Mill</u>

A conventional mill uses uranium ore extracted by either open-pit or deep mining. The rock is then crushed and sent through a mill, where extraction processes concentrate the uranium into a uranium oxygen compound called yellowcake. The remainder of the crushed rock is placed in a tailings pile.

<u>In-Situ Leach</u>

With the in-situ leach process, wells are drilled into rock formations containing uranium ore. Water, with varying concentrations and combinaitons of sodium carbonate (Na_2CO_3), sodium bicarbonate ($NaHCO_3$), oxygen, hydrogen peroxide (H_2O_2 and carbon dioxide (CO_2), is injected down the wells to oxidize the uranium into a soluble state (i.e., mobilize the uranium) and form stable uramium complexes that can be easily recovered from the ore body.

Ion-Exchange

An ion-exchange facility selectively removes the uranium from solution by replacing the uranium ions with a substitute ion. This principle is the same as that used in a commercial or domestic water softener. Ion-exchange takes place on resin beads that are loaded into tanks. The resin is made of a mineral or chemical that has an affinity for uranium ions in solution. Once the resin becomes fully loaded with uranium, the resin is flushed with a highly concentrated salt (sodium chloride) solution, which reverses the exchange and releases the uranium into solution. The purified enriched uranium solution then goes to another process for concentration and drying.

Heap Leach

In a heap leach facility, a coated concrete, asphalt pad, or lined compacted clay layer (similar to a parking lot) is placed on the ground and then crushed uranium ore is piled in a heap on top of the pad. A sprinkler is positioned over the top of the heap and an acid is continually sprayed over the pile. The acid trickles through the ore and mobilizes the uranium into solution. Perforated pipes underneath the ore collect the uranium solution. This leaching is not selective for only uranium; other metals such as radium are also mobilized. The principle is very similar to a drip coffee maker. The liquid is collected for further processing to remove and concentrate the uranium.

Conventional Milling Process

The basic steps in the conventional milling process include:

- Weighing to determine moisture content - moisture determination and moisture control help maintain desirable handling characteristics during processing.
- Sampling to determine uranium content.
- Blending/Storage - ores are stored on-site at the mill, and those of various grade and composition are blended to improve the efficiency of operations by providing a more consistent feed material.
- Crushing/Milling - the blended ore is crushed and ground. Water is added to form a slurry.
- Extraction - the ore slurry is leached with an acid (usually sulfuric acid) or an alkaline solution (sodium bicarbonate) to extract the uranium.
- Purification - solvent extraction or ion exchange is used to purify the uranium.
- Precipitation - uranium is chemically precipitated from the purified solution.
- Filtration/Drying/Packaging - The precipitated slurry is filtered, dried, and packaged into drums for shipping to a plant for conversion to uranium hexafluoride. The output of the uranium mill is a fine powder that is suitable for subsequent conversion to uranium hexafluoride. It is called yellowcake and is assayed in terms of its U3O8 equivalency content.

Extraction of Uranium from Ore

Before the uranium can be extracted from the ore, the ore may be pre-treated with one or more of the following processes to improve the extraction process:

- Crushing and grinding
- Roasting and calcining

Crushing and Grinding

Crushing or milling is conducted for the purpose of creating a greater surface area to improve the extraction of uranium from the ore. Jaw crushers are used for coarse-crushing the ore. Crushing reduces the ore size to between ¾" to 1". The crushed ore is graded to determine the appropriate leaching process. Low-grade ores are frequently heap-leached after grinding. Higher grade ores are blended to produce a more uniform feed to the batching process. The crushed ore is then ground to a finer size, using ball, rod, or hammer mills. Some newer mills use a one-step wet process called semiautogenous grinding to eliminate the dry-ore crushing step.

Roasting and Calcining

Roasting is commonly performed on ores containing vanadium to enable subsequent recovery of vanadium as well as uranium. A high-temperature roasting or calcining operation prior to leaching is frequently desirable and may be useful for several purposes. The characteristics of many ores are improved by roasting. Conversion of uranium to the reduced state may be accomplished by a reducing roast, which serves to prevent the dissolution of uranium in a by-product recovery.

In summary, roasting improves the solubility of important constituents for proper extraction and the physical characteristics of the ore.

Extraction Processes

Conventional uranium mills use one of three basic extraction processes: acid leach - solvent extraction; acid leach - ion exchange; and alkaline leach. The leaching process removes the uranium from crushed ore. Acid leach uses sulphuric acid, and alkaline leach uses a mixed solution of sodium carbonate and sodium bicarbonate.

Most of the mills have used the acid leaching process followed by solvent extraction, but the choice of the process has depended largely on the chemical and mineralogical nature of the ore. Treatment with suitable solvents (acids or alkalies) converts uranium contained in the ore to water-soluble species. See Figures 2-4 and 2-5 for the processes for acid leaching and alkaline leaching.

Heap Leach

Heap leaching is another method of extracting uranium from ore using a leaching solution. Small pieces of low-grade ore or old mill tailings are placed in a heap on an impermeable surface (plastic, clay, asphalt) with perforated pipes under the heap. Acidic solution is then sprayed over the ore, dissolving the uranium. The circuit (i.e., solution spray) recycles until the uranium concentration in the solution is high enough for efficient extraction. The solution in the pipes is then collected and transferred to an ion-exchange system for concentration of the uranium.

Figure 2-4. Acid Leach Process

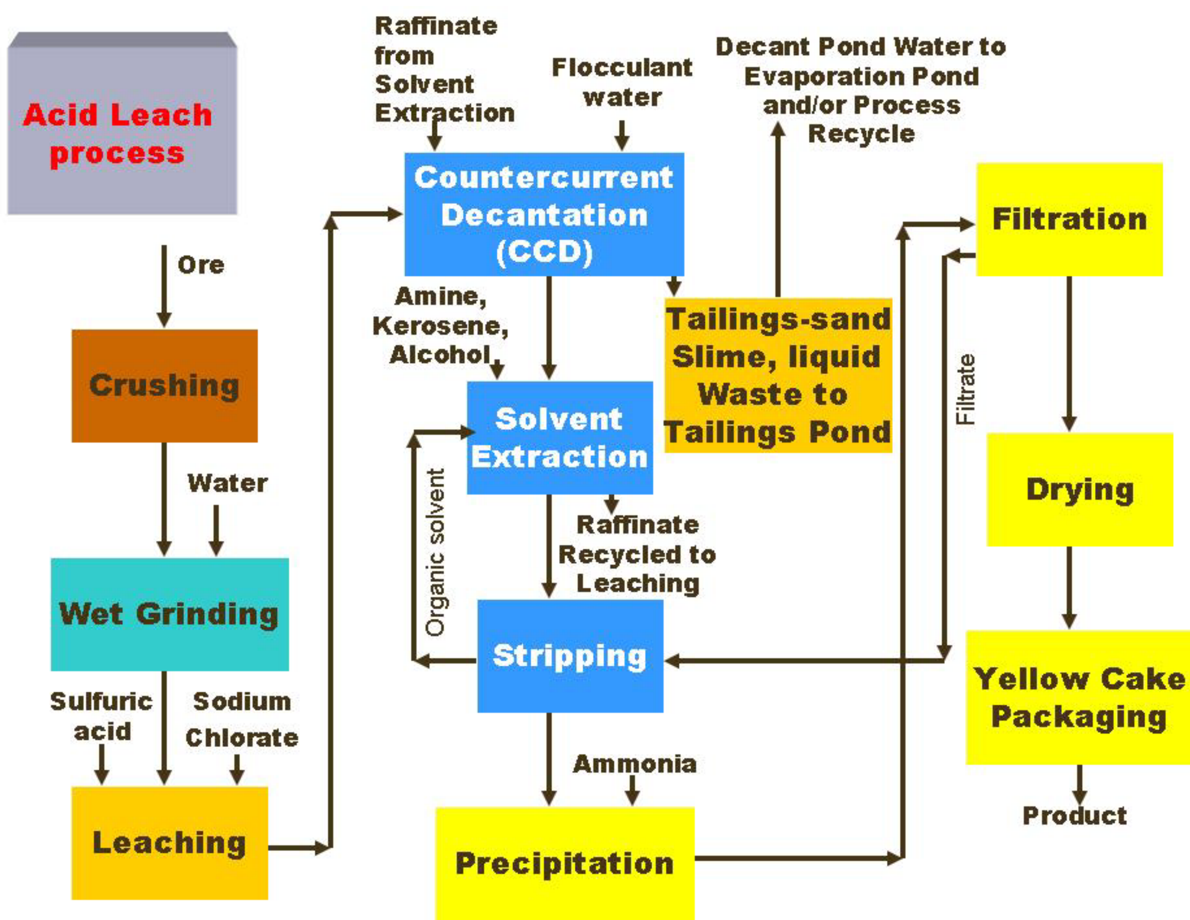
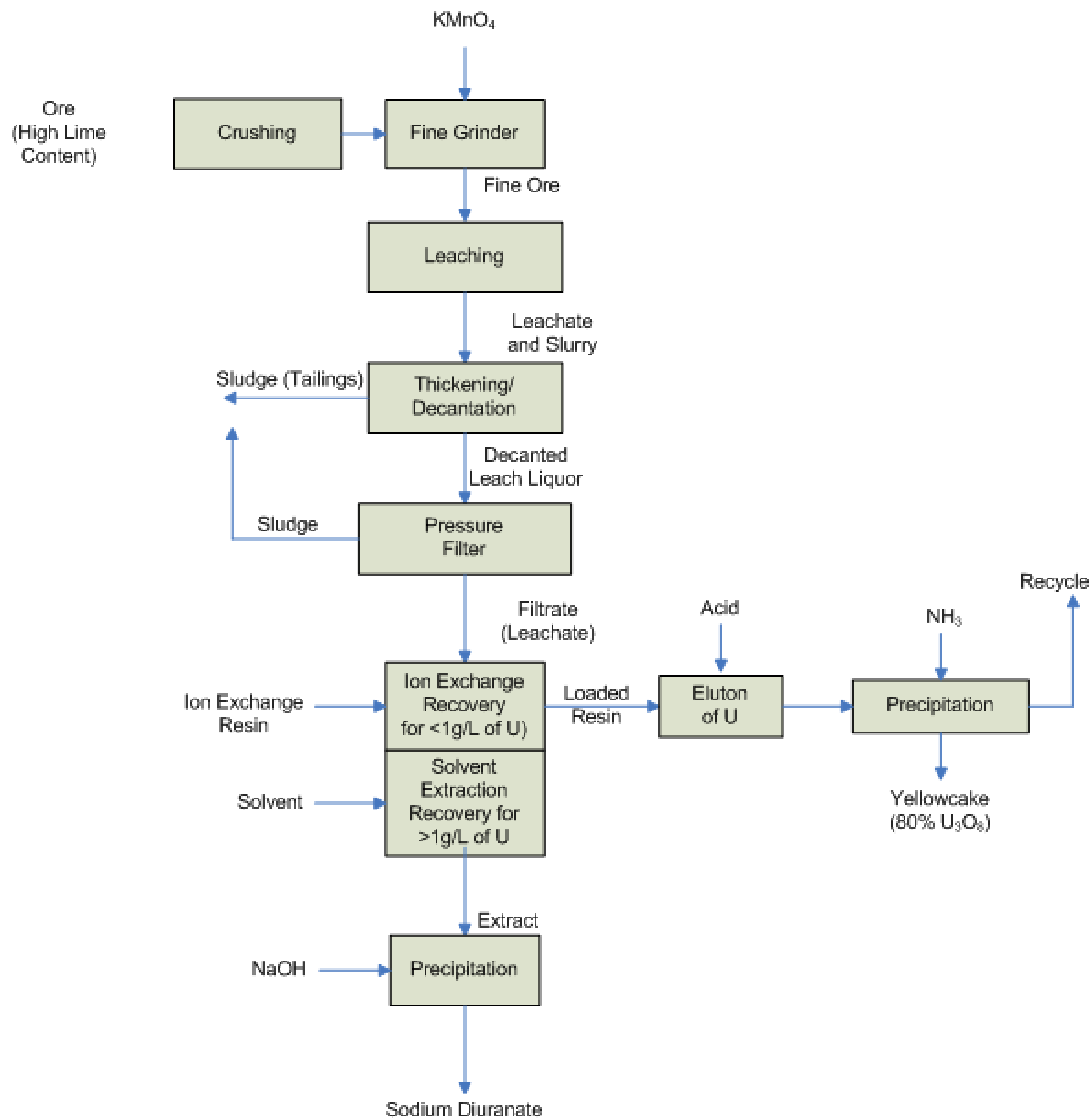


