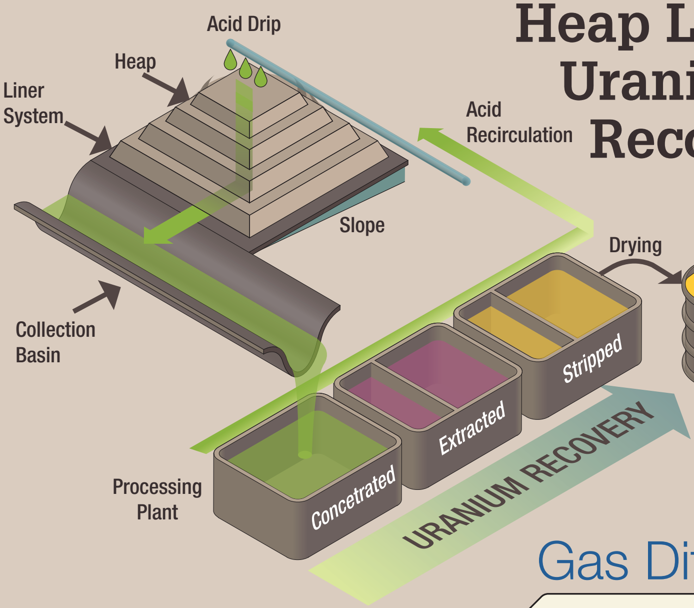
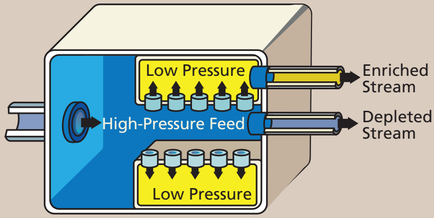
Nuclear Materials

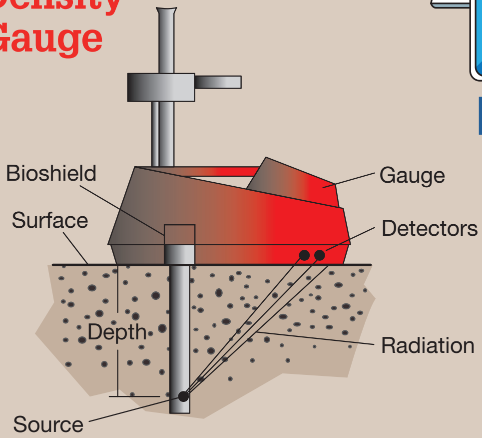
Heap Leach Uranium Recovery



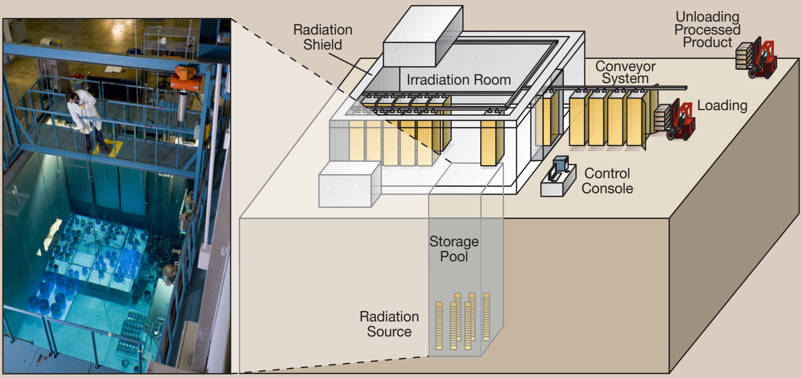
Gas Diffusion Process



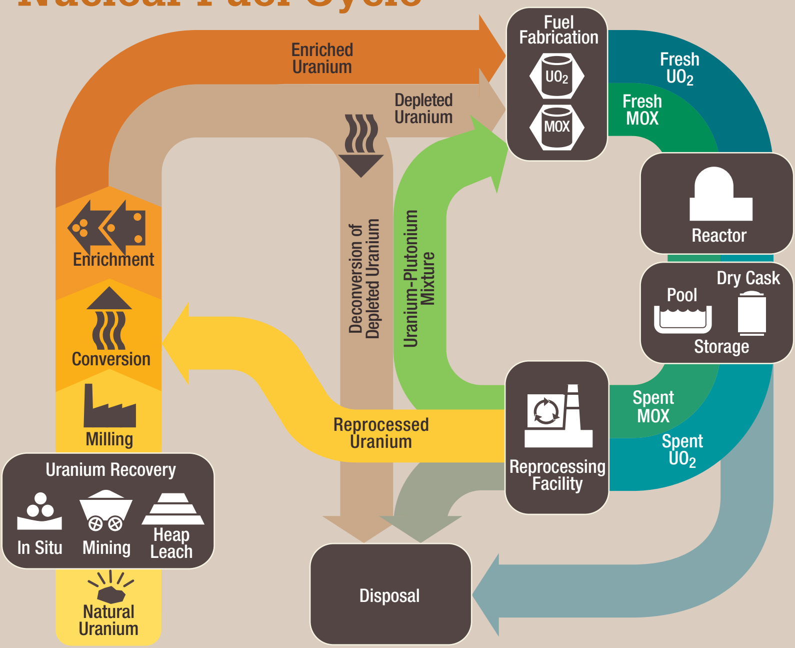
Moisture Density Gauge



Commercial Irradiator



Nuclear Fuel Cycle



The NRC regulates nuclear materials for use in medical, industrial, and academic applications. It also regulates the phases of the nuclear fuel cycle, which begins with the uranium recovery, conversion, enrichment, and fabrication facilities that produce nuclear fuel for power plants.

