Chapter 2. Uranium Mining and Extraction Processes in the United States

In 1946, Congress passed the Atomic Energy Act (AEA), establishing the Atomic Energy Commission (AEC) and designating it as the sole purchasing agent for domestically produced uranium. The AEA also set fixed prices for uranium ore and provided production incentives (e.g., including access roads, haulage allowances, and buying stations) in an effort to bolster development within the domestic uranium industry. Since then, the industry has gone through two boom-to-bust cycles (U.S. DOE/EIA 1992). The first of these cycles, in the 1950s, was prompted by the demand generated by the U.S. government's weapons program. The second, in the 1970s to early 1980s, was fueled by expectations for increasing demand from commercial nuclear power production and the "energy crisis". Since the 1970s, the NRC succeeded the AEC in the role of licensing uranium extraction operations, but the demand and price of uranium has been determined by external market forces. Rising demand, beginning in 2003 for uranium has begun to increase production in the domestic industry. The importance of the uranium market and price of uranium is their role in mining industry decisions. Some of these decisions are: how to extract ore from a mineral deposit, how many and which mineral deposits should be mined, and when they should be mined. Those decisions ultimately affect the volumes of waste produced and how it is managed.

This chapter examines the location and geology of uranium deposits in the United States, the methods used to mine uranium, and the methods used to extract it from ore. Many of the geological and mining terms used in the text that follows are defined in the chapter and are also in included in the glossary in Appendix I.

The Early Years of Uranium Production

As a result of the AEC's financial incentives—first announced in 1948 and 1949 and then increased in 1951—uranium prospectors searched prospective areas of the United States throughout the 1950s for radioactivity that might signal a viable uranium deposit. Prospectors locating areas with mining potential would file claims for the discovery site and nearby areas. The ownership claims were regulated according to the Mining Law of 1872 and were enforced by the U.S. Department of Interior. To maintain ownership of these claims, prospectors needed to perform a variety of activities every year, including digging small pits, adits[1], and trenches. If they found ore grade material higher than 0.10 percent uranium, they would mine the material and ship it to regional AEC buying stations for sale. AEC offered bonuses for shipments meeting minimum criteria.

In many parts of the Colorado Plateau, the characteristic geologic forms of uranium ore bodies were small to moderate-sized isolated pods or linear sinuous channels of ore, as opposed to large lithologic[2] beds typical of coal or iron. As a result, thousands of diminutive mines were developed in the Plateau region on ore bodies sometimes as small as a single uraniferous petrified log weighing a few metric tons. In many cases, these ore bodies were clustered into districts (Table 2.1.), and ores were shipped from producing properties to centralized mills. These small mines produced small quantities of waste rock typically discarded within several to over 100 yards (several to about 100 meters) of the mine opening or pit. Mine maps typically show extensive underground mining following ore zones with only small piles of

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[1] Adits are horizontal or nearly horizontal passages driven from the surface for the working or dewatering of a mine. If driven through a hill or mountain to the surface on the other side it would be a tunnel.

[2] Lithologic is defined as character of a rock described in terms of its structure, color, mineral composition, grain size, and arrangement of its component parts; all those visible features that in the aggregate impart individuality to the rock. Lithology is the basis of correlation in coal and other types of mines and commonly is reliable over a distance of a few to several miles.

waste rock at the mouth of the mine entry. Mines of this type, now abandoned, are scattered over wide areas of southeastern Utah, southwestern Colorado, northwestern New Mexico, and northeastern Arizona, as can be seen in Figure 2.1. As described further in Chapter 3 of this report, the mines which were abandoned or left unrestored prior to the early 1970s left residual wastes that are a main focus of this study. The migration of radionuclides and other hazardous substances from those mines and their waste piles have resulted from biologic, hydrologic, wind, and human actions, and are discussed in more detail in Chapter 3 and Volume II of this report (U.S. EPA 2006a).

The primary database for uranium mine locations for the public has been the MAS/MILS (McFaul et al. 2000) database. However, the MAS/MILS data used to construct Figure 2.1 has known flaws, and sites shown on the map using the database do not constitute all known uranium mines and fields. For example, the Crow Butte *in situ* leach (ISL) field in Northwest Nebraska near the Wyoming border is not included; however Figure 2.9, based on different data compiled in the EPA Uranium Location Database (U.S. EPA 2006b), does show the location of the Northwest Nebraska uranium district. The MAS/MILS database though, does provide a general overview of uranium mine geographic distributions in the western U.S. The larger data sets that comprise the EPA Uranium Location Database are discussed in the database documentation (U.S. EPA 2006b).

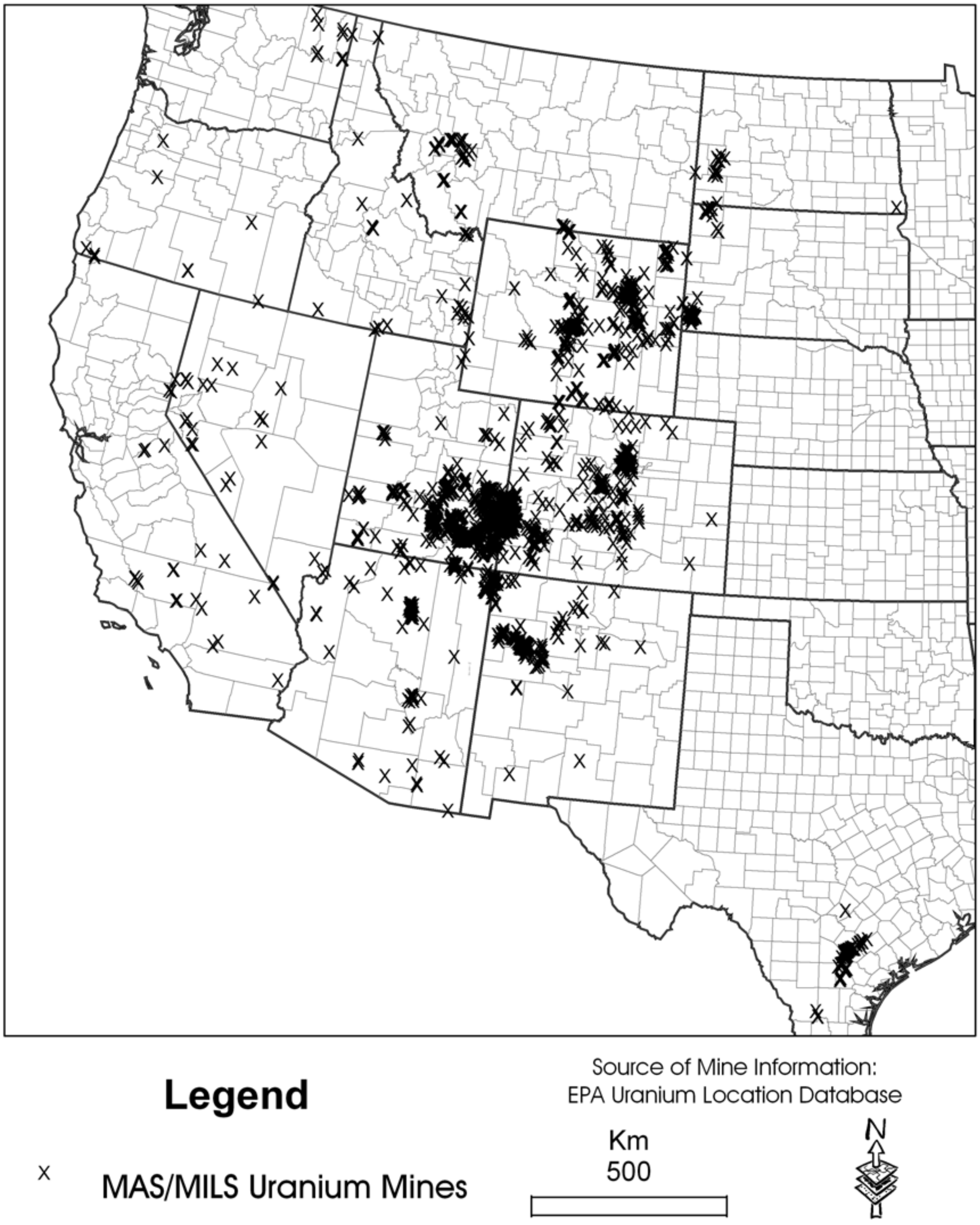
Table 2.1. Major U.S. Uranium Mining Districts