Figure 2-5. Alkaline Leach Process



Purification

The crude uranium isolated in the leach liquors require additional purification steps to meet the specifications of both Department of Energy (DOE) and private producers of nuclear fuel. All extraction processes have been designed with the primary objectives of high recovery yield and purity. The leach liquor is clarified in pressure filters, and the solids are collected and washed on drum filters before being discarded as tailings.

Precipitation

Uranium may be precipitated directly from the clarified solution by neutralization with a base (acid solutions) or by reduction with hydrogen (alkaline solutions), but the precipitate requires further purification.

The solution containing the uranium is separated from the residual solids, and the uranium is removed from the solution and purified by ion exchange or solvent extraction. For low-grade solutions of uranium from leach liquors containing concentrations of uranium greater than 1 gram per liter of uranium. Both ion exchange and solvent extraction are effective and economical. Either process is acceptable for acid leachates, but only ion exchange is economically viable for alkaline leachates.

Filtration/Drying/Packaging

Uranium is precipitated from the purified solution in the form of yellowcake containing about 80% U_3O_8. The yellowcake is filtered and then sent to a steam-heated dryer or a gas-fired roaster to remove the excess moisture. The dried yellowcake is packaged into 55-gallon drums for shipment to a plant for conversion to uranium hexafluoride.

Recovery Hazards

The primary hazards associated with the milling or recovery operation are those occupational hazards found in any metal milling operation that uses chemical extraction. The hazards of the uranium milling operations are shown in Table 2-4, Uranium Recovery Hazards.

Table 2-4. Uranium Recovery Hazards

Type	Hazard
Chemical	Sulfuric acid (acid leach is the most commonly used process)
	Hydrochloric acid
	Liquid oxygen
	Hydrogen peroxide
	Sodium chlorate
	Manganese dioxide
	Kerosene
	Ammonia
	Alcohol
Physical/Mechanical	Noise from heavy equipment
	Ergonomic
	Explosions
	Fires—most often solvent-related
	Electrical
	External—flooding, earthquakes
Radiological	Ore dusts and radon emission from ore crushing and storage
	Yellowcake dust from drying and packaging area
	Windblown particulates and radon emission from the tailings disposal area

The specific health and safety concerns depend on the specific method(s) used for extraction and recovery; appropriate controls for each hazard should be identified. The milling operation uses hazardous/corrosive chemicals to extract uranium from ores.

Radiological Hazards

Radiological hazards associated with uranium milling include inhalation of dust from the various processing operations and also radioactive contamination of equipment and personnel. During operation of the mill, the major sources of airborne emissions are:

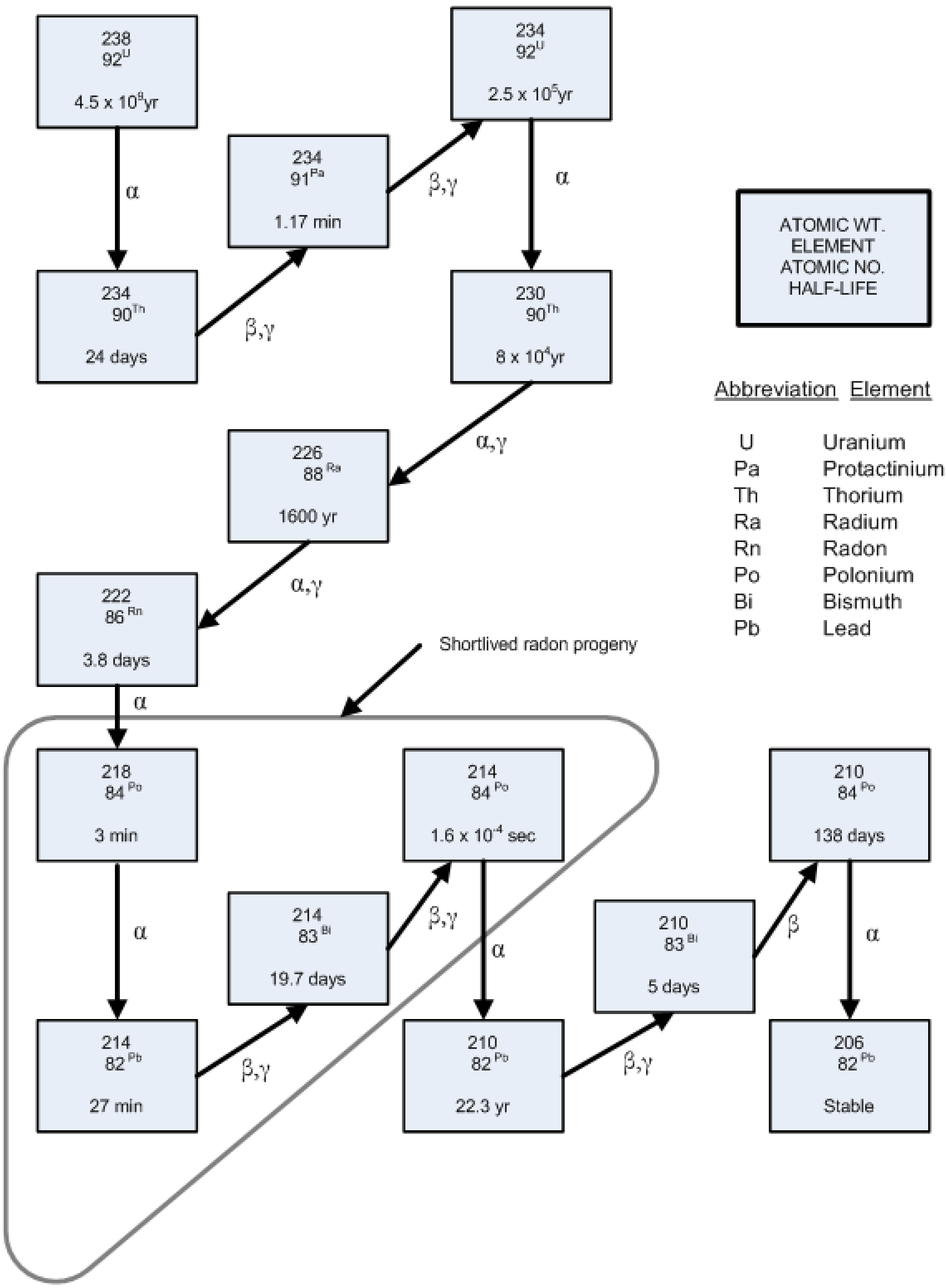
- Ore dusts and radon-222 emission from the ore crushing and storage area.
- Yellowcake dust from the yellowcake drying and packaging area.

- Windblown particulates and radon-222 emission from the tailings disposal area.
- Secular equilibrium, defined as equal activities of the parent and decay product after the decay product activity has remained undisturbed for 6-10 half lives.

The first uranium decay products decay by beta particle emission. The inhalation hazards associated with these decay products (thorium-234, protactinium-234m, thorium-231) are usually overshadowed by the alpha-emitting decay products. Beta radiation can be an external hazard to the skin and lens of the eye. The internal beta hazards are not as significant as internal alpha. The fact that some uranium decay products have short half-lives indicates that these decay products will be present during uranium processing.

The chemical processing steps separate the uranium from its decay products and increase the inhalation and external exposure hazards whenever the decay products are concentrated. Some of the decay products give rise to external radiation gamma exposures. The overall inhalation hazard will probably decrease in those areas due to the removal of the uranium. Figure 2-6 shows the uranium U-238 decay series.

Figure 2-6. The Uranium (U-238) Decay Series



Uranium Tailings

Mill tailings (the finely ground remains of the ore after the uranium has been removed) must be managed to confine the material and prevent the spread of contamination to the surrounding area.