Materials Licenses

Through agreements with the NRC, many States have assumed regulatory authority over radioactive materials, with the exception of nuclear reactors, fuel facilities, and certain quantities of special nuclear material. These States are called Agreement States. The NRC and Agreement State regulatory programs are designed to ensure that licensees use these materials safely and do not endanger public health and safety or cause damage to the environment.

See Appendix K for Agreement States

The NRC and Agreement States have issued approximately 21,800 licenses for general use of nuclear materials (see Table 2):

- The NRC administers approximately 2,900 licenses.
- 37 Agreement States administer approximately 18,900 licenses.

Reactor- and accelerator-produced radionuclides are used extensively throughout the United States for civilian and military industrial applications; basic and applied research; manufacture of consumer products; academic studies; and medical diagnosis, treatment, and research.

Medical and Academic

In both medical and academic settings, the NRC reviews the facilities, personnel, program controls, and equipment to ensure the safety of the public, patients, and workers who might be exposed to radiation.

Medical

The NRC and Agreement States issue licenses to hospitals and physicians for the use of radioactive materials in medical treatments. In addition, the NRC develops guidance and regulations for use by licensees and maintains a committee of medical experts to obtain advice about the use of radioactive materials in medicine.

Table 2. U.S. Materials Licenses by State

State	Number of Licenses: NRC	Number of Licenses: Agreement States
Alabama	18	439
Alaska	64	0
Arizona	12	366
Arkansas	5	213
California	57	1,852
Colorado	20	356
Connecticut	180	0
Delaware	52	0
District of Columbia	42	0
Florida	22	1,720
Georgia	17	520
Hawaii	60	0
Idaho	74	0
Illinois	32	711
Indiana	283	0
Iowa	3	170
Kansas	11	286
Kentucky	9	431
Louisiana	11	519
Maine	2	125
Maryland	84	598
Massachusetts	25	500
Michigan	501	0
Minnesota	12	177
Mississippi	6	331
Missouri	282	0
Montana	89	0
Nebraska	5	148
Nevada	3	237
New Hampshire	8	82
New Jersey	39	638
New Mexico	14	198
New York	22	1,403
North Carolina	17	760
North Dakota	8	83
Ohio	40	629
Oklahoma	17	233
Oregon	5	335
Pennsylvania	53	745
Rhode Island	1	49
South Carolina	15	414
South Dakota	41	0
Tennessee	22	589
Texas	49	1,665
Utah	10	197
Vermont	34	0
Virginia	59	426
Washington	15	405
West Virginia	176	0
Wisconsin	14	321
Wyoming	84	0
Others*	162	0
Total	2,886	18,871

Agreement State

* Others include major U.S. territories.

Note: The NRC and Agreement State data is as of June 2012. The NRC licenses Federal agencies in Agreement States.

Photo courtesy: Nordion

Gamma Knife® used for treating brain tumors.

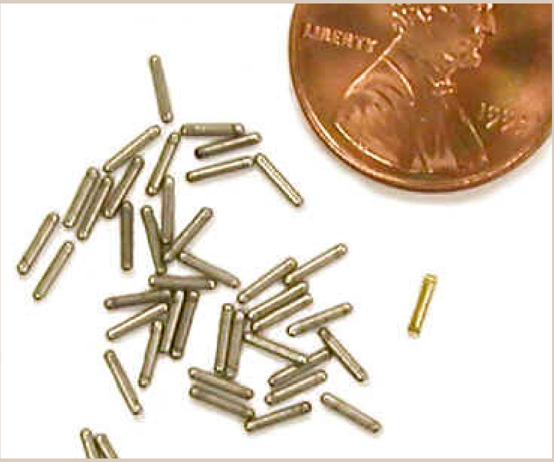


Photo courtesy: Oak Ridge Associated Universities

Iodine-125 and palladium-103 used in implantable seeds are primarily used to treat prostate cancer.

The NRC regulations require that physicians and physicists have special training and experience to practice radiation medicine. The training emphasizes safe operation of nuclear-related equipment and accurate recordkeeping. The Advisory Committee on the Medical Uses of Isotopes is comprised of physicians, scientists, and other health care professionals who advise the NRC staff on initiatives in the medical uses of radioactive materials.

Nuclear Medicine

About one-third of all patients admitted to hospitals are diagnosed or treated using radioactive materials. This branch of medicine is known as nuclear medicine, and the radioactive materials for treatment are called radiopharmaceuticals. Doctors of nuclear medicine use radiopharmaceuticals to diagnose patients through in vivo tests (direct administration of radiopharmaceuticals to patients) or in vitro tests (the addition of radioactive materials to lab samples taken from patients). Doctors also use radiopharmaceuticals and radiation-producing devices to treat conditions such as hyperthyroidism and certain forms of cancer and to ease pain caused by bone cancer. In the past decade, the use of nuclear medicine for treatment and diagnoses has increased significantly.