Several major uranium districts produced uranium ore in the past and contain potential for future exploitation.

Uranium District	State
Spokane	Washington
Wind River Central Wyoming	Wyoming
Washakie Sand Wash	Wyoming, Colorado
Powder River	Wyoming, Montana
Northwest Nebraska	Nebraska
Uravan Front Range Marshall Pass Tallahassee Creek	Paradox Basin, Colorado & Utah
Paradox Basin	Colorado, Utah
Marysvale	Utah
Northern Arizona	Arizona
Grants Mineral Belt	New Mexico, Arizona
Texas Gulf Coast	Texas

Source: U.S. DOE/EIA 1997.

Figure 2.1. Mines and Other Locations with Uranium in the Western U.S.
Thousands of uranium mine sites are scattered over wide areas of the western United States. This map shows locations provided in the MAS/MILS database.



Source: (U.S. EPA 2006b)

Large companies were also in the uranium prospecting business. Many mining properties proved to have much larger ore bodies than originally thought, both on the Colorado Plateau and in other states. Extensive mining operations were developed at these sites. Since the early 1960s, most uranium has been mined on a larger scale than early mining efforts and conventional mining techniques were established to recover the ores.

Although the AEC incentives ceased in 1962, the agency continued to purchase ore from properties with reserves discovered before November 24, 1958, at guaranteed prices through the end of 1970. Initially, the AEC paid $8.00 per pound, but this declined to $6.70 per pound in the late 1960s (Chenoweth 2004). Several ore processing mills closed from late 1959 through the end of the 1960s. In 1961, for the first time since 1948, uranium production declined in the United States. By the end of the buying program in 1970, several hundred small to intermediate-sized underground and open-pit mines were either mined out or had become uneconomical and were abandoned.

The industry was revitalized shortly thereafter by the prospect of supplying fuel to the developing commercial nuclear power industry. The production and market prices of uranium grew rapidly through the mid- and late 1970s and early 1980s, as commercial markets began to emerge. However, production and prices peaked in the early 1980s, when domestic demand for uranium ore fell far short of its expected growth, and low-cost, high-grade Canadian and Australian deposits began to dominate world markets. As planning and construction of new U.S. commercial nuclear power plants came to a halt (U.S. DOE/EIA 1992) and the domestic price of uranium dropped dramatically, the U.S. industry shifted from higher-cost to lower-cost production sites, and the nation faced an oversupply of uranium despite the fact that demand remained about even through 2003.

Throughout the high uranium production years, trends in the industry changed, leading to new mining methodologies and subsequent changes in the nature of their resulting waste generation and hazards. Environmental concerns and regulatory requirements, as well as discovery of high uranium content deposits with low extraction costs, resulted in increased uranium mining overseas. Traditional mining techniques can have high associated costs for heavy metal and TENORM waste management, acid mine runoff, and mine site restoration. These issues made many uranium mines unprofitable when market prices were low. Increasing world demand raised the price of uranium starting in 2003 (AAPG 2005) and although most mines that were inactive at the time employed the less disruptive ISL technique, (described in the following section), conventional mine sites have begun to reopen as a result (Teluride Watch 2005).

Conventional Uranium Mining Methods

The following discussion describes physical methods of mining. Mining is the mechanical process by which mineral ores are extracted from the earth. These methods are referred to in this report as conventional mining methods, as opposed to the solution chemical extraction processes of ISL and heap leaching.

Ore is a mineral source from which a valuable commodity (e.g., metal) is recovered. The term ore implies economic viability, given the concentration of metal in the host rock, the costs of extraction, processing and refinement, waste management, site restoration, and the market value of the metal. Protore is conventionally mined uranium ore that is not rich enough to meet the market demand and price. This subeconomic ore is often stockpiled at the mine site for future exploitation under the appropriate economic or market demand conditions. Waste materials that are, or could be classified as, technologically enhanced, include overburden, unreclaimed protore, waste rock, drill and core cuttings, liquid wastes and pit water (for more detailed discussion, see Chapter 3). The size, grade, depth, and geology of an ore body (or deposit) are used in combination to determine which extraction method is most efficient and economical. Conventional mining generally refers to open-pit and underground mining. Open-pit mining is employed for ore deposits that are located at or near the surface, while underground mining is used to extract ore from deeper deposits or where the size, shape, and orientation of the ore body may permit more cost-effective underground mining. Since the early 1960s, most uranium has been mined on a larger scale than earlier mining efforts, and, until recently, by using conventional mining techniques. Radioactive mine wastes from conventional open-pit and underground mines are considered to be TENORM, whose regulatory responsibility resides with EPA or the states. In recent years, ISL operations (regulated by the NRC or its Agreement States) in the United States are described further below. Those operations have generally replaced conventional mining because of their minimal surface disturbance and avoidance of associated costs (See Appendix VI for discussion on statutory and regulatory authorities).