Until the mid-1970s, the wastes from uranium mills (generally called "uranium mill tailings") were not believed to be an environmental or health concern. Tailings were left in large, uncontrolled piles out in the open. By the late 1970s, concern about adverse health effects of exposure to low levels of radiation over long periods of time resulted in the Uranium Mill Tailings Radiation Control (UMTRCA) Act of 1978. The act requires cleanup of mill tailings sites.

Liquid and solid wastes (tailings) generated during uranium milling operations contain radioactive materials in excess of the allowable discharge limits and are generally confined by an embankment retention system or pit.

During milling, only about 2% of actual uranium ore removed from the mines becomes yellowcake. It has been estimated that the worldwide accumulation of leftover mill wastes (tailings) will exceed 10^9 tons by the year 2000. These tailings are a concern because they still contain most of their initial radioactivity (approximately 86%).

However, because of the relatively low specific activity of uranium (large mass for a small amount activity), the tailings cannot result in an exposure situation that would produce immediate health effects. The total specific activity of natural U is only about 7 E-7 Ci/g as compared to Ra-226 which is about 1 Ci/g. External gamma exposure rates from U mill tailings piles are low and the biggest problem is internal dose from inhalation of Rn-222 and windblown tailings. A major release could contaminate a large area of the environment and contribute measurably to the level of background radiation due to the radionuclides present.

A DOE survey examined all aspects of radiation protection for communities in the vicinity of uranium mill tailings. The radon, an inert gas, may pass through confinement barriers. The rules and doctrine for radiological management used in the rest of the fuel cycle are difficult to transfer directly. The radon-222 equilibrium activity in tailings decays with the half-life of thorium-230, which is 8×10^4 years. Therefore, the radon problem cannot be resolved through decay. It becomes almost impossible to identify the radionuclides originating from tailings from those already present naturally if more than a few kilometers away from the point of release. Table 2-5 lists the chemical and radiological characteristics of tailing wastes from a representative mill.

The most significant radioactive element in the tailings is radium-226, which has a half-life of about 1,600 years. Radium is significant because it continuously produces Rn-222, an alpha emitter. Other decay products are gamma emitters that could contribute to dose and must be considered. The tailings must be confined to prevent or control release to the environment for the life of the facility and beyond.

Other radionuclides, such as Th-230 or uranium, may be more significant for special types of wastes.

Uranium and thorium mill tailings standards are established by EPA through 40 CFR 192, "Health and Environmental Protection Standards for Uranium and Thorium Mills Tailings." These regulations contain requirements for management of tailings at licensed mill sites and for remediation of tailings at 24 designated abandoned sites.

40 CFR 192.12 specifies clean-up standards for Ra-226 in soil at inactive sites:

- surface: <5pCi/g averaged over top 15 cm of soil
- buried: <15pCi/g averaged over 15 cm thick layers at least 15 cm below surface

Section 12 also specifies the goals of remedial action for occupied or habitable buildings at inactive sites, which are: 1) average annual concentration of radon progeny of 0.02 working levels, and 2) gamma radiation levels of <20uR/hr above background. The radon 222 emissions from tailing piles at inactive sites must be <20pCi/m 2-sec averaged over the disposal site for a year. The regulations also provide for protection of groundwater contamination from tailing piles at inactive sites by requiring protective liners be placed under (as well as over) piles that are being moved, and specifying groundwater contaminant levels for Ra-226 and Ra-228 combined gross alpha levels, and U-234 and U-238 combined.

EPA standards for mill tailings were incorporated into NRC regulations in 10 CFR 40, Appendix A.

Table 2-5. Chemical and Radiological Characteristics of Tailing Waste from a Typical Mill

Parameter Value[a]		*Reported Value*[b]
Dry Solids		
U_3O_8, wt %	0.007	
U nat, pCi/g[c]	39	
Ra-226, pCi/g	280	
Th-230, pCi/g	280	
Tailings Liquid		
ph	2	
Aluminum, mg/ℓ	2,000	700-1,600
Ammonia mg/ℓ	500	
Arsenic, mg/ℓ	0.2	0.1 – 3.4
Calcium, mg/ℓ	500	
Carbonate, mg/ℓ		
Cadmium, mg/ℓ	0.2	0.08 – 5
Chloride, mg/ℓ	300	
Chromium, mg/ℓ	0.02 - 2.9	
Copper, mg/ℓ	50	0.7 - 8.6
Fluoride, mg/ℓ	5	1.4 – 2.1
Iron, mg/ℓ	1,000	300 - 3,000
Lead, mg/ℓ	7	0.8 – 2
Magnesium, mg/ℓ		400 – 700
Manganese, mg/ℓ	500	100-210
Mercury, mg/ℓ	0-07	
Molybdenum, mg/ℓ	100	0.3 – 16
Nickel, mg/ℓ		0.13 – 1.4
Selenium, mg/ℓ	20	
Sodium, mg/ℓ	200	
Sulfate, mg/ℓ	30,000	
Vanadium, mg/ℓ	0.10	0.1 - 120
Zinc, mg/ℓ	80	
Total dissolved solids, mg/ℓ	35,000	
U nat, pCi/ℓ	3,300	
Ra-226, pCi/ℓ	250	
Th-230, pCi/ℓ	90,000	
Pb-210, pCi/ℓ	250	
Po-210, pCi/ℓ	250	
Bi-210, pCi/ℓ	250	

a) Based on: M.D. Sears et al. "Correlation of Radioactive Waste Treatment Costs and the Environmental Impact of Waste Effluents in the Nuclear Fuel Cycle for Use in Establishing as Low as Practicable Guides—Milling of Uranium Ores, " ORNL-TM-4903, 1975.
"WIN Reports on Uranium Ore Analysis," U.S. AEC Contract 49-6-924, various reports 7 January 1957 through 10 July 1958.
"United States Mineral Resources," Geological Survey Professional Paper 830, 1973.
"Mineral Facts and Problems," U.S. Bureau of Mines Bulletin 667, 1975.

b) "Environmental Study on Uranium Mills," by Jackson, Coleman, Murray and Scints, TRW, Inc., for U.S. Environmental Protection Agency, Contract #68-03-2560, EPA Effluents Guidelines Division.

c) A picocurie of natural uranium (U nat) weighs 1.5μg and contains 0.49 pCi each of U-238 and U-234, and 0.023 pCi of U -235.

Wind and water erosion of the tailings needs to be prevented, during and after the milling operations. Statistics of water-retention dam failures, based on the sum of years of operation of a group of regional dams, show a frequency of one failure every 1,500 to 1,800 dam-years. Statistics on uranium mill tailing retention dam failures show a frequency of one failure every 40 dam-years in the early days of the industry. The causes of latent danger arise from site conditions, hydrological and hydraulic features, types and qualities of the structures, operation and maintenance, and influence of the environment. See Table 2-6, Uranium Mill Tailings Releases 1977-1979. Most failures were caused by gradually worsening defects due to design, construction, operation, or lack of maintenance. Monitoring and analysis of performance data are important to ensure detection of adverse conditions.

Table 2-6. Uranium Mill Tailings Releases 1977-1979

Date	Mill and Location	Incident	Remarks
2/5/77	United Nuclear Homestake Partners Grants, N.M.	Slurry pipeline rupture	Tailings slurry pipeline ruptured by high-pressure buildup on frozen line. The slurry release eroded a V-cut in the dam face, releasing approximately 50,000 tons of solids and slimes and between 2 million and 8 million gallons of liquid. All material released on company property.
4/77	Western Nuclear Jeffrey City, W.Y.	Failure of tailings pond embankment	Tailings slurry overtopped the embankment because of insufficient freeboard space, less than the requisite 3:1 slope, and a loss of structural integrity due to melted snow and fill used to construct the embankment; ~2 million gallons of liquid tailings were released. No material released to unrestricted areas.
9/77	United Nuclear Church Rock, N.M.	Release from tailings slurry line	In the process of flushing tailings lines, it was discovered that a two-inch water line had insufficient pressure to flush out a plug. The line was uncoupled, and roughly 1/4 ton of tailings ran out of the line. With the line still uncoupled, flushing was inadvertently initiated again, resulting in the release of 4,000 gallons of flush water and an additional ton of tailings. Approximately 1 ton of solids and slurries and 900 gallons of liquid entered the watercourse. The liquid flowing to the watercourse was almost entirely mine water, a portion of which had not been treated (i.e., high in uranium and radium values).
7/16/79	United Nuclear Church Rock, N.M.	Tailings dike failure	The tailings embankment failure was a result of internal erosion of the embankment caused by a combination of two factors. Differential settlement occurred in the foundation materials underlying the embankment and resulted in cracking of the embankment. In addition, tailings liquid was allowed to come into direct contact with the embankment near the area eventually breached. The flow of liquid through the cracks resulted in the internal erosion and eventual breach; ~100 million gallons of tailings solution and 1,100 tons of tailings solids. Cleanup actions were undertaken for the Rio Puerco River channel.

Milling Controls

The controls used for milling require that chemicals be handled to minimize worker exposure by isolation and/or enclosure of the process. Air from the drying and packaging area is vented through filters or wet impingement collectors. The primary method of removing dust from the exhaust is wet scrubbing, in which dust particles are removed by impinging them with water droplets and collecting them onto baffle plates and a vaned demister. In venturi scrubbers, the velocity of the air is increased by passing it through a constricted passage. Water is atomized into the dusty air, where it wets the dust, which is then collected by demisters. Baghouses, using filters made of woven or felted fabric, are frequently used to remove dust from the cool, dry air in crushing and packaging exhaust areas.

They are not suitable, however, for cleaning the drier off-gas because of the high temperature and moisture content. High-efficiency particulate air filters made of fiberglass have high efficiencies, but they can be used only in dry systems, following a roughing filter.

The chemical storage and extraction areas are provided with safety showers and eyewash stations in accordance with Occupational Safety and Health Administration requirements. Full-face respirators are worn by plant operators when using corrosive chemicals. Area and personnel sampling is used to ensure adequate monitoring of the chemical process. The process control system and safety-related valves and instruments are designed to actuate safety shutdown of the milling operations in the event of loss of instrument, air, or electrical power. An maintenance program is necessary to prevent operational failure.

Radiological hazards will be controlled by many of the same controls used for chemical exposures. The dust controls noted above will provide protection against the radiological hazards of the yellowcake, which is in the form of dry, finely divided particulates.