Diagnostic Procedures

For most diagnostic procedures in nuclear medicine, a small amount of radioactive material is administered, either by injection, inhalation, or by mouth. The radiopharmaceutical collects in the organ or area being evaluated, where it emits photons. These photons can be detected by a device known as a gamma camera, which produces images that provide information about the organ function and composition.

Radiation Therapy

The primary objective of radiation therapy is to deliver an accurately prescribed dose of radiation to the target site while minimizing the radiation dose to surrounding healthy tissue. Radiation therapy can be used to treat cancer or to relieve symptoms associated with certain diseases. Treatments often involve multiple exposures spaced over a period of time for maximum therapeutic effect. When used to treat malignant diseases, radiation therapy is often delivered in combination with surgery or chemotherapy.

There are three main categories of radiation therapy:

1. External beam therapy (also called teletherapy) is a beam of radiation directed to the target tissue. There are several different categories of external beam therapy units. The type of treatment machine that is regulated by the NRC contains a high-activity radioactive source (usually cobalt-60) that emits photons to treat the target site.
2. In brachytherapy treatments, sealed radioactive sources are permanently or temporarily placed near or on a body surface, in a body cavity, directly on a surface within a cavity, or directly on the cancerous tissue. The radiation dose is delivered at a distance of up to an inch (a few centimeters) from the target area.
3. Therapeutic radiopharmaceuticals are quantities of unsealed radioactive materials that localize in a specific region or organ system to deliver a large radiation dose.

Academic

The NRC issues licenses to academic institutions for educational and research purposes. For example, qualified instructors use radioactive materials in classroom demonstrations. Scientists in a wide variety of disciplines use radioactive materials for laboratory research.

Industrial

The NRC and Agreement States license users of radioactive material for the specific type, quantity, and location of material that may be used. Radionuclides are used in industrial and commercial applications, including industrial radiography, gauges, well logging, and manufacturing. For example, radiography uses radiation sources to find structural defects in metallic materials and welds. Gas chromatography uses low-energy radiation sources for identifying the chemical elements in an unknown substance. Gas chromatography can determine the components of complex mixtures, such as petroleum products, smog, and cigarette smoke, and can be used in biological and medical research to identify the components of complex proteins and enzymes. Well-logging devices use a radioactive source and detection equipment to make a record of geological formations down a bore hole. This process is used extensively for oil, gas, coal, and mineral exploration.

Nuclear Gauges

Nuclear gauges are used as nondestructive devices to measure the physical properties of products and industrial processes as a part of quality control. Gauges use radiation sources to determine the thickness of paper products, fluid levels in oil and chemical tanks, and the moisture and density of soils and material at construction sites. There are fixed and portable gauges.

A fixed gauge consists of a radioactive source that is contained in a source holder. When the user opens the container's shutter, a controlled beam of radiation hits the material or product being processed or controlled. A detector mounted opposite the source measures the radiation passing through the product. The gauge readout or computer monitor shows the measurement. The material and process being monitored dictate the selection of the type, energy, and strength of radiation.

Fixed fluid gauges are installed on a pipe that is used by the beverage, food, plastics, and chemical industries to measure the densities, flow rates, levels, thicknesses, and weights of a wide variety of materials and surfaces.

Figure 30 shows a portable gauge configuration in which the gamma source is placed under the surface of the ground through a tube. Radiation is then transmitted directly to the detector on the bottom of the gauge, allowing accurate measurements of compaction. Industry uses such gauges to monitor the structural integrity of roads, buildings, and bridges and to explore for oil, gas, and minerals. Airport security uses nuclear gauges to detect explosives in luggage at airports.

A portable gauge is a radioactive source and detector mounted together in a portable shielded device. The device is placed on the object to be measured, and the source is either inserted into the object or the gauge relies on a reflection of radiation from the source to bounce back to the bottom of the gauge. The detector in the gauge measures the radiation either directly from the inserted source or from the reflected radiation.

The radiation measurement indicates the thickness, density, moisture content, or some other property that is displayed on a gauge readout or on a computer monitor. The top of the gauge has sufficient shielding to protect the operator while the source is exposed. When the measuring process is completed, the source is retracted or a shutter closes, minimizing exposure from the source.

Figure 30. Moisture Density Gauge

Direct Transmission

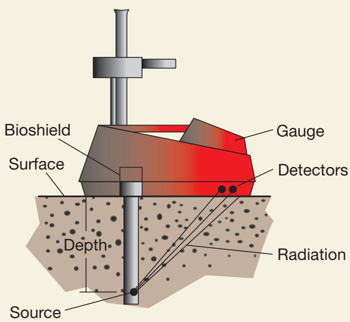
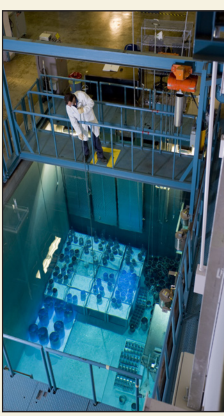


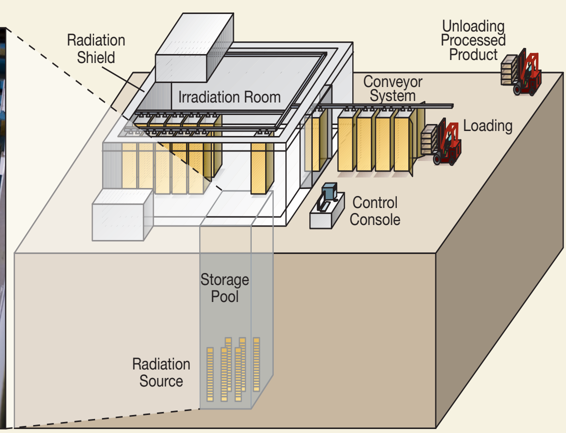
Photo courtesy: APNGA

A moisture density gauge indicates whether a foundation is suitable for constructing a building or roadway.

