4

Nuclear Materials

The NRC regulates each phase of the nuclear fuel cycle—the steps needed to turn uranium ore into fuel for nuclear power plants, as well as storing and disposing of the fuel after it is used in a reactor. In some States, the NRC also regulates nuclear materials used for medical, industrial, and academic purposes.

Materials Licenses

See Appendix L for a list of the number of materials licenses by State.

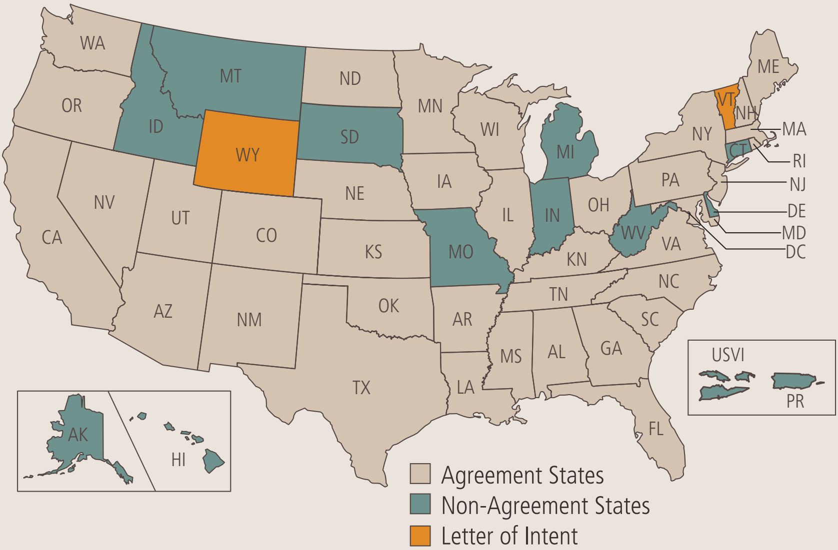
States have the option to regulate certain radioactive materials themselves under agreements with the NRC. Thirty-seven States, called Agreement States, have taken on this responsibility (see Figure 27: Agreement States). These States developed regulations and appointed officials to ensure nuclear materials are used safely and securely. Agreement States must adopt rules consistent with the NRC's. Only the NRC regulates nuclear reactors, fuel fabrication facilities, consumer product distribution, and certain amounts of what is called "special nuclear material"—that is, radioactive material that can fission or split apart.

The NRC and Agreement States administered about 20,800 licenses to use nuclear materials:

- the NRC administers approximately 2,800 licenses.
- 37 Agreement States administer approximately 18,000 licenses.

Radioactive materials, or radionuclides, are used for many purposes. They can be produced in a reactor or an accelerator—a machine that propels charged particles.

Figure 27. Agreement States



The NRC does not regulate accelerators but does license the use of radioactive materials produced in accelerators. Radionuclides are used in civilian and military industrial applications; basic and applied research; manufacture of consumer products; academic studies; and medical diagnosis, treatment, and research.

Medical and Academic

The NRC and Agreement States review the facilities, personnel, program controls, and equipment involved in using radioactive materials in medical and academic settings. These reviews ensure the safety of the public, patients, and workers who might be exposed to radiation from those materials. The NRC regulates only the use of radioactive material, which is why the NRC does not regulate x-ray machines or other devices that produce radiation without using radioactive materials.

Medical

The NRC and Agreement States license hospitals and physicians to use radioactive materials in medical treatments. The NRC also develops guidance and regulations for licensees. These regulations require licensees to have experience and special training, focusing on operating equipment safely, controlling the radioactive material, and keeping accurate records.

To help the NRC stay current, the agency sponsors an Advisory Committee on the Medical Uses of Isotopes. This expert committee includes scientists, physicians, and other health care professionals.

Nuclear Medicine

Doctors use radioactive materials to diagnose or treat about one-third of all patients admitted to hospitals. This branch of medicine is known as nuclear medicine, and the radioactive materials are called radiopharmaceuticals.