After termination of milling operations, the dried tailings are potential long-term sources of windblown particles and emission of radon-222. The management of the mill tailings has been controlled by the high standards now required for the construction and operation of retention facilities. Embankments are constructed to prevent the uncontrolled release of retained water or semifluid tailings. Seepage from the tailing pond, which contains dissolved radium and other toxic substances, needs to be controlled to prevent the possibility of unacceptable contamination of the groundwater or nearby streams.

Also, it is desired, when possible, that tailings be stored below the surface levels in basins dug for that purpose. Old open-pit mines have been used if they do not alter topography or allow the movement of the radioactive sludge. Ideally, the bottoms of such structures would remain permanently higher than the water table. The health effects and controls of the primary chemical and radiological hazards of uranium milling are shown in Table 2-7.

Table 2-7. Chemical and Radiological Hazards and Controls in Milling

Hazard	Use	Target Organ	Health Effect	Control(s)
Sulfuric acid	Used in leaching of uranium ore	Lungs, respiratory system, eyes, skin, teeth	Local: Irritation and chemical burns upon contact, blindness Systemic: Irritation of mucous membranes, pulmonary edema, emphysema, erosion of teeth	- Proper labeling - Isolation/ enclosure of process - Air filtration
Solvents Amine Kerosene Alcohol	Used in extraction	Central nervous system (CNS), blood, bone marrow, respiratory, skin, liver, kidney	CNS depression, decreased alertness, headache, sleepiness, defatting, dermatitis	- Personal protective equipment: Respiratory, gloves, clothing
Ammonia	Used in precipitation	Lungs, respiratory system, eyes	Local: Irritation and possible chemical burns to eyes, mucous membranes, skin Systemic: Headache, salivation, cough, pulmonary edema, respiratory arrest	
Ore dust Yellowcake dust	Crushing and storage Drying and packaging area	Respiratory, blood, kidney, liver, bone marrow	Systemic: Highly toxic; kidney damage, chronic-pneumoconiosis, blood changes, cancer of the lung, osteosarcoma, and lymphoma	

Table 2-7. Chemical and Radiological Hazards and Controls in Milling

Hazard	Use	Target Organ	Health Effect	Control(s)
Tailings	Mill waste	Respiratory ingestion	Long-term environmental concern for health hazard	- Proper engineering design for long-term storage - Isolate/enclose - Monitor - Leak detection and shutoff valves on slurry piping - Leak detection systems on the liner - Dikes

Abnormal Occurrences

The primary safety concerns during uranium milling operations have been due to abnormal occurrences. Incidents leading to the release of radioactive materials or hazardous chemicals at uranium mills are listed below:

- Leaks or ruptures in tanks or piping
- Centrifuge failure
- Rupture of a pipe in the tailings disposal system
- Fire or explosion in the solvent extraction circuit
- Gas explosion in the yellowcake drying operation
- Tornado
- Release of tailings slurry
- Loss of chemical tank integrity

Controls Summary

Controls for uranium milling include:

- High standards in design of tanks and piping
- Proper maintenance
- Sampling and monitoring
- Self-actuated shutoff valves for leak detection
- Dikes and mill sumps
- High standards in ventilation design
- Stacks routinely monitored for uranium during operations
- Design/isolation (the solvent extraction circuit often in a separate building
- Control of temperature, ventilation system and filters
- High standards of design found in NRC Regulatory Guide 3.11
- Automatic cutoff valve (Department of Transportation regulation 10 CFR 178.377 requires use of this safety valve for ammonia)

Hazards Summary for Recovery

The recovery of uranium poses occupational hazards similar to those of any metal mining and milling operation. In addition, the workers require protection against the risks of exposure to external gamma radiation, the inhalation of radon progeny, and the inhalation of uranium dust. The public and the environment must be protected against the effects of uranium mill tailings. The miners are protected by control of ventilation rates and the use of methods such as wet drilling to keep the dust from becoming airborne. The tailings provide a long-term environmental concern that can be managed by proper engineering design and monitoring.

In-Situ Leach Process

In-situ leaching is a milling process as defined in 10 CFR Part 40, Appendix A. The ore is left in the ground, and liquids are pumped through the ore to recover the minerals. Consequently, there is little surface disturbance and no tailings or waste rock generated. However, the ore needs to be permeable to the liquids used and located so that they do not contaminate ground water away from the ore.

In-situ leach was first used at sites expected to present major ground-water problems for conventional mining, for sites with narrow and deep ore bodies which could not justify the expense of developing shafts and underground passages, and for open pit mines where the cost of stripping overburden could not be justified.

ISL mining was used on an experimental basis in Wyoming during the early 1960s. The first commercial mine began operating in 1974. Today in-situ leaching is seen as the most cost effective and environmentally acceptable method of mining. It is preferred over open pit-mining and milling.

Uranium deposits suitable for ISL occur in permeable sand or sandstone and are below the water table. These deposits were formed by the lateral movement of ground water bearing uranium in solution (i.e., oxidized uranium). As the uranium bearing ground water passed from oxidized zones into low oxygen (reduced) zones, uranium minerals precipitated out of solution along the oxidation-reduction interfaces. In the US, these uranium bearing sedimentary formations are frequently crescent-shaped ore bodies known as "roll fronts." The uranium minerals are usually uraninite (oxide) or coffinite (silicate) coatings that form as precipitants on individual sand grains.

Operating regimes for ISL are determined by the hydrogeology and hydrogeochemistry of these roll front deposits. Ideally, these ore bodies should be located between overlying and underlying units of low permeable (confining) strata, which are established/verified through numerous exploratory boring and hydraulic (pump) testing.

The ISL process essentially involves artificially reversing the formation of the uranium ore body; however, the reversal occurs in a much shorter time frame. The initial step in the ISL process involves injecting a leaching solution (lixiviant) into the uranium ore body (a.k.a. the Production Zone). The injected lixiviant consists of native water, with varying concentrations and combinations of sodium carbonate (Na_2CO_3), sodium bicarbonate ($NaHCO_3$), oxygen, hydrogen peroxide (H_2O_2) and carbon dioxide (CO_2). Upon entering the Production Zone, the dissolved oxidant in the lixiviant reacts with the uranium mineral, converting the uranium from the $U+^4$ to the $U+^6$ oxidized state.

$$UO_2(s) + 1/20_2 + 2H^+ = 2UO_2^{\,2+} + H_20$$

$$UO_2^{\,2+} + H_2O = UO_3 + 2H^+$$

The $U+^6$ species form complexes with some of the carbonates in the lixiviant to create uranyldicarbonates $(UO_2(CO_3)_2)^{-2}$ and/or uranyltricarbonates $(UO_2(CO_3)_3)^{-4}$, both of which are stable and soluble species in solution.

$$UO_3 + Na_2CO_3 + NaHCO_3 = UO_2(CO_3)_2^{\,-2} + 3Na^+ + 2H^+$$

It should be noted that radium is also mobilized in the process, as are select trace metals (e.g., arsenic, selenium, and/or vanadium), if present.

The dissolution and complexation of uranium in the Production Zone occurs as the lixiviant flows through the ore body from the injection to the extraction (production) wells. Figure 2-7 shows a well completion sequence. Typically, an ISL well field is installed in a grid pattern with alternating injection and extraction (production) wells (see Figure 2-8). Injection of a lixiviant and recovery of uranium-bearing or pregnant lixiviant in a given Production Zone is terminated when uranium recovery is no longer economically practicable. Reportedly, successful operations have achieved a total overall recovery of about 80% of the ore.