Open-Pit (Surface) Mining

Open-pit mining is the surface removal of soil and rock overburden and extraction of ore. Open-pit mines are broad, open excavations that narrow toward the bottom, and are generally used for shallow ore deposits. The maximum depth of open-pit mining in the United States is usually about 550 feet (168 meters). Lower-grade ore can be recovered in open-pit mining, since costs are generally lower compared to underground mining. There are deeper surface mines for copper and other minerals (Berkeley pit in Butte, Montana, reportedly at the north end is approximately 1780 feet, or 543 meters deep). Figure 2.2 shows a commonly used excavation method for removing overburden from surface mines, whereas Figure 2.3 shows the layout of a larger surface mine operation.

Delineation of the ore deposit by drilling and computer modeling is followed by development of a plan for removing and disposing of overburden. This planning is important, since the handling of waste material comprises one of the largest shares of overall mining costs (Grey 1993).

Figure 2.2. Surface Mine Showing Drag Line and Overburden

Source: U.S. EPA 1997

In open-pit mining, topsoil is the natural soil overlying the pit outline, while overburden includes material lying between the topsoil and the uranium ore deposit. In more recent open-pit operations, soil is removed and stockpiled for later site reclamation (i.e., restoration). Overburden is removed using scrapers, mechanical shovels, trucks, and loaders. In some cases, the overburden may be ripped or blasted free for removal. Overburden forms the largest volume of waste, is generally lowest in naturally radioactive elements, and is not as enriched in uranium as protore. Protore is often stockpiled at the mine site as well, and is much higher in radionuclide or heavy metal content than overburden or soil.

Once the ore body is exposed, radiometric probing is used to define the exact extent of the ore body. Ore, protore, and low-grade mineralized rock are outlined, and plans are developed for mining and stockpiling them. Many times parts of an ore body delineated by drilling cannot be economically mined by open-pit methods. Where parts of the deposit lie adjacent to the bottom of the planned pit, underground mines may be developed from the pit bottom to recover these ores. Often waste material, including overburden, is returned to mined-out areas during mining to reduce hauling costs.

Figure 2.3. Surface Mine

This figure shows a surface mine operation in Nevada.

Source: U.S. EPA RCRA Program

“Rim stripping” was a technique applied in areas of the Colorado Plateau. In this type of open-pit mining, the ore body occurred at or near the surface along the edge (or rim) of a canyon. Miners would strip the shallow overburden from the deposit and generally drop the waste material down the adjacent canyon wall. In practice, this mining resembles strip mining for coal in the eastern United States. Rim stripping was generally limited to the edge of the canyon because the overburden grew thicker farther away from the rim.

Underground Mining

Deeper uranium ore deposits require underground mining by one of several excavation techniques, including:

- longwall retreat (a method of underground mining in which the ore bearing rock is removed in one operation by means of a long working face or wall; the space from which the ore has been removed either is allowed to collapse, or is completely or partially filled with stone and debris);
- room and pillar (a conventional method of mining in which natural pillars are left unmined for support between the mined rooms); and,
- panels (a method of mining whereby the workings of a mine are divided into sections, each surrounded by solid strata with only necessary roads through the rock barrier).

The mining method of choice depends on several factors, including the size, shape, depth, and grade of the ore body, the stability of the ground, and economics (Grey 1993). For small ore bodies near the surface, miners may use:

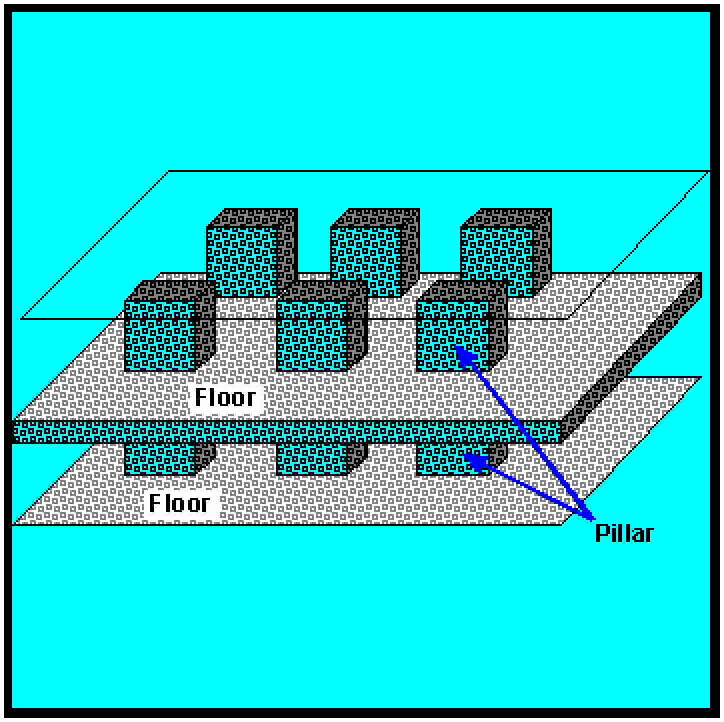
- adits;
- inclines (a slanting shaft from the surface into the underground mine); or,
- small shafts to reach and remove ore.

Larger, deeper deposits may require one or more vertical concrete-lined shafts or declines large enough for motorized vehicles to reach the ore. Stopes (an underground excavation from which ore has been removed in a series of steps) reaching out from the main shaft provide access to the ore.

Ore and waste rock generated during mining are usually removed through shafts via elevators, or carried to the surface in trucks along declines. Because of the high costs of removing such materials, some waste rock may be used underground as backfill material in mined-out areas. As with surface mining, radioactive waste rock in underground mining is generally considered to be TENORM. The extracted ore is stockpiled at the surface or trucked directly to a processing mill, which may be on site or at some centralized location. Figure 2.4 is a diagram of an underground uranium mine with room and pillar excavation.

Figure 2.4. Diagram of Room and Pillar Underground Mining

This figure shows a simplified diagram of a room and pillar underground mining operation. Main vertical shafts connect with underground "rooms" that have been excavated using unmined rock columns as support pillars. Rail cars move ore and waste through the mine.