Figure 31. Commercial Irradiator

Photo courtesy: Nordion





Commercial Irradiators

Commercial irradiators expose products such as food, food containers, spices, medical supplies, and wood flooring to radiation to eliminate harmful bacteria, germs, and insects or for hardening or other purposes (see Figure 31). The gamma radiation does not leave any radioactive residue or cause any of the treated products to become radioactive themselves. The source of that radiation can be radioactive materials (e.g., cobalt-60), an x-ray tube, or an electron beam.

The NRC and Agreement States license approximately 50 commercial irradiators nationwide. For the past 40 years, the U.S. Food and Drug Administration and other agencies have approved the irradiation of meat and poultry, as well as other foods, including fresh fruits, vegetables, and spices. The amount of radioactive material in the devices can range from 1 curie to 10 million curies. NRC regulations protect workers and the public from radiation involved in irradiation operations. Generally, two types of commercial irradiators are in operation in the United States: underwater and wet-source-storage panoramic models.

In the case of underwater irradiators, the sealed sources (radioactive material encased inside a capsule) that provide the radiation remain in the water at all times, providing shielding for workers and the public. The product to be irradiated is placed in a watertight container, lowered into the pool, irradiated, and then removed.

With wet-source-storage panoramic irradiators, the radioactive sealed sources are also stored in the water, but they are raised into the air to irradiate products that are automatically moved in and out of the room on a conveyor system. Sources are then lowered back to the bottom of the pool. For this type of irradiator, thick concrete walls or steel barriers protect workers and the public when the sources are lifted from the pool.

Transportation

About 3 million packages of radioactive materials are shipped each year in the United States, either by road, rail, air, or water. This represents less than 1 percent of the Nation's yearly hazardous material shipments. Regulating the safety of commercial radioactive material shipments is the joint responsibility of the NRC and the U.S. Department of Transportation (DOT). The vast majority of these shipments consist of small amounts of radioactive materials used in industry, research, and medicine. The NRC requires such materials to be shipped in accordance with DOT's hazardous materials transportation safety regulations.

Material Security

In January 2009, the NRC deployed its National Source Tracking System (NSTS), by which the agency and the Agreement States track the manufacture, distribution, and ownership of the most high-risk sources. Licensees use the NSTS, a secure Web-based system, to enter up-to-date information on the receipt or transfer of tracked radioactive sources (see Figure 32). Over the past several years, the NRC and the Agreement States have increased the controls they have imposed on the most sensitive radioactive materials, including physical security requirements and limited personnel access to the materials. Working with other Federal agencies, such as DHS and the National Nuclear Security Administration, the NRC has also implemented a voluntary program of additional security improvements. Together, these activities help make potentially dangerous radioactive sources even more secure and less vulnerable to terrorists.

Principal Licensing and Inspection Activities

Each year, the NRC issues approximately 2,900 new licenses, license renewals, or amendments for existing material licenses. The NRC conducts approximately 1,250 health and safety and security inspections of its nuclear materials licensees each year.

Nuclear Fuel Cycle

Figure 33 illustrates the nuclear fuel cycle, which begins with the uranium recovery and continues with conversion, enrichment, and fabrication facilities that produce nuclear fuel for power plants. To make fuel for reactors, uranium is recovered or extracted from the ore, converted, enriched, and yellowcake is manufactured into fuel pellets.

Uranium Recovery

The NRC does not regulate traditional mining, but it does regulate the processing of uranium ore. It has jurisdiction over uranium recovery facilities such as conventional mills, heap leach facilities, and in situ recovery (ISR) facilities. The NRC has a well-established regulatory framework for ensuring that uranium recovery facilities are appropriately licensed, operated, decommissioned, and monitored to protect public health and safety.

Conventional Uranium Mill

A conventional uranium mill is a chemical plant that extracts uranium from mined ore. Conventional mills are typically located in areas of low population density, within about 50 kilometers (30 miles) of a uranium mine.