Figure 2-7. Well Completion Sequence

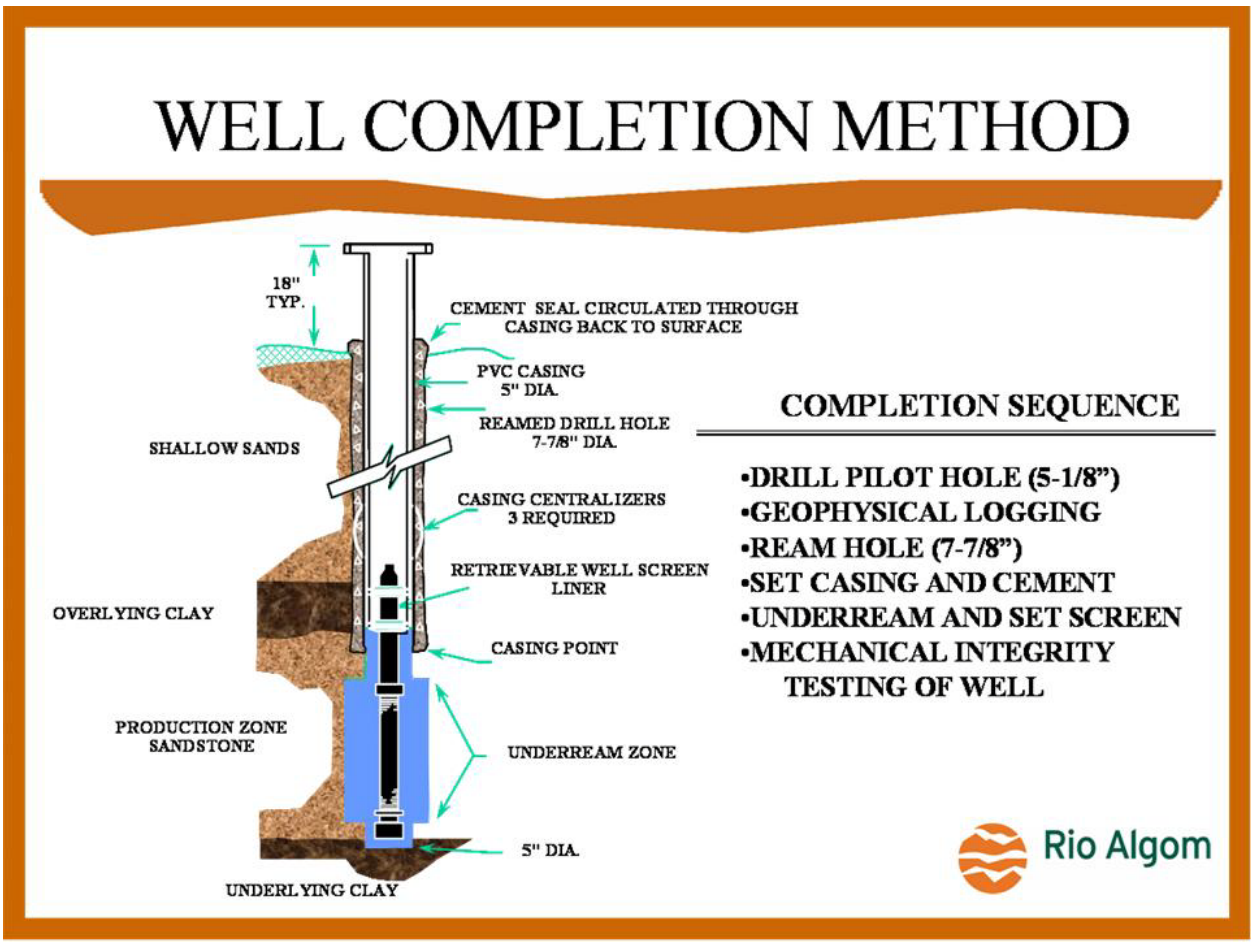
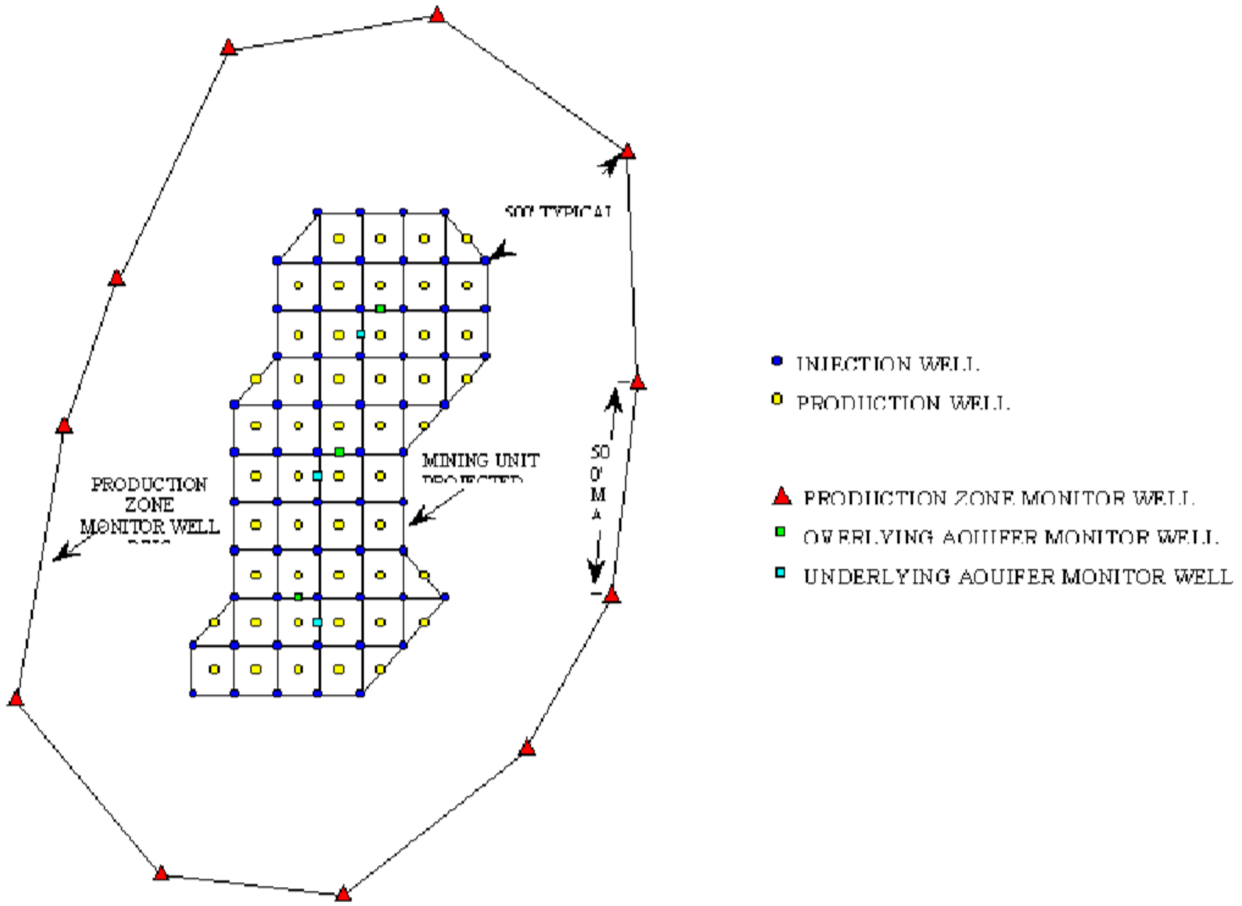


Figure 2-8. Well Development Pattern



MODULE 2.0: URANIUM RECOVERY

The pregnant lixiviant pumped from the wellfield is piped to high efficiency down-flow ion exchange (IX) units for uranium recovery (IX circuit). These IX units consist of large vessels or columns containing resins which preferentially remove the uranium complexes (i.e., uranyldicarbonates and uranyltricarbonates) from the pregnant lixiviant. CO_2 is added upstream of the resin, favoring the formation of uranyl dicarbonate [U_3O_8 per ft^3 resin (70%)]. With one-half the ionic charge, uranyl dicarbonate loads twice the mass of uranium as does uranyl tricarbonate.

$$\left[UO_2\left(CO_3\right)_2\right]^{-2} + 2R + Cl^- \rightarrow R_2^{+2}\left[UO_2\left(CO_3\right)_2\right]^{-2} + 2Cl^-$$
$$\left(\text{fluid pH} = 6.5 \text{ to } 7.9\right)$$

$$\left[UO_2\left(CO_3\right)_3\right]^{-4} + 4R + Cl^- \rightarrow R_4^{+4}\left[UO_2\left(CO_3\right)_3\right]^{-4} + 4Cl^-$$
$$\left(\text{fluid pH} > 7.9\right)$$

After the resin is loaded with uranium, the vessel is removed from the active flow line and placed in the elution circuit. Elution consists of contacting the resin with a strong sodium chloride salt solution. This process brings the uranium back into solution and regenerates the resin for reuse. Eluate typically contains 90-g/L sodium chloride and 20-g/L sodium carbonate. The chloride and carbonate ions displace uranyl dicarbonate ions from the resin.

$$R_2 + 2\left[UO_2\left(CO_3\right)_2\right]^{-2} + 2Cl^- = \left[UO_2\left(CO_3\right)_2\right]^{-2} + 2R + Cl^-$$

$$\left[UO_2\left(CO_3\right)_2\right]^{-2} + CO_3^{-2} = \left[UO_2\left(CO_3\right)_3\right]^{-4}$$

Both reactions efficiently strip the resin to less than 0.03 lbs U_3O_8 per Ft^3 resin (99.6% removal efficiency). Following an elution, acid is added to the rich eluate to destroy the uranyl tricarbonate complex and free the uranyl ion.

$$H_2SO_4 + CO_{3-}^{-2} \rightarrow SO_4^{-2} + H_2O + CO_2$$

$$3H_2SO_4 + \left[UO_2\left(CO_3\right)_3\right]^{-4} \rightarrow 3SO_4^{-2} + 3H_2O + 3CO_2 + UO_2^{+2}$$

The acidified-rich eluate is pumped to the precipitation circuit that consists of cascaded and continuously stirred tank reactors. Ammonia is added to adjust the pH and hydrogen peroxide is added, producing uranyl peroxide crystals.

$$UO_2^{+2} + H_2O_2 + XH_2O = UO_4XH_2O + 2H^+$$

The precipitation circuit discharges to the "thickener" tank where solids settle and concentrate. Yellowcake slurry is pumped from the bottom of the thickener and routed to a recessed plate filter press where solids are captured and dewatered. Washed yellowcake is pumped to a rotary vacuum dryer to yield a hydrated uranium peroxide product. The drier prevents the formation of insoluble uranium compounds in the final yellowcake product. The yellowcake is then packaged into 55-gallon drums and prepared for shipment. Figure 2-9 contains an ISL Flow Process Schematic.

Figure 2-10 is an aerial photo of the Smith Ranch facility located in North Central Wyoming. Smith Ranch is the largest in-situ leach uranium facility in North America and is licensed for an a annual capacity of 5 mm lbs. U_3O_8. The primary facility consists of a Central Processing Plant (CPP) and a Recovery Plant. A second Recovery Plant or Satellite facility is located away from the main plant and consists of the injection/extraction and IX circuit portions of the ISL circuit.