Source: U.S. EPA (1997)

Unconventional Mining Methods

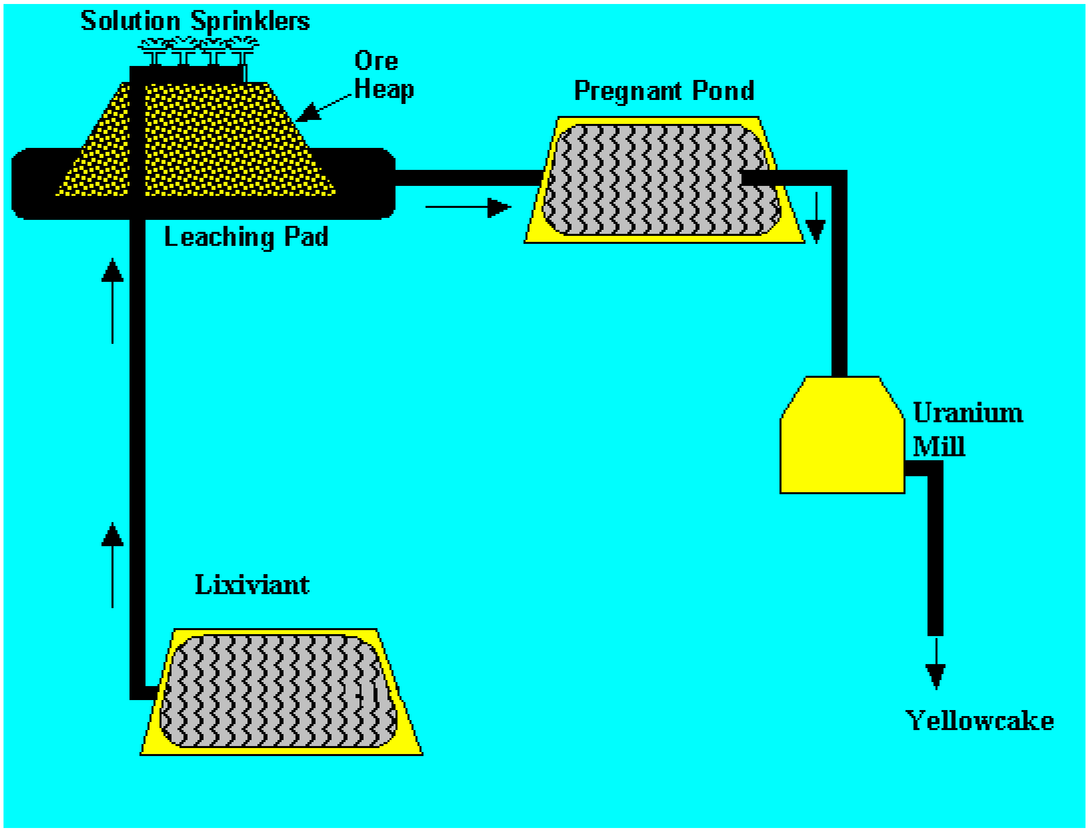
Open-pit and underground mining methods, both of which rely on physical extraction to obtain raw uranium ore, are commonly referred to as conventional mining methods. The reliance on chemical or other means to extract uranium are referred to as unconventional mining methods, even though they may have been used as extraction processes for decades. The sections which follow describe the heap leaching and ISL extraction processes.

Heap Leaching

As this is an extraction process, heap leaching is regulated by the NRC or its Agreement States; the waste rock is considered byproduct material (see Appendix VI). Ore that is removed from open-pit and underground mining operations undergoes further processing to remove and concentrate the uranium; the heap leaching may be located near the mine site. Ore is crushed in a large mill, grounded to sand consistency, and mounded above grade on a prepared pad, usually constructed of clay, coated concrete, or asphalt. A sprinkler system, positioned over the top, continually sprays leach solution over the mound. For ores with low lime content (less than 12 percent), an acid solution is used, while alkaline solutions are used when the lime content is above 12 percent. The leach solution trickles through the ore and mobilizes uranium, as well as other metals, into solution. The solution is collected at the base of the mound by a manifold and processed to extract the uranium. Figure 2.5 below provides an illustration of the process. Heap leaching was used mostly on an experimental basis in the 1970s and 1980s, but is generally not in use in the U.S. today.

Figure 2.5. Illustration of Heap Leaching Process

In this illustration, leaching solutions (either acidic or alkaline) comprising the lixiviant are sprinkled on crushed ore mounded on a liner or leaching pad. Uranium bearing fluids collect by gravity on the bottom of the pile and drain into a pit (or pregnant pond); the fluids are then piped or transported to a mill for further extraction and turned into yellowcake.



Source: EPA

In Situ Leaching (Solution Mining)

Since this is also an extraction process, ISL is regulated by the NRC or its Agreement States; the waste materials and fluids are considered byproduct material (see Appendix VI). However, EPA standards and requirements for uranium extraction facilities developed under UMTRCA, as well as requirements of EPA's Underground Injection Control (UIC) program are applicable to ISL facilities (See Appendix VI for more information). ISL operations are discussed here to provide a more complete representation of the impacts from uranium production.

ISL is used when specific conditions exist, for example:

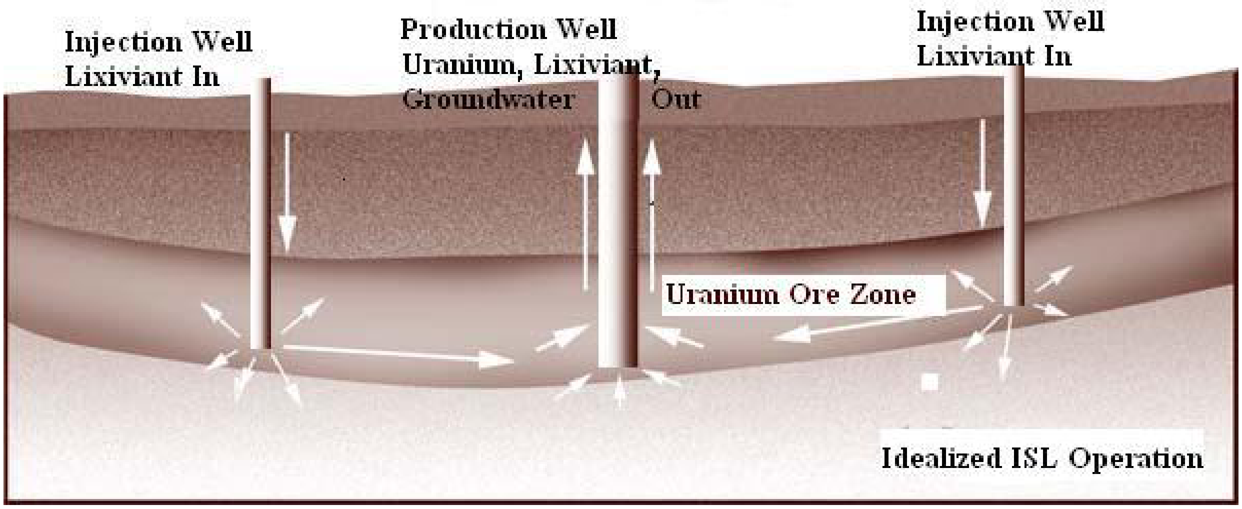
- The ore is too deep to be mined economically by conventional means;
- The uranium is present in multiple-layered roll fronts that may be offset by faulting;
- The ore body is below the water table;
- Considerable methane and hydrogen sulfide are associated with the ore;
- The ore grade is low, and the ore body is too thin to mine by conventional means;
- A highly permeable rock formation exists in which uranium can be economically produced.