Figure 32. Life-Cycle Approach to Source Security

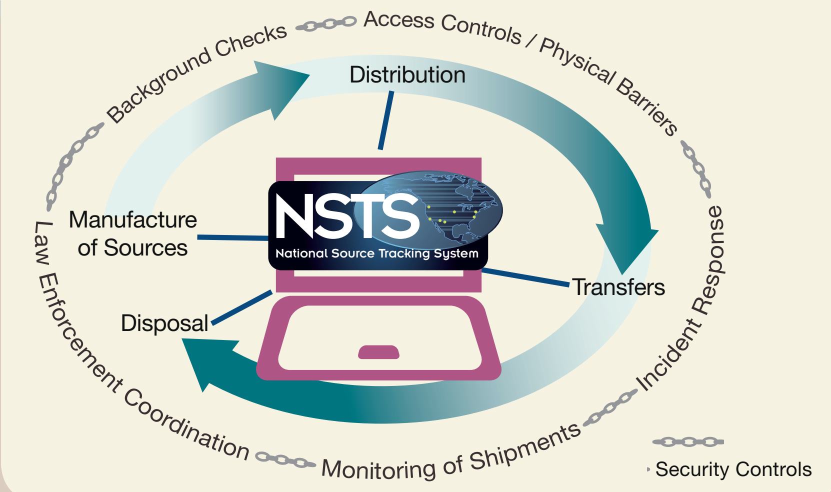
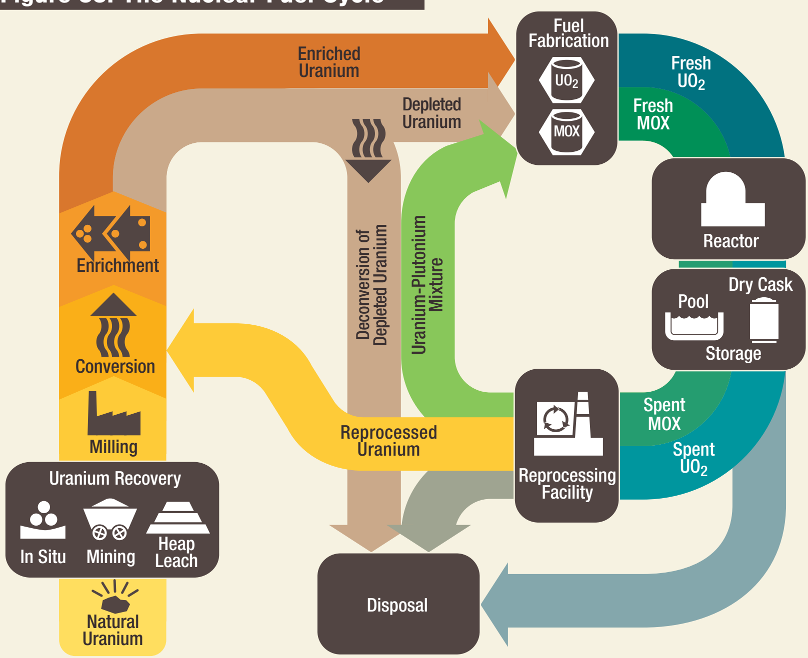


Figure 33. The Nuclear Fuel Cycle



The mined ore is transported to the mill, where it is crushed. Sulfuric acid then dissolves the soluble components, including 90 to 95 percent of the uranium, from the ore. The uranium is then separated from the solution, concentrated, and dried to form yellowcake. There are 18 uranium recovery sites licensed by the NRC—11 are conventional mills and seven are ISR facilities. Of these, 10 are in various stages of decommissioning and one is in standby status with the potential to restart in the future.

Heap Leach Facility

Heap leach facilities are used to extract uranium. Uranium ore is transported to the site and placed in piles or heaps. These heaps are lined to prevent uranium and other chemicals from migrating into the subsurface. Sulfuric acid is dripped onto the heap, which dissolves uranium as it migrates through the ore. Uranium solution collects at the bottom of the heap and drains to collection basins, where it is piped to the processing plant. At the plant, uranium is concentrated, extracted, stripped, and dried to form yellowcake (see Figure 34). The NRC does not currently license any heap leach facilities; however, applications for such facilities are expected within the next few years.

In Situ Recovery

ISR is another means of extracting uranium—this time from underground ore. ISR facilities recover uranium from ores for which recovery may not be economically viable by other methods. In this process, a solution of native ground water typically mixed with oxygen or hydrogen peroxide and sodium bicarbonate or carbon dioxide is injected through wells into the ore to dissolve the uranium. The resulting solution is pumped from the rock formation, and the uranium is then separated from the solution to form yellowcake (see Figure 35). The United States has about 14 ISR facilities. Of these facilities, the NRC licenses seven and Agreement States license the rest (see Figure 36 and Table 3).

Because of the resurgence of interest in the construction of new nuclear power plants, the agency anticipates as many as 28 applications for new uranium recovery facilities and expansions or restarts of existing facilities in the next few years.

As of April 2012, the agency had received six applications for new facilities and six applications to expand or restart an existing facility. One new facility and one expansion application have been withdrawn; however, these applications may be resubmitted in the future.