Figure 2-9. In-Situ Leach (ISL) Flow Process

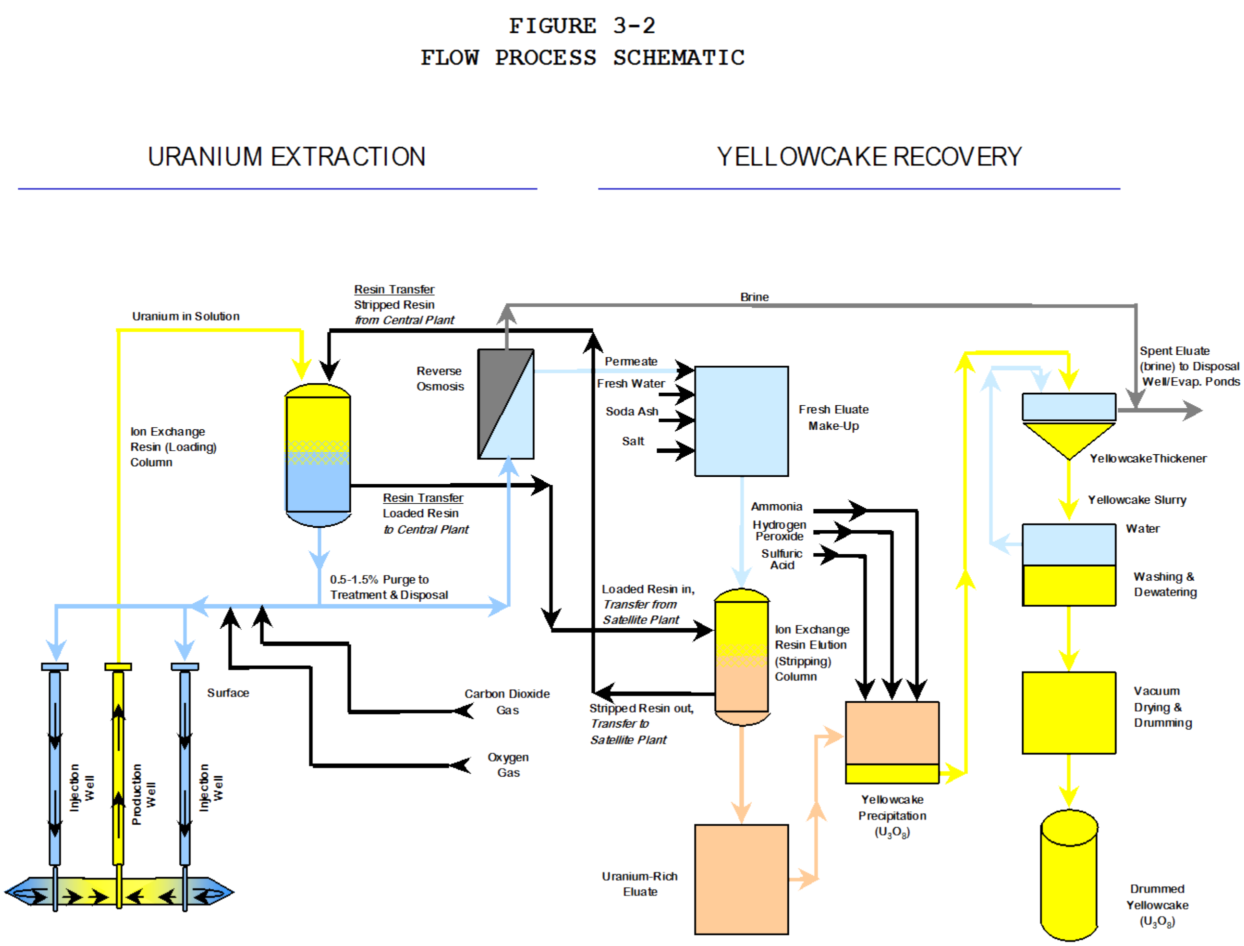


Figure 2-10. Smith Ranch Uranium Project

Use of in-situ leach eliminates the problem of dust generation and control in the mines and the disposal of tailings, which contain the majority of the uranium decay products. There still exists a problem with the liquid waste that is generated and that can ultimately contaminate soil and ground water.

In-Situ Leach Facilities Hazards

The hazards for in-situ leach are similar to those of any chemical process, with specific concerns dependent on the type of acid used. For this type of operation, nitric oxide or sulfuric acid is generally used. Additional hazards and controls would be the same as those used for other types of uranium processing.

Impact associated with in-situ leach include the:

- Risk of leaching liquid excursions beyond the uranium deposit and subsequent contamination of ground water.
- Unpredictable effects of the leaching liquid on the host rock of the deposit.
- Production of some amounts of waste sludge and waste water when recovering the leaching liquid.
- Difficulty of restoring natural conditions in the leaching zone after finishing the leaching operation.

General physical/mechanical hazards are similar to those at conventional mills. These include heavy equipment, ergonomic, electrical, fire, explosions, and external (e.g., flooding or earthquakes).

The usual radiation safeguards are applied at an ISL operation, despite the fact that most of the ore's radioactivity remains well underground and there is minimal increase in radon release and no ore dust. Procedures call for routine monitoring of air, dust, and surface contamination.

In-Situ Leach Radioactive Hazards

The principal radiological gas representing a potential dose to man is radon-222 gas released to the atmosphere form the circulating pregnant lixiviant and/or in the elution and precipitation circuit. Ventilation systems connected to process vessels and in the general work areas are installed to address the radon-222 gas related hazard.

Another radiological concern are particulates associated with yellowcake drying. Vacuum dryers are utilized at ISL facilities to address this hazard. Such dryers provided a negative pressure on the entire drying cycle. Ventilation systems are also used in yellowcake drying and packaging areas.

In-Situ Leach Radioactive Spills

Radioactive spills can occur at in-situ leach uranium facilities. Events have been reported to NRC in which spills of uranium recovery solution from recovery wells have occurred from the top of a wellhead due to loose fittings. Such spills will contaminate the ground in the vicinity of the wellhead. In such cases, soil samples would have to be taken and analyzed to determine the degree of environmental impact. Some in-situ leach licensees have a license condition to maintain a log of all significant solution spills that may have a radiological impact on the environment and to notify the NRC by telephone within 48 hours of such a spill. See 10 CRF 20, 2202(b) for the 24-hour dose-related reporting requirements. The spill must be reported if a radiological release exceeds a certain dose level.

Sampling and Measurement Activities

Since one of the concerns in uranium in-situ leach is the potential for contaminating groundwater, a groundwater monitoring program and NRC approval of its design, installation, and implementation is required at these facilities. Guidelines for groundwater monitoring can be found in NUREG-1569, "Standard Review Plan for In-Situ Leach Uranium Extraction License Application," June 2003.

Decommissioning ISL Sites

When a site is to be closed, wells are sealed to meet the well abandonment criteria of the State, and the process facilitates are removed. After site surface cleanup is complete and all byproduct material is removed to a licensed byproduct burial facility, the site is returned to unlimited use, or the land reverts to its previous uses. See Reclamation and Decommissoning in section 2.1.6, NRC Regulatory Authority.

Self-Check Questions 2-3

INSTRUCTIONS: Complete the following questions. Answers are located in the Trainee Guide.

1. What percent of uranium is extracted from ore?

2. At a mill, what is the resulting purified form of uranium concentrate called?

3. At a conventional mill, what happens to the remainder of crushed rock after extraction of uranium takes place?

4. How does an ion-exchange facility remove uranium from solution?

5. Briefly describe a heap leach facility.

6. In the extraction step, what happens to ore slurry?

7. In the milling process, what processes are used to purify the uranium?

8. In the milling process, what step immediately follows purification?

9. What is the final step of the milling process?

10. What is the product of the uranium mill and how is it assayed?

11. One of the concerns in uranium in-situ leach is the potential for contaminating_______________ .

12. During operation of a mill, where are the major sources of airborne emissions?

13. When chemical processing steps separate the uranium from its decay products, what happens to inhalation and external exposure hazards whenever the decay products are concentrated?

14. What 1978 act requires cleanup of mill tailings sites?

15. How are liquid and solid wastes (tailings) generated during uranium milling operations confined?

16. During milling, what percent of actual uranium ore removed from the mines becomes yellowcake?

17. Why are tailings an environmental concern?

18. What is the most significant radionuclide to control in tailings to minimize the hazard from inhalation (ingestion), and why?

19. What are causes of uranium mill tailings releases?

20. What are some milling controls used in the drying and packaging areas?

21. What milling controls are used in the chemical storage and extraction areas?

22. Why does seepage from a tailing pond need to be contained?

23. Match the hazard in column A with the process used in column B.

Column A Hazard	**Column B Use**
A. Sulfuric acid	1. ____ Precipitation
B. Solvents	2. ____ Leaching
C. Ammonia	3.____ Crushing and storage
D. Ore dust	4.____ Extraction
E. Yellowcake dust	5.____ Drying and packaging area
F. Tailings	6.____ Mill waste

24. Name at least three abnormal occurrences that could lead to the release of radioactive materials or hazardous chemicals at uranium mills.

1.

2.

3.

You have completed this section.
Please check off your progress on the tracking form.
Go to the next section.

Learning Objective

When you finish this section, you will be able to:

2.1.6 Identify NRC regulatory authority for uranium recovery and mill tailings.

NRC REGULATORY AUTHORITY

The Office of Surface Mining, U.S. Department of Interior, and individual states regulate mining. The NRC regulates milling and the disposal of tailings in nonagreement states, while state agencies regulate these activities in Agreement States when the Agreement specifically includes tailings. Note: There are five Agreement States for uranium recovery [source and 11e.(2) of the Atomic Energy Act by-product material]: Colorado, Illinois, Texas, Utah, and Washington.

NRC requires licensees to meet NRC standards for cleanup of uranium and thorium mill sites after the milling operations have permanently closed. This includes requirements for long-term stability of the mill tailings piles, radon emissions control, water quality protection and cleanup, and cleanup of lands and buildings.

NRC regulation 10 CFR 40, Appendix A, requires that a cover be placed over the mill tailings to control the release of radon gases at the end of milling operations. The cover must be effective in controlling radon releases for 1,000 years to the extent reasonably achievable and, in any case, for no less than 200 years.

The NRC licenses and regulates the following:

- Uranium milling, siting, and operations
- Commercial in-situ leach operations
- Uranium extraction research and development projects
- Disposal and stabilization of uranium mill tailings and wastes

The NRC also evaluates and concurs with DOE remedial action plans and completion reports for inactive mill tailings sites as required by Title I of the UMTRCA. DOE is responsible for the cleanup and long-term stabilization of tailings.

Of 16 uranium recovery facilities currently licensed by the NRC under its regulations (10 CFR Part 40), there are 12 conventional uranium mills and four in situ leach (ISL) facilities. The NRC-licensed sites are located in Nebraska, New Mexico, and Wyoming. No NRC-licensed conventional uranium mills are operating. One mill is in stand-by status and will likely resume commercial operation in the future. The remaining conventional uranium mill sites have completed, or are completing, reclamation activities to provide long-term stabilization and closure of the tailings impoundments and the sites. Two of the four ISL facilities are presently operating, one is on stand-by status, and one will likely resume operations in the future. The NRC inspects these sites at semiannual to three-year intervals depending on the operational (or stand-by) and reclamation status.

In the Agreement States of Colorado, Texas, Utah, and Washington, there are eight conventional uranium mills that have non-operational tailings impoundments. One mill in Colorado (Cotter Mill, Canon City, Colorado) is operating. Three uranium mill sites are located in Utah, with one being active (White Mesa Mill, Blanding Utah), one in reclamation (Rio Algom, Lisbon Valley, Utah), and one returning to active status (Shootaring Cyn Mill, Ticaboo, Utah). An active mill tailings disposal facility is also located in Utah (Envirocare, Tooele County, Utah). This mill tailings disposal facility was licensed by NRC as a commercial facility in November 1993 to receive and dispose of 11e.(2) byproduct material. In 2004, Utah became an Agreement State for 11e.(2) byproduct material and regulatory authority over the site transferred to the state. The site also has disposal cells licensed under Utah Agreement State authority for the disposal of low-level radioactive waste and mixed waste.