In this method of extraction, uranium ores are leached underground by the introduction of a solvent solution, called a lixiviant, through injection wells drilled into the ore body. The process does not require the physical extraction of ore from the ground. Lixiviants for uranium mining commonly consist of water containing added oxygen and carbon dioxide or sodium bicarbonate, which mobilize uranium. The lixiviant is injected, passes through the ore body, and mobilizes the uranium. The uranium-bearing solution is pumped to the surface from production wells.

The pregnant leach solution is processed to extract the uranium, usually by ion exchange or by solvent extraction. The ion exchange process employs a resin that, once fully saturated with uranium, is flushed with a highly concentrated salt (e.g., sodium chloride) solution. This reverses the exchange process and releases uranium into the solution. The uranium solution is then sent to another process for concentration, precipitation and drying, as yellowcake. The solvent extraction process relies on unmixable properties between the pregnant leach solution and (uranium) solute. Normally, the solvents are organic compounds that can combine with either cationic or anionic solutes. For example, anionic solutions include amine chains and ammonium compounds, and cationic solutions are phosphoric acid-based. Figure 2.6 shows a simplified version of the ISL process.

Figure 2.6. Illustration of ISL Process

This figure shows a simplified version of how ISL solution mining works. Lixiviant is injected into the ground through a well on the left and far right, the fluid flows underground dissolving uranium and carrying it in solution until it reaches a production well in the center. The fluid carrying dissolved uranium is returned to the surface from the production well, then is piped off to a production facility for refinement into yellowcake.



Source: Modified after ANAWA : http://www.anawa.org.au/mining/isl-diagram.html

When the ISL process is completed, the ore body and aquifer are placed in a restoration phase, as required by mine permits, NRC and Agreement State regulatory programs. Typically, the aquifer must be restored to background or EPA drinking water maximum contaminant limit levels where possible or practical, or to Alternate Concentration Limits (ACLs) in terms of the presence of metals, organics, pH level, and radioactivity, approved by the NRC and its Agreement States, with EPA concurrence. Therefore, in some cases, restoring it to the pre-operation level does not necessarily make it potable. EPA groundwater protection standards issues under authority of UMTRCA are required to be followed by ISL licensees of the NRC and its Agreement States. In addition to those requirements, ISL operators must apply for UIC permits from EPA. Through the UIC aquifer exemption process, EPA and its Delegated States determine if an aquifer or part of an aquifer is exempt from protection as an underground source of drinking water during the mining process. Approval of this exemption is necessary before a UIC permit may be issued for ISL mineral extraction wells. EPA requires, however, that non-exempted groundwater sources be protected from contamination.

Uranium Milling

While not a central focus for this report, information is provided below primarily from U.S. EPA (1995a) on the uranium milling process; for more detailed discussions on the milling process, the reader is referred to that report. Licensed by the NRC under 10 CFR Part 40, Appendix A, mills process source materials (see Chapters 1 and Appendix VI) from conventional uranium mines and occasionally from other industrial activities or mines. Uranium mills have typically been associated with specific mines or functioned as custom mills, serving a number of mines. Most available information on milling operations was written when a dozen or more were operational, therefore the following discussions may not precisely describe milling activities being conducted at present, or in the future. The chemical nature of the ore determines the type of leach circuit required and, in turn, the extent of grinding of ore received from a mine.

The initial step in conventional milling involves crushing, grinding, and wet and/or dry classification of the crude ore to produce uniformly sized particles. Ore feeds from crushers to the grinding circuit where various mechanical mills grind the rock to further reduce the size of the ore. Water or lixiviant is added to the system in the grinding circuit to facilitate the movement of solids, for dust control, and (if lixiviant is added) to initiate leaching (U.S. DOI 1980). Screening devices are used to size the finely ground ore, returning coarse materials for additional grinding. The slurry generated in the grinding circuit contains 50 to 65 percent solids. Fugitive dust generated during crushing and grinding is usually controlled by water sprays or, if collected by air pollution control devices, recirculated into the beneficiation circuit. Water is typically recirculated through the milling circuit to reduce consumption (U.S. EPA 1983d).

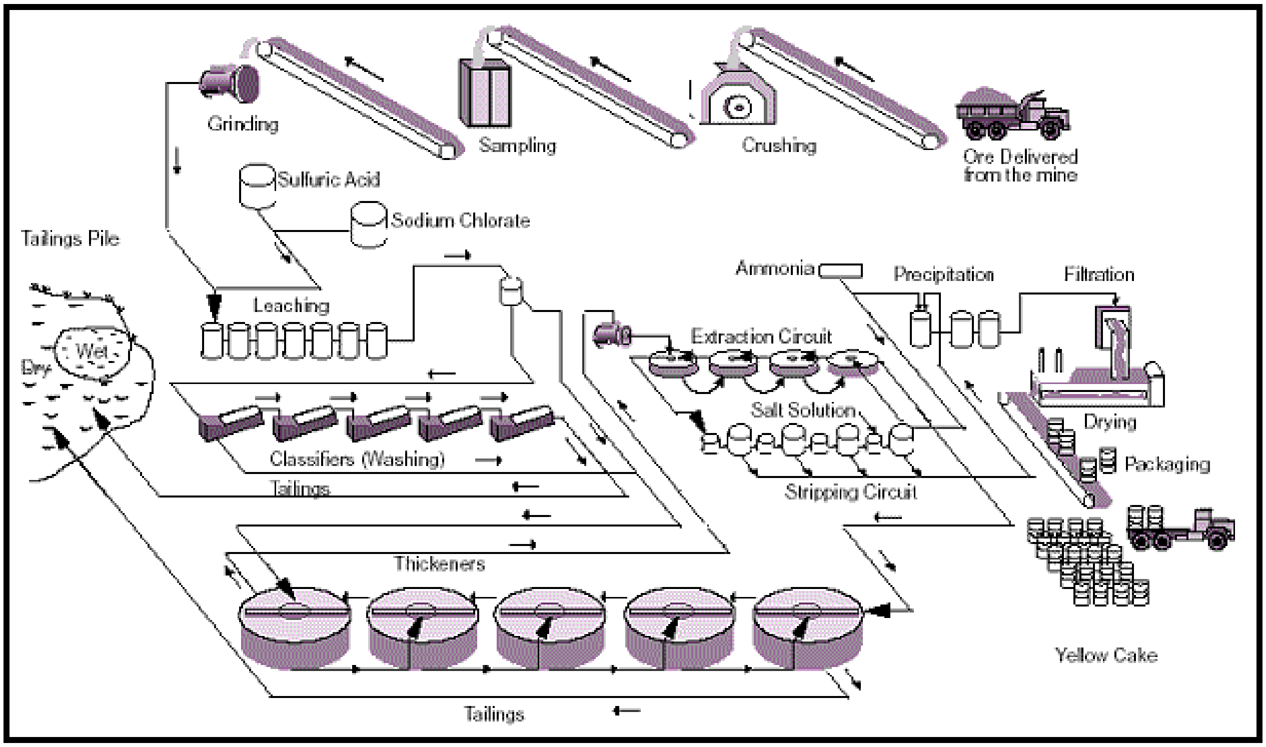
After grinding, the slurry is pumped to a series of tanks for leaching. Two types of leaching have been employed by uranium mills, acid and alkaline. A solvent (lixiviant) is brought into contact with the crushed ore slurry. The desired constituent (uranyl ions) is then dissolved by the lixiviant. The pregnant lixiviant is separated from the residual solids (tails); typically the solids are washed with fresh lixiviant until the desired level of recovery is attained. The uranyl ions are recovered (stripped) from the pregnant lixiviant. The final steps consist of precipitation to produce yellowcake, followed by drying and packaging (Pehlke 1973). The stripped lixiviant may be replenished and recycled for use within the leaching circuit or as the liquid component in the crushing/grinding operation. Ultimately, the solids may be washed with water prior to being pumped to a tailings pond; this wash serves to recover any remaining lixiviant and reduce the quantity of chemicals being placed in the tailings impoundment. Wash water may be recycled to the lixiviant or to the crushing and grinding circuits.