Two types of radiopharmaceutical tests can diagnose medical problems. In vivo tests (“within the living”) administer radiopharmaceuticals directly to patients. In vitro tests (“within the glass”) add radioactive materials to lab samples taken from patients.

Radiation Therapy

Doctors also use nuclear materials and radiation-producing devices to treat medical conditions. They can treat hyperthyroidism and some cancers, for example, and can also ease the pain caused by bone cancer.

Radiation therapy aims to deliver an accurate radiation dose to a target site while protecting surrounding healthy tissue. To be most effective, treatments often require several exposures over a period of time. When used to treat malignant cancers, radiation therapy is often combined with surgery or chemotherapy.

Photo courtesy: Sirtex

Samples from two manufacturers of Y-90 SIR-Spheres® (left) TheraSphere® (below)

Vial containing millions of yttrium-90 (Y-90) microspheres used to treat liver cancers

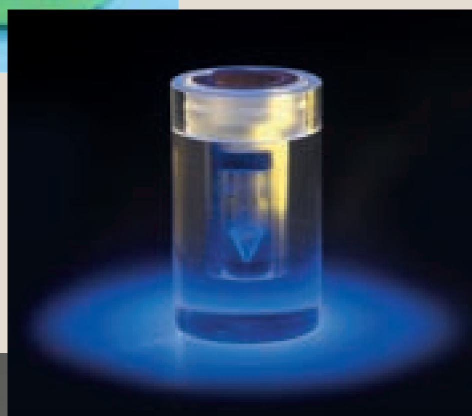


Photo courtesy: Nordion

Photo courtesy: Biodex

A shielding and syringe holder (left) is used to protect medical workers as they load a syringe from a bulk vial of a radiopharmaceutical containing fluorine-18 (F-18). The F-18 produces gamma rays, which show up in a PET Scan, allowing the radiologist to see internal organs and the blood flowing to and from them.

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. Several different types of machines are used in external beam therapy. Treatment machines regulated by the NRC contain high-activity radioactive sources (usually cobalt-60) that emit photons to treat the target site.
2. Brachytherapy treatments use sealed radioactive sources placed near or even directly in cancerous tissue. The radiation dose is delivered at a distance of up to an inch (up to 2.54 centimeters) from the target area.
3. Therapeutic radiopharmaceuticals deliver a large radiation dose inside the body. Different radioactive materials can be given to patients and will concentrate in different regions or organ systems.

Academic

The NRC issues licenses to academic institutions for education and research. For example, qualified instructors may use radioactive materials in classroom demonstrations. Scientists in many disciplines use radioactive materials for laboratory research.

Industrial

The NRC and Agreement States issue licenses that specify the type, quantity, and location of radioactive materials to be used. Radionuclides can be used in industrial radiography, gauges, well logging, and manufacturing. Radiography uses radiation sources to find structural defects in metal and welds. Gas chromatography uses low-energy radiation sources to identify the chemical elements in an unknown substance. This process can determine the components of complex mixtures, such as petroleum products, smog, and cigarette smoke. (It can also be used in biological and medical research to identify the parts that make up complex proteins and enzymes.) Well-logging devices use radioactive sources and detection equipment to make a record of geological formations from inside a well. This process is used extensively for oil, gas, coal, and mineral exploration.

Nuclear Gauges

Nuclear gauges are used to measure the physical properties of products and industrial processes nondestructively 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. Gauges may be fixed or portable.

See Glossary for illustrations of fixed and portable gauges.

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

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 shielding to protect the operator while the radioactive source is exposed. When the measuring process is completed, the source is retracted or a shutter closes, minimizing exposure from the source.

A fixed gauge has a radioactive source shielded in a container. When the user opens the container's shutter, a 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 type, energy, and strength of radiation used.