In 1991, NRC and EPA entered into a Memorandum of Understanding (MOU) to eliminate the dual regulation by EPA under the Clean Air Act and the NRC under UMTRCA. EPA rescinded Subpart T when NRC added similar regulations to Part 40, Appendix A, Criterion 6. The MOU ensures that nonoperational uranium mill tailings piles will be closed to comply with the radon standards as expeditiously as practicable, with a goal that such closure occur by the end of 1997. For reasons beyond the control of the licensees, the 1997 closure goal has not been met, but all piles had interim covers or ponds on the tailings and met the radon limit by the end of 1997, which met the milestones in licenses for completion of coverings.

Licensees are also evaluated for NEPA requirements. Facilities must submit Environmental Assessments (EA) and, in some cases, an Environmental Impact Statement (EIS).

Decommissioning and Reclamation

Uranium mill tailings are primarily sandy process waste material from a conventional mill. This ore residue contains the radioactive decay products from the uranium chains (mainly the U-238 chain) and heavy metals. By definition in section 11e.(2) of the Atomic Energy Act and in 10 CFR Part 40, the tailings or wastes produced by the extraction or concentration of uranium or thorium from any ore processed primarily for its source material content, is byproduct material. This includes discrete surface waste resulting from uranium solution extraction processes such as in-situ leach, heap leach, and ion-exchange but does not include underground ore bodies depleted by solution extraction. The wastes from solution extraction facilities can be transported to a mill tailings impoundment for disposal.

Decommissioning reduces residual radioactivity to a level that permits termination of the license. Most of the NRC regulations for this type of byproduct material are in Appendix A of 10 CFR Part 40, Criteria Relating to the Operation of Uranium Mills and the Disposition of Tailings or Wastes Produced by the Extraction or Concentration of Source Material from Ores Processed Primarily for Their Source Material Content. The criteria in Appendix A cover the siting and design of tailings impoundments, disposal of tailings or wastes, decommissioning of land and structures, groundwater protection standards, testing of the radon emission rate from the impoundment cover, monitoring programs, airborne effluent and offsite exposure limits, inspection of retention systems, financial surety requirements for decommissioning and long-term surveillance and control of the tailings impoundment, and eventual government ownership of the tailings site under a NRC general license.

Reclamation is the stabilization of the tailings impoundment that includes drainage modifications and cover construction to control the radiological hazards for a least 200 years and, to the extent reasonably achievable, for 1000 years. NRC has issued a Standard Review Plan (SRP) applicable to reclamation sites: NUREG-1620, Rev. 1, “Standard Review Plan for the Review of a Reclamation Plan for Mill Tailings Sites,“ June 2003. The SRP addresses: tailings pile stability, cover stability, groundwater protection, and radon attenuation. The areas of review for decommissioning (radiological cleanup) of land and structure are based mainly on 40.42g(4) and (5).

In reviewing site conditions, it is important to get a number of samples and determine representative soil background values. Also, if in-situ ore is present, it must be distinguished from byproduct material.

Monitoring Regulations

Uranium mill operators are required by NRC regulations and license conditions to conduct radiological effluent and environmental monitoring programs. Regulations applicable to uranium milling are contained in 10 CFR Part 20, Standards for Protection Against Radiation, and 10 CFR Part 40, Domestic Licensing of Source Material.

10 CFR Part 40 requires submission to the NRC of semiannual reports containing information required to estimate doses to the public from effluent releases.

Information on radiation doses and the radionuclides in a mill's effluents and environment both prior to and during operations is needed by the NRC staff to do the following:

- Estimate maximum potential annual radiation doses resulting from effluent releases.
- Ascertain whether regulatory requirements are being met.

- Evaluate performance of effluent controls, including stabilization of active and inactive tailings piles.
- Evaluate the environmental impact of milling operations.
- Establish baseline data to aid in evaluation of decommissioning operations or decontamination following any unusual releases, such as a tailings dam failure.

A complete preoperational report with 12 consecutive months of data should be submitted prior to beginning milling operations. Reports from operational mills are summarized quarterly and submitted to the NRC semiannually.

Regulatory Guide 4.14, Radiological Effluent and Environmental Monitoring at Uranium Mills, describes preoperational and operational sampling and measurement activities at uranium mills and is in a format acceptable for submission to the NRC.

NRC Regulatory Guide 8.30

NRC Regulatory Guide 8.30, Health Physics Surveys in Uranium Mills, describes several types of surveys suggested to protect uranium mill workers from radiation and chemical toxicity of uranium while on the job. These surveys include the following:

- Airborne uranium ore dust
- Airborne yellowcake
- Radon-222 and its progeny
- External radiation
- Surface contamination
- Skin and personal clothing
- Equipment to be released
- Packages containing yellowcake
- Ventilation
- Contamination on respirators

When planning a visit to a facility, regulators should review inspection modules and reports along with documentation of any actions that have been taken.

Airborne Uranium Ore Dust

Surveys for airborne ore dust are necessary to do the following:

- Demonstrate compliance with the intake limits for workers specified in 10 CFR 20.
- Meet posting requirements for radioactivity areas.
- Determine whether precautionary procedures should be considered.

- ◙ Determine whether exposures to radioactive materials are being maintained ALARA.

In areas that are not "airborne radioactivity areas," an acceptable sampling program for airborne ore dust includes monthly grab samples of 30 minutes duration in worker-occupied areas while ore is being actively handled.

Ore dust samples should be representative of the air inhaled by the workers. Samples should be taken at a height of about 3 to 6 feet between the source and the worker. The state of operation of major equipment during sampling should be recorded. Special breathing zone sampling may not be necessary for ore dust.

Airborne Yellowcake

Calcining (high temperature) yellowcake results in more insoluble uranium compounds. Therefore, inhalation of calcined yellowcake is cleared rapidly from the upper lung (bronchial tree) so it is less of a health hazard. The more soluble compounds create a greater hazard to the kidneys from chemical toxicity. Solubility classification is important with respect to the NRC's weekly intake regulations for soluble uranium. The limit in 10 CFR Part 20 for soluble uranium intake is 10 mg per week.

The method of sampling airborne yellowcake is a combination of general air sampling and breathing zone sampling during operations. According to NRC Regulatory Guide 8.30, the following sampling procedures should be observed to ensure that representative samples are taken:

- ◙ Weekly grab sampling with a duration of 30 minutes should be performed in airborne radioactivity areas.
- ◙ Monthly grab sampling with a duration of 30 minutes should be performed in areas not designated as airborne radioactivity areas.

OR

If the licensee can demonstrate that the volume of air sampled is accurately known, weekly grab sampling with a duration of 5 minutes using a high-volume sampler (roughly 30 cubic feet per meter) instead of monthly 30-minute sampling is acceptable in areas that are not airborne radioactivity areas.

- Breathing zone sampling for specific jobs should be used to monitor intakes of individual workers doing special high-exposure jobs, if the jobs are likely to involve more than the administrative or action limit, which is usually 0.1 Derived Air Concentration (DAC) (unit per 10 CFR Part 20.) An example of a job during which such breathing zone sampling may be used is maintenance of yellowcake drying and packaging equipment.
- The quantity of air sampled and the method of analysis should allow a lower limit of detection of at least 1x10-11 µCi/ml.

Radon-222 and Its Progeny

In uranium mills, significant concentrations in air of radon-222 and its progeny may occur near ore storage bins and crushing and grinding circuits or anywhere large quantities of ore are found, particularly dry ore. In addition, any poorly ventilated room can have high radon progeny concentrations, even if large quantities of ore are not present.

NRC regulations permit measurements of concentrations of either radon itself or the radon progeny. However, measurements of progeny are considered more appropriate, because radon progeny concentrations are both easy to measure and the best indicator of worker dose.

Depending on the radon or radon progeny concentrations, the frequency of sampling and measurements will vary. The following are the frequency requirements for sampling and measurements as developed in NRC Regulatory Guide 8.30, Health Physics Surveys in Uranium Mills.

- **Weekly**. The weekly sampling should be conducted if radon progeny concentrations are normally greater than a 0.08 working level (25% of limit) or radon concentrations are above 3 X 10-8 µCi/ml or 0.33 working level.
- **Monthly**. Monthly measurements should be made where radon progeny routinely exceed 10% of the limit or a 0.03 working level.
- **Quarterly**. Quarterly sampling should be made where previous measurements have shown that the progeny are not generally present in concentrations exceeding 0.03 working level (10% of the limit), but where proximity to sources of radon progeny might allow them to be present.

External Radiation

Most, but not all, mill workers receive external gamma radiation doses of less than 1 rem per year. During the buildup of the uranium progeny thorium-234 and protactinium-234 in fresh yellowcake, the radiation levels increase somewhat for several months following yellowcake production because of the beta radiation from these progeny in “aged” yellowcake.

The survey frequency in radiation areas should be quarterly. Survey measurements should be representative of where workers might stand, so that their whole-body radiation exposures can be estimated.

Thus, measurements should generally be made at about 12 inches from the surfaces.

There are two types of measurements for external radiation:

- **Gamma radiation** measurements should be performed semiannually at locations where workers are exposed in order to allow determination of "radiation area" boundaries.
- **Beta surveys** of specific operations that involve direct handling of large quantities of aged yellowcake are advised to ensure that extremity and skin exposures for workers are not unduly high. Beta measurements can be performed only once for an operation, but should be repeated for an operation any time a piece of equipment or operating procedure is modified in a way that may have changed the beta dose which would be received by the worker.

Beta surveys should be used to determine the need for protective clothing and whether procedures should be changed to reduce beta dose. Beta dose rates, unlike gamma dose rates, are usually measured on the surface and at short distances, rather than at 12 inches.

Surface Contamination

NRC regulations provide no specific limit on surface contamination levels in restricted areas. However, yellowcake or ore dust lying on surfaces can become resuspended and contribute to the intake of radionuclides, something that is limited by regulations. See regulatory guidance 1.86 and 8.30.