Figure 34. The Heap Leach Recovery Process

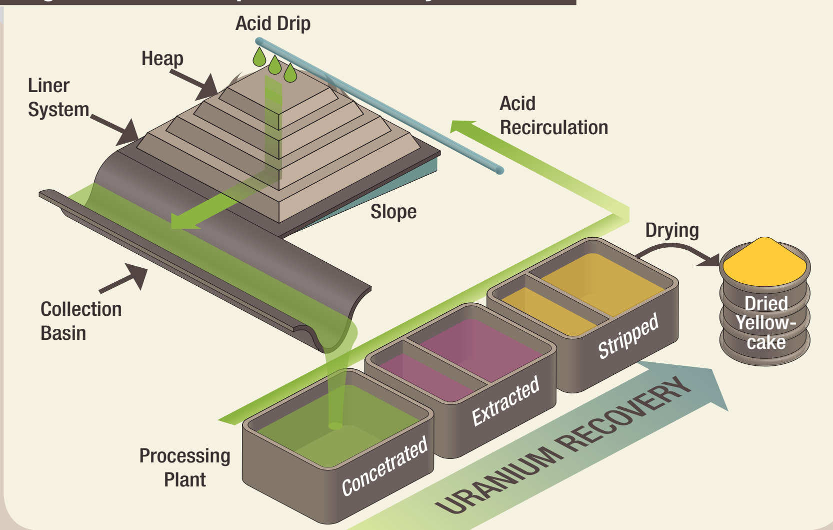
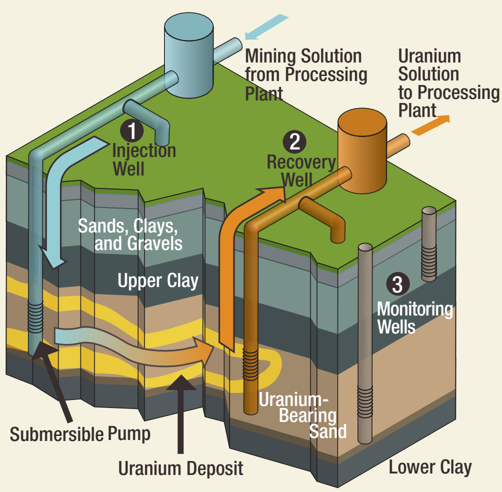
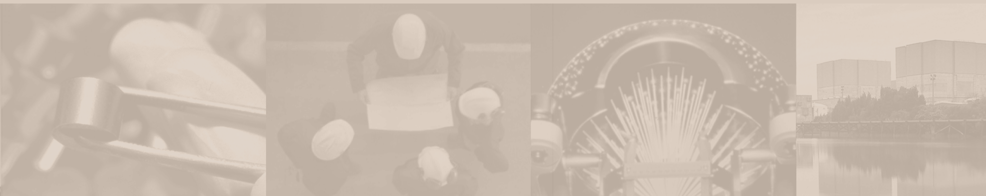


Figure 35. The In Situ Uranium Recovery Process



Injection wells (1) pump a chemical solution—typically groundwater mixed with sodium bicarbonate, hydrogen peroxide, and oxygen—into the layer of earth containing uranium ore. The solution dissolves the uranium from the deposit in the ground and is then pumped back to the surface through recovery wells (2) and sent to the processing plant to be processed into uranium yellowcake. Monitoring wells (3) are checked regularly to ensure that uranium and chemicals are not escaping from the drilling area.



The current status of applications can be found on the NRC's Web site (see the Web Link Index). Existing facilities and new potential sites are located in Wyoming, New Mexico, Nebraska, South Dakota, Oregon, and Nevada, and in the Agreement States of Texas, Colorado, and Utah (see Figure 37). The NRC works closely with stakeholders, including Native American Tribal governments, to address concerns with the licensing of new uranium recovery facilities. The NRC is also responsible for the following:

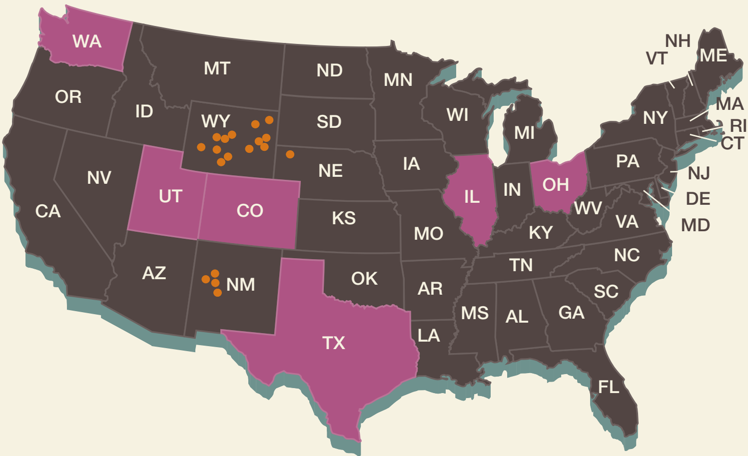
See Appendix M for Major U.S. Fuel Cycle Facility Sites

- inspecting and overseeing both active and inactive uranium recovery facilities;
- ensuring that siting and design features of mill tailings (waste) minimize the release of radon and the disturbance of tailings by natural forces (see Glossary);
- developing requirements to ensure cleanup of active and formerly active uranium recovery facilities;
- formulating stringent financial requirements to ensure funds are available for decommissioning;
- monitoring adherence to requirements for below-grade disposal of mill tailings and liners for tailings impoundments;
- monitoring to prevent ground water contamination; and
- long-term monitoring and oversight of decommissioned facilities.

Fuel Cycle Facilities

The NRC licenses and routinely conducts safety, safeguards, and environmental protection inspections at all commercial fuel cycle facilities involved in conversion, enrichment, and fuel fabrication (see Figures 37–39). These special fuel facilities use a process that turns uranium from the ground into fuel for nuclear reactors. This process converts uranium yellowcake into uranium hexafluoride (UF_6), enriches the uranium in the isotope uranium-235, and fabricates ceramic fuel pellets. Fabrication is the final step in the process used to produce uranium fuel. Fabrication begins with the conversion of enriched UF_6 gas to a uranium dioxide (UO_2) solid. On average, the NRC completes approximately 85 new licenses, license renewals, license amendments, and safety and safeguards reviews for fuel cycle facilities annually. Fuel fabrication facilities mechanically and chemically process the enriched uranium into nuclear reactor fuel.