Fixed fluid gauges are used by the beverage, food, plastics, and chemical industries. Installed on a pipe or the side of a tank, these gauges measure the densities, flow rates, levels, thicknesses, and weights of a variety of materials and surfaces.

A portable gauge uses both a shielded radioactive source and a detector. The gauge is placed on the object to be measured. Some gauges rely on radiation from the source to reflect back to the bottom of the gauge. Other gauges insert the source into the object. The detector in the gauge measures the radiation either directly from the inserted source or from the reflected radiation.

The moisture density gauge, shown above, is a portable gauge that places a gamma source under the surface of the ground through a tube. Radiation is 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. Airport security uses nuclear gauges to detect explosives in luggage.

Commercial Irradiators

The U.S. Food and Drug Administration and other agencies have approved the irradiation of food. Commercial irradiators expose food and spices, as well as products such as medical supplies and wood flooring, to gamma radiation. This process can be used to eliminate harmful bacteria, germs, and insects or for hardening or other purposes. The gamma radiation does not leave radioactive residue or make the treated products radioactive. The radiation can come from radioactive materials (e.g., cobalt-60), an x-ray tube, or an electron beam.

See Glossary for information and illustration of commercial irradiators.

The NRC and Agreement States license about 50 commercial irradiators. Up to 10 million curies of radioactive material can be used in these types of irradiators. NRC regulations protect workers and the public from this radiation. Two main types of commercial irradiators are used in the United States: underwater and wet-source-storage panoramic models.

Underwater irradiators use sealed sources (radioactive material encased inside a capsule) that 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.

Wet-source-storage panoramic irradiators also store radioactive sealed sources in water. But the sources 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 into the pool. For this type of irradiator, thick concrete walls and ceilings or steel barriers protect workers and the public when the sources are lifted from the pool.

Transportation

More than 3 million packages of radioactive materials are shipped each year in the United States by road, rail, air, or water. This represents less than 1 percent of the Nation's yearly hazardous material shipments. The NRC and the U.S. Department of Transportation (DOT) share responsibility for regulating the safety of radioactive material shipments. 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 safety regulations.

Material Security

To monitor the manufacture, distribution, and ownership of the most high-risk sources, the NRC set up a National Source Tracking System (NSTS) in January 2009. Licensees use this secure Web-based system to enter information on the receipt or transfer of tracked radioactive sources (see Figure 28: Life-Cycle Approach to Source Security). The NRC and the Agreement States use the system to monitor where high-risk sources are made, shipped, and used.

The NSTS tracks more than 80,000 sources held by about 1,400 NRC and Agreement State licensees. Of those sources, about 46 percent are Category 1 sources and 54 percent are Category 2. The majority are cobalt-60, the most widely used isotope in large sources.

See Glossary for definitions of the categories of radioactive sources.

The NRC and the Agreement States have increased controls on the most sensitive radioactive materials. Stronger physical-security requirements and stricter limits on who can access the materials give the NRC and the Agreement States added confidence in their security. The NRC has also joined with other Federal agencies, such as the U.S. Department of Homeland Security and DOE's National Nuclear Security Administration, to set up an additional layer of voluntary protection. Together, these activities help make potentially dangerous radioactive sources even more secure and less vulnerable to malevolent uses.

Major Licensing and Inspection Activities

Each year, the NRC issues about 1,800 new licenses, renewals, or amendments for existing materials licenses. The NRC conducts around 900 health, safety, and security inspections of materials licensees each year.

Nuclear Fuel Cycle

Figure 29: The Nuclear Fuel Cycle, illustrates the nuclear fuel cycle, including uranium recovery, conversion, enrichment, and fabrication to produce fuel for nuclear power plants. Uranium is recovered or extracted from ore, converted, and enriched. Then the enriched uranium is manufactured into pellets. These pellets are placed into fuel assemblies to power nuclear reactors.

Figure 28. Life-Cycle Approach to Source Security