Operational mills currently function independently of specific conventional mines and generate materials that are, in most cases, unique from those generated at the site of extraction. Under UMTRCA, source-handling licenses place specific requirements on the disposal of radioactive wastes; the design and construction of tailings impoundments address NRC requirements for permanent storage of these wastes. Radionuclide-containing wastes generated by ISL operations are typically shipped to tailings impoundments at mill sites. Figure 2.7 shows the general physical layout of a typical uranium mill.

Information on statutory requirements for closure and reclamation of abandoned and inactive uranium mills can be found in Appendix VI, characteristics of mill tailings in Chapter 3, and reclamation procedures for closed mills and mill tailings impoundments can be found in Chapter 4. Mills in operation and inactive are discussed below.

Figure 2.7. Generalized Uranium Mill Physical Layout

This figure shows how a uranium mill is physically set up to crush raw ore into particles amenable to chemical treatments for extracting uranium.



Source: U.S. DOE/EIA, http://www.eia.doe.gov/cneaf/nuclear/page/uran_enrich_fuel/uraniummill.html

The Uranium Industry Today

Due to worldwide oversupply of uranium, and dearth of new U.S. nuclear plants, the U.S. uranium mining industry was depressed from the early 1980s until about 2003, when only a few mines remained in operation. In 1981, the United States produced nearly 14,800 metric tons of oxide of uranium (U_3O_8) equivalent at an average price of over $34 per pound. U_3O_8 equivalent production in 1991 was approximately 3,600 metric tons sold at an average price of $13.66 per pound. While it had decreased to less than $8 per pound in 2000, by 2004, due to increasing demand, the price of uranium increased substantially. In early 2006, it had increased to approximately $40 per pound. These fluctuations in price affect the numbers of operating mines and mills in the country, and the methods of extraction used.

The employment structure in the uranium industry has significantly changed since the mid-1970s, when nearly 60 percent of the uranium industry labor force was devoted to uranium mining and production. This fraction steadily declined until recently, when only about 25 percent of the employment was related to mining (including ISL) and almost one-half of that was associated with reclamation of past production facilities. The industry experienced the highest level of employment in 1979 with 21,500 workers. In 1981 employment was about 13,600, and in 2000 the work force was down to 627 workers (U.S.

DOE/EIA 2001). Due to increased demand for uranium which resulted in higher prices, steady increases were seen in employment and production of uranium commencing in 2004.

The U.S. Department of Energy's EIA reports that in 1992, 51 person-years were expended in exploration, 219 in mining activities, 129 in milling operations, and 283 in processing facilities (U.S. DOE/EIA 1992, 1993). By 2000, one person-year was expended in exploration, 157 in mining, 106 in milling, and 137 in processing (U.S. DOE/EIA 2001); the remainder (226 person years) were involved in site reclamation. It is reported in the “Domestic Uranium Report” (U.S. DOE/EIA 2005b) released by the Department of Energy in August, 2005, that employment in the U.S. uranium production industry totaled 420 person-years, an increase of 31 percent from the 2003 total. Reclamation employment increased three percent. Wyoming accounted for 33 percent of the total 2004 employment, while Colorado and Texas employment almost tripled since 2003. Overall, \$86.9 million went to drilling, production, land exploration and restoration activities in 2004.

A total of 17 uranium mines were operational in 1992: five conventional mines (both underground and open-pit), four ISL and eight reported as "other" (mill tails recovery operations, mine water extraction, or from low-grade stockpiles). Uranium in 1992 was also produced to a limited extent as a side product of phosphoric acid production at four sites (U.S. DOE/EIA 1993). By 2002, production had been reduced to three ISL operations and one underground mine (U.S. DOE/EIA 2003a). The ISL sites were located in Wyoming and Nebraska. A number of mines were closed and inactive with the possibility of reopening should the price of uranium increase in the future. In 2002, only 2.4 million pounds (~1090 MT) of U_3O_8 were produced domestically by: ISL operations, processing of waste mine-water, or reclamation and restoration activities at closed ISL sites.

The uranium production industry had a turnaround in 2004. An increase in all aspects of the industry was noticed for the first time since 1998. This included drilling, mining, production and employment. In 2004 (latest statistics available) 2.5 million pounds (~1135 MT) of U_3O_8 were mined in the U.S. which was 11 percent higher than the previous year (U.S. DOE/EIA 2005a). A new underground mine and a new ISL mine started in 2004. Total U.S. production of yellowcake (uranium concentrate) was 2.3 million pounds (~1045 MT) which was 14 percent higher than the production in 2003. Table 2.2 below provides U.S. uranium concentrate production by quarters.