Figure 36. Locations of NRC-Licensed Uranium Recovery Facility Sites



- States with authority to license uranium recovery facility sites
- States where the NRC has retained authority to license uranium recovery facilities
- NRC-licensed uranium recovery facility sites (18)

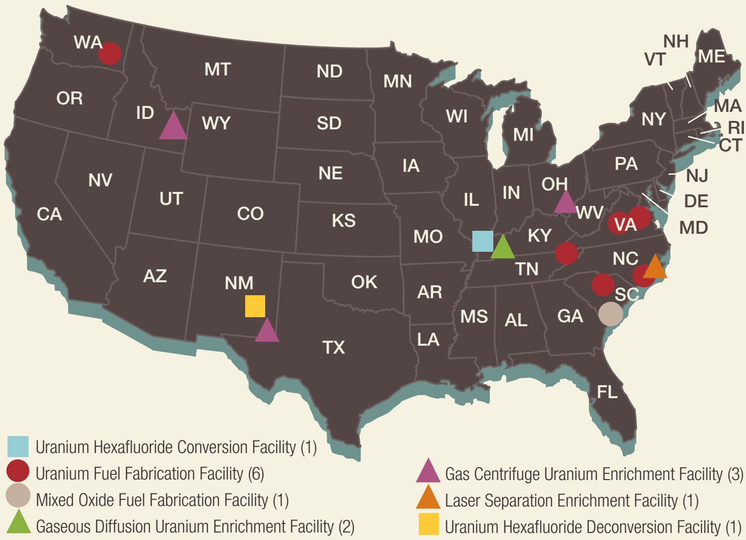
Table 3. Locations of NRC-Licensed Uranium Recovery Facilities

Licensee	Site Name, Location
In Situ Recovery Facilities	
Uranium One	Willow Creek, WY
Cameco Resources, Inc.	Crow Butte, NE*
Hydro Resources, Inc.°	Crownpoint, NM
Cameco Resources, Inc.	Smith Ranch and Highlands, WY*
Uranium One	Moore Ranch, WY
Lost Creek ISR, Inc.	Lost Creek, WY
Uranerz Energy Corp.	Nichols Ranch, WY
Conventional Uranium Mill Recovery Facilities	
American Nuclear Corp.†	Gas Hills, WY
Bear Creek Uranium Co.†	Bear Creek, WY
Exxon Mobil Corp.†	Highlands, WY
Homestake Mining Co.†	Homestake, NM
Kennecott Uranium Corp.°	Sweetwater, WY
Pathfinder Mines Corp.†	Lucky Mc, WY
Pathfinder Mines Corp.†	Shirley Basin, WY
Rio Algom Mining, LLC†	Ambrosia Lake, NM
Umetco Minerals Corp.†	Gas Hills, WY
United Nuclear Corp.†	Church Rock, NM
Western Nuclear, Inc.†	Split Rock, WY

Note: For further details on NRC-related uranium recovery facility applications in review and applications, restarts, and expansions, see the Web Link Index. This table does not include uranium recovery facilities licensed by Agreement States.

* Satellite facilities are located within the State.
† These sites are undergoing decommissioning.
° Hydro has an operating license, but the facility has not yet been constructed. Kennecott has an operating license but is in "standby" mode.

Figure 37. Locations of Fuel Cycle Facilities



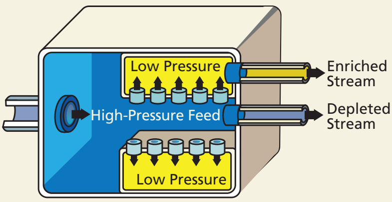
Note: There are no fuel cycle facilities in Alaska or Hawaii.

Photo courtesy: Louisiana Energy Services

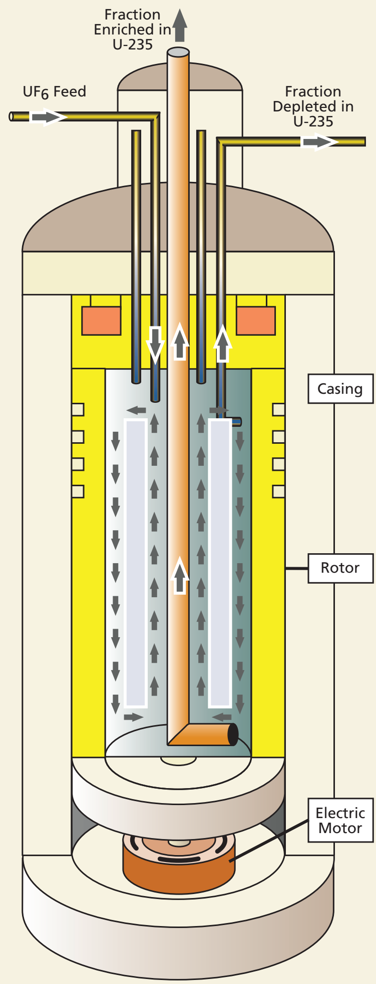
URENCO USA gas centrifuge uranium enrichment facility in Eunice, NM.