When necessary, cleanup is performed by hosing down the ore dust into floor sumps or by using vacuum suction systems with filtered exhausts.

It is recommended that surfaces where yellowcake may accumulate be painted in contrasting colors because surveys for surface contamination in work areas may be conducted visually rather than by instrument.

In yellowcake areas, daily visual inspections should be made for locating yellowcake contamination on surfaces. In rooms where work with uranium is not performed, such as eating rooms, change rooms, control rooms, and offices, a lower level of surface contamination should be maintained. These areas should be spot-checked weekly using smear tests for removable surface contamination.

Visual Inspections and Contamination of Skin and Personal Clothing

Visual examination for yellowcake is not sufficient evidence that the worker's skin or clothing is sufficiently free of contamination to permit the worker to leave the work environment. Prior to leaving a restricted area, each person should either shower or monitor his or her skin after changing clothes. An alpha survey instrument should be available at the exit of the employee change room. In addition, the licensee should at least quarterly use a calibrated alpha survey instrument to perform an unannounced spot survey for alpha contamination on selected yellowcake workers leaving the facility.

Contamination of skin and personal clothing should be controlled to prevent the spread of contamination to unrestricted areas.

Release of Equipment to Unrestricted Areas

Sampling and measurement are performed before potentially contaminated equipment is released to unrestricted areas. The licensee develops methods to prevent potentially contaminated equipment from leaving restricted areas without being monitored. For this release of equipment to unrestricted areas, the licensee is required to follow standard operating procedures.

Packages for Shipment

External surfaces of yellowcake packages prepared for shipment should be sampled and measured before shipment. The surveys should be adequate to ensure that washdowns are reducing surface contamination levels to less than Department of Transportation (DOT) limits.

The bottoms of some, but not necessarily all, barrels should be sampled to determine the effectiveness of the washdowns.

Contamination of packages should not exceed DOT limits in 49 CFR 173.397. Packages having higher contamination levels should be cleaned and resurveyed prior to shipment. Visible yellowcake should be cleaned off.

Ventilation System

The operation of the ventilation system is the most effective means of worker protection from inhalation hazards at a uranium mill or mine. It should be checked each day by the radiation safety staff during the daily walkthrough of the facility.

Contamination on Respirators

After use, respirator face pieces and hoods should be sampled by a standard wipe or smear technique for alpha contamination.

Summary of Survey Frequencies

Table 2-8 shows the summary of survey frequencies from Regulatory Guide 8.30. It also indicates the locations and frequency for sampling and the lower limit of detection for measurement.

Note: In Table 2-8, the NRC decommissioning regulations give survey frequency requirements for Ra-226 in soil, as well as other requirements. Also, the NEPA has survey frequency requirements along with other requirements.

ISL Regulatory Authority

A NRC source and byproduct material license is required under provisions of title 10 of the U.S. code of Federal Regulations, Part 40 (10 CFR 40), domestic licensing of source material, to recover uranium by in situ leach. NRC authority to regulate in situ leach facilities comes from the Atomic Energy Act of 1954, as amended, and the Uranium Mill Tailings Radiation Control Act of 1978, as amended. Specific requirements for ISL facilities are taken from 10 CFR part 40, Appendix A criteria. NUREG-1569 "Standard Review Plan for In-Situ Leach Uranium Extraction License Application," June 2003 provides specific guidance on the review of license applications for in situ leach facilities.

Over the past several years, the industry has expressed concern that NRC's regulation of ground water at in-situ leach facilities is duplicative of the ground-water protection programs required by the Safe Drinking Water Act (SDWA), as administered by EPA or EPA-authorized States.

In an effort to eliminate dual regulation by the NRC and EPA of ground water protection at ISL uranium recovery facilities, the NRC has recently initiated a rulemaking effort specifically tailored to ISL ground water protection programs. It is envisioned that the NRC would retain its jurisdiction over the wellfield and ground water under its Atomic Energy Act authority, but would defer active regulation of ground water protection programs to the EPA or the EPA-authorized state through EPA's underground injection-control permit program. The current rulemaking schedule is for a draft rule to be developed by January 2007, followed by a final rule in September 2007.

Table 2-8. Summary of Survey Frequencies

Type of Sampling and Measurement	Type of Area	Frequency	Lower Limit of Detection
Uranium ore dust	Airborne radioactivity areas	Weekly grab samples	5×10^{-12} µCi/ml (uranium)
	Other indoor process areas	Monthly grab samples	
	Outdoor areas	Quarterly grab samples	
Yellowcake	Airborne radioactivity area	Weekly grab samples	1×10^{-11} µCi/ml
	Other indoor process areas	Monthly grab samples	
	Special maintenance involving high airborne concentrations of yellowcake	Extra breathing zone grab samples	

Table 2-8. Summary of Survey Frequencies

Type of Sampling and Measurement	Type of Area	Frequency	Lower Limit of Detection
Radon progeny	Areas that exceed 0.08 working level Areas that exceed 0.03 working level Areas below 0.03 working level	Weekly radon progeny grab samples Monthly radon progeny grab samples Quarterly radon progeny grab samples	0.03 WL
External radiation: Gamma Beta	 Throughout the facility Radiation areas Where workers are in close contact with yellowcake	 Semiannually Quarterly Survey by operation done once, plus whenever procedures change	 0.1 mR/hr 1 mrad/hr
Surface contamination	Yellowcake areas Eating rooms, change rooms, control rooms, offices	Daily Weekly	Visual 500 dpm alpha per 100 cm^2
Skin and personal clothing	Yellowcake workers who shower Yellowcake workers who do not shower	Quarterly Each day before leaving	500 dpm alpha per 100 cm^2
Equipment to be released	Equipment to be released that may be contaminated	Once before release	500 dpm alpha per 100 cm^2
Packages containing yellowcake	Packages	Spot check before release	500 dpm alpha per 100 cm^2
Ventilation	All areas with airborne radioactivity	Daily	Not applicable
Respirators	Respirator face pieces and hoods	Before reuse	100 dpm alpha per 100 cm^2

Self-Check Questions 2-4

INSTRUCTIONS: Complete the following questions. Answers are located in the Trainee Guide.

1. What does the Nuclear Regulatory Commission regulate in regards to uranium milling?

2. What does the NRC require once milling operations have permanently closed?

3. With which agency does the NRC concur regarding remedial action plans for inactive mill tailings sites as required by Title I of the UMTRCA of 1978?

4. Where are NRC-licensed sites located?

5. In regard to regulating radon emissions, what does the Memorandum of Understanding between NRC and the Environmental Protection Agency ensure?

6. How frequently does 10 CFR Part 40 require reports containing information to estimate doses to the public from effluent releases to the NRC?

7. Why is information on radiation doses and the radionuclides in a mill's effluents and environment both prior to and during operations needed by the NRC staff?

8. Why are surveys for airborne ore dust necessary?

9. According to Regulatory Guide 8.30, what is an acceptable sampling program for airborne ore dust in areas that are not "airborne radioactivity areas?"

10. At what distance should airborne samples be taken for workers?

11. With regard to airborne yellowcake, radiation dose to the lung and other organs is the limiting consideration, rather than chemical toxicity, primarily due to what?

12. What are the recommended methods of sampling airborne yellowcake?

13. Where in uranium mills can significant concentrations in air of radon-222 and its progeny occur?

14. Do NRC regulations permit measurements of concentrations of either radon itself or the radon progeny?

15. What are two types of measurements for external radiation and why and when should they be performed?

16. What instrument should be available at the exit of the employee change room?

17. Why should contamination of skin and personal clothing be controlled?

18. What should happen prior to equipment being released to unrestricted areas?

19. What should happen to external surfaces of yellowcake packages prepared for shipment?

20. How often should the operation of the ventilation system be checked?

21. After the use of respirator face pieces and hoods, what should happen?

It's time to schedule a progress meeting with your administrator. Review the progress meeting form on the next page. In Part III, as a Regulator, write your specific questions to discuss with the administrator.

PROGRESS REVIEW MEETING FORM

Date Scheduled: ___________________________________Location:________________________

I. The following suggested items should be discussed with the administrator as to how they pertain to your current position:

- Geographic distribution of uranium ore
- Mining processes: Open-pit, underground, in-situ solution
- Uranium recovery facilities: Conventional mill, in-situ leach, ion-exchange, heap leach
- Milling process: Weighing to determine moisture content, sampling to determine uranium content, blending/storage, crushing/milling, extraction, purification, precipitation, filtration/drying/packaging
- Milling radiological and nonradiological hazards
- Milling controls
- Abnormal occurrences
- Milling sampling and measurement activities
- NRC regulatory authority
- NRC Regulatory Guide 8.30

II. Use the space below to take notes during your meeting.

III. As a Regulator:

- Tell me about types of releases and spills associated with milling facilities.
- What are some of the similarities and differences in uranium recovery facilities/operations?
- Before I visit a mill, what documentation should I review?

Use the space below to write your specific questions.

IV. Further assignments? If yes, please note and complete. If no, initial completion of progress meeting on tracking form.

Suggested: NUREG-1569, "Standard Review Plan for In-Situ Leach Uranium Extraction License Application," June 2003

Ensure that you and your administrator have dated and initialed your progress on your tracking form for this module.
Go to the module summary.

MODULE SUMMARY

Key Points:

- The Nuclear Regulatory Commission licenses and regulates the following:
  - Commercial in-situ leach operations
  - Uranium milling operations
  - Byproduct materials from these operations, under 11e.(2)
- Regulatory activities include:
  - Uranium extraction research and development
  - Disposal of uranium tailings and wastes
  - Reclamation and decommissioning of sites
- Milling of uranium poses occupational hazards similar to those of any metal mining and milling operations, primarily:
  - Exposure to external gamma radiation
  - Inhalation of radon progeny
  - Inhalation of uranium dust
- Mill tailings are a long-term environmental concern; however, tailings effects can be managed by proper engineering design and monitoring to protect the public and the environment.
- Sampling and measurement activities during in-situ leach and uranium milling are an integral part of the site operations, and such activities help to:
  - Ensure that operations are not harmful to workers, the public and the environment
  - Maintain the quality of the product

Congratulations! You are ready to go to the next assigned module.