Table 2.2. U.S. Uranium Mine Production: 2000–2005

This table shows Total Production of Uranium Concentrate in the United States, 2000 -2005

Production is reported in pounds U_3O_8, metric tons are included in parentheses

	2000	2001	2002	2003	2004	2005^P
1st Quarter	1,018,683 (462 MT)	709,177 (322 MT)	620,952 (282 MT)	^{E} 400,000 (181 MT)	^{E} 600,000 (272 MT)	708,980 (322 MT)
2nd Quarter	983,330 (446 MT)	748,298 (339 MT)	643,432 (292 MT)	^{E} 600,000 (272 MT)	^{E} 400,000 (181 MT)	630,057 (286 MT)
3rd Quarter	981,948 (445 MT)	628,720 (285 MT)	579,723 (263 MT)	^{E} 400,000 (181 MT)	588,738 (267 MT)	585,925 (266 MT)
4th Quarter	973,585 (442 MT)	553,060 (251 MT)	^{E} 500,000 (227 MT)	^{E} 600,000 (272 MT)	^{E} 600,000 (272 MT)	NA
Calendar-Year Total	**3,957,545 (1795 MT)**	**2,639,256 (1197 MT)**	**^{E} 2,344,107 (1063 MT)**	**^{E} 2,000,000 (907 MT)**	**2,282,406 (1035 MT)**	NA

P = Preliminary data.

E = Estimate - The 2003 and 1st, 2nd, and 4th quarter 2004 production amounts were estimated by rounding to the nearest 200,000 pounds to avoid disclosure of individual company data. The 4th quarter 2002 production amount was estimated by rounding to the nearest 100,000 pounds to avoid disclosure of individual company data. This also affects the 2002 annual production.

NA = Not Available.

Notes: Totals may not equal sum of components because of independent rounding or reporting methods mentioned previously. Next update is approximately 45 days after the end of the fourth quarter 2005.

Source: Modified from U.S. DOE/EIA (2005b): Form EIA-858, "Uranium Industry Annual Survey."

Only 16 percent of all uranium purchased by U.S. utilities in 2000 was domestically produced (U.S. DOE/EIA 2000a). According to surveys of owners and operators of U.S. civilian nuclear power reactors, future deliveries of U_3O_8 for 2001–2010 would amount to 116.5 to 179.0 million pounds (53 to 81 thousand MT). It was also estimated that foreign suppliers would provide 54 percent of the maximum projected deliveries through 2010.

U.S. non-conventional extraction facilities are primarily ISL plants. The decision to reopen a plant primarily depends upon the prevailing economics and market conditions. A few ISL operations are remaining open or inactive today, opening intermittently as the price of uranium continues to fluctuate. The only mills currently operating are Cotter Corporation mill in Colorado and International Uranium's White Mesa mill in Utah, while the Kennecott Sweetwater Wyoming mill is inactive, and the Plateau Resources mill in Utah is amending its license to operations (U.S. DOE/EIA 2005a).

Recent power uprates[3] and upgrades to U.S. nuclear plants have had the equivalent impact of nineteen new reactors starting operation, and other countries have indicated interest in building new plants as well. Since most of the demand for uranium originates from the commercial sector (nuclear power plants), and that demand is increasing, it is likely it will affect uranium market demand and supplies (Wyoming Mining Association 2004).

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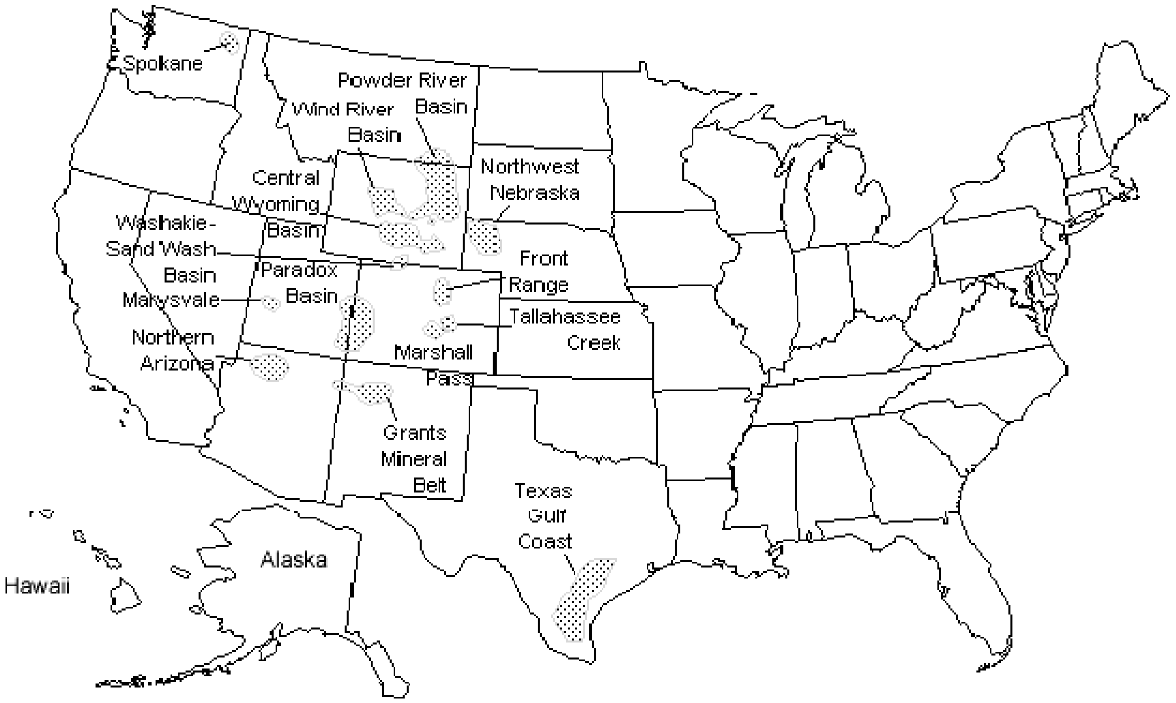
[3] The process of increasing the maximum power level at which a commercial nuclear power plant may operate.

U.S. uranium reserves must also be taken into consideration, because changes in the price of uranium may make them important resources in the future. Figure 2.8 provides a map with locations of reserve areas, while reserve estimates are included in Table 2.3. Reserve estimates represent the quantities of uranium (as U_3O_8) that occur in known deposits, such that portions of the mineralized deposits can be recovered at specific costs under current regulations using state-of-the-art mining and milling methods (U.S. DOE/EIA 2004). At of the end of 2004, EIA estimated uranium reserves in the \$30- and \$50-per-pound categories were 265 and 890 million pounds (120 and 400 thousand MT), respectively. Underground mine reserves accounted for about one- half of the total reserves in each cost category. The reserve decreases are based on 2003 mine production of uranium and reflect the combined effects of depletion and erosion of in-place ore quantities remaining at year-end. Figure 2.9 below shows the status of mines, ISL operations, and mills in the U.S. as of late 2005.