Figure 38. Enrichment Processes

A. Gaseous Diffusion Process



B. Gas Centrifuge Process



A. *The gaseous diffusion process uses molecular diffusion to separate a gas from a two-gas mixture. The isotopic separation is accomplished by diffusing uranium, which has been combined with fluorine to form* UF_6 *gas, through a porous membrane (barrier) and using the different molecular velocities of the two isotopes to achieve separation.*

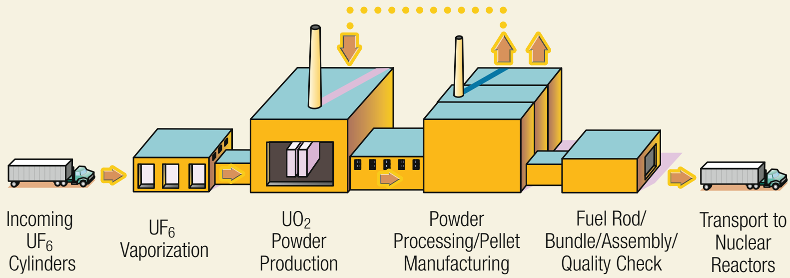
B. *The gas centrifuge process uses a large number of rotating cylinders in series and parallel configurations. Gas is introduced and rotated at high speed, concentrating the component of higher molecular weight toward the outer wall of the cylinder and the component of lower molecular weight toward the center. The enriched and the depleted gases are removed by scoops.*

Nuclear fuel is made to maintain both its chemical and physical properties under the extreme conditions of heat and radiation present inside an operating reactor vessel. After the UF_6 is chemically converted to UO_2, the powder is blended, milled, pressed, and fused into ceramic fuel pellets about the size of a fingertip. The pellets are stacked into tubes about 14 feet (2.6 meters) long made of material called “cladding” (such as zirconium alloys). After careful inspection, the resulting fuel rods are bundled into fuel assemblies for use in reactors. The assemblies are washed, inspected, and stored in a special rack until ready for shipment to a nuclear power plant site. The NRC inspects this operation to ensure it is conducted safely.

Domestic Safeguards Program

The NRC’s domestic safeguards program for fuel cycle facilities and transportation is aimed at ensuring that special nuclear material (such as plutonium or enriched uranium) is not stolen for possible malevolent uses. The program also works to ensure that such material does not pose an unreasonable risk to the public from sabotage or terrorism. The NRC verifies through licensing and inspection activities that licensees apply safeguards to protect special nuclear material. Additionally, the NRC and DOE developed the Nuclear Materials Management and Safeguards System (NMMSS) to track transfers and inventories of special nuclear material, source material from abroad, and other material. The NRC has issued licenses to approximately 180 facilities authorizing them to possess special nuclear material in quantities ranging from a single kilogram to multiple tons. These licensees verify and document their inventories in the NMMSS database. The NRC or State governments license several hundred additional sites that possess special nuclear material in smaller quantities (typically ranging from 1 gram to tens of grams). Licensees that possess small amounts of special nuclear material are now required to confirm their inventory annually in the NMMSS database. Previously, those licensees reported transfers of material but not annual inventories.

Figure 39. Simplified Fuel Fabrication Process

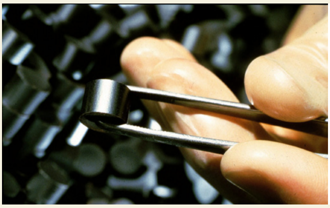


Fabrication of commercial light-water reactor fuel consists of the following three basic steps:

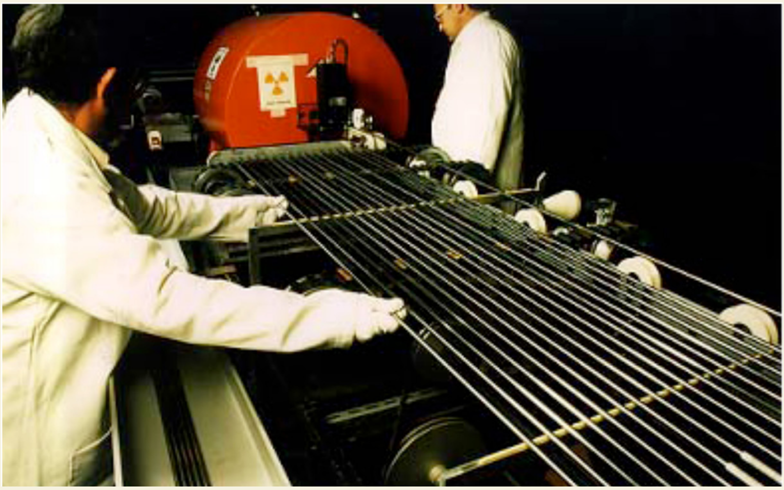
(1) the chemical conversion of UF_6 to UO_2 powder

(2) a ceramic process that converts UO_2 powder to small ceramic pellets

(3) a mechanical process that loads the fuel pellets into rods and constructs finished fuel assemblies



Small ceramic fuel pellets.



Fuel pellets being assembled into fuel rods.