Figure 2.8. Major U.S. Uranium Reserve Areas

This map shows major areas of remaining uranium reserves, all in the western U.S.

Major U.S. Uranium Reserves



Sources: Based on U.S. Department of Energy, Grand Junction Project Office (GJPO), National Uranium Resources Evaluation, Interim Report (June 1979) Figure 3.2; and GJPO data files.

Source: From DOE/EIA http://www.eia.doe.gov/cneaf/nuclear/page/reserves/uresarea.html)

Table 2.3. Uranium Reserves of the United States as of December 31, 2003.
This table developed by the Energy Information Administration of DOE provides a breakdown of uranium reserves by mining method based on price of uranium of $30 per pound and $50 per pound.

U.S. Forward-Cost Uranium Reserves by Mining Method, December 31, 2003

Mining Method	**Forward-Cost Category**					
	$30 per pound			**$50 per pound**		
	Ore in million tons (million Metric Tons)	**Grade[a] (percent U_3O_8)**	**U_3O_8 in million pounds (Metric Tons)**	**Ore in million tons (million Metric Tons)**	**Grade[a] (percent U_3O_8)**	**U_3O_8 in million pounds (Metric tons)**
Underground	25 (23)	0.272	138 (62,600)	143 (130)	0.163	464 (210,500)
Open-pit	10 (9)	0.139	29 (13,150)	163 (148)	0.079	257 (116,600)
In Situ Leaching	39 (35)	0.127	98 (44,450)	116 (105)	0.071	165 (74,800)
Other[b]	< 1 (0.9)	0.265	<1 (<453)	3 (2.7)	0.059	4 (1,814)
Total	**74 (67)**	**0.178**	**265 (120,200)**	**424 (385)**	**0.105**	**890 (404,000)**

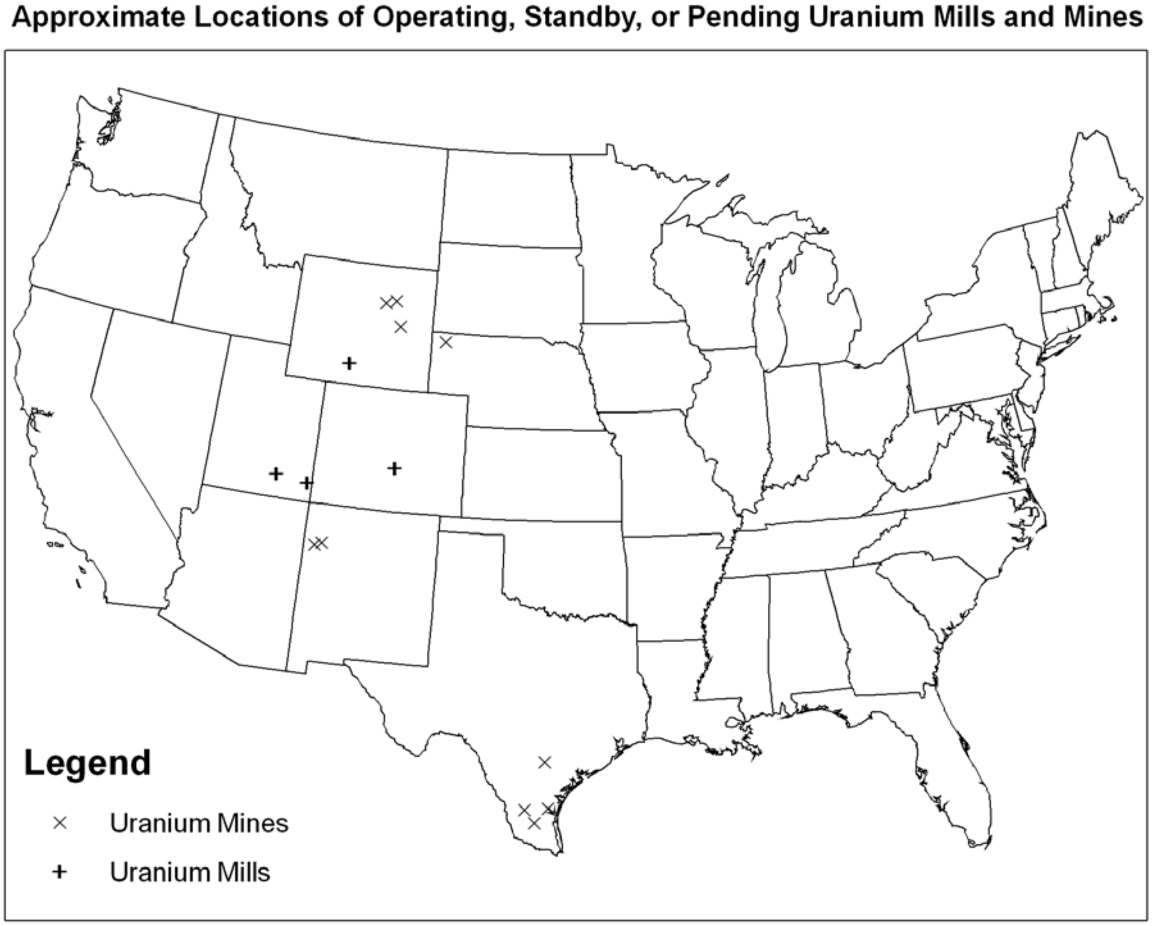
[a] Weighted average percent U_3O_8 per ton of ore.
[b] Includes low grade material and miscellaneous.

Notes: Uranium reserves that could be recovered as a byproduct of phosphate and copper mining are not included in this table. Reserves values in forward-cost categories are cumulative: that is, the quantity at each level of forward-cost includes all reserves at the lower costs. Totals may not equal sum of components because of independent rounding.
Sources: Estimated by Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels, based on industry conferences; U.S. Department of Energy, Grand Junction Office, files; and Energy Information Administration, Form EIA-858, "Uranium Industry Annual Survey," Schedule A, Uranium Raw Material Activities (1984-2002) and Form EIA-851A, "Domestic Uranium Production Report" (2003).

Source: Modified from U.S. DOE/EIA (2005c), http://www.eia.doe.gov/cneaf/nuclear/page/reserves/uresmine.html

Figure 2.9. Status of Mines, ISL Operations, and Mills in the U.S. as of November 2005

This figure shows the locations and operating status of uranium operations in the U.S. as of the end of 2005. An increase in the price and demand for uranium resulted in the re-opening of some conventional uranium mines and ISL operations, and decisions to re-start some sites which were undergoing closure.



Source: U.S. EPA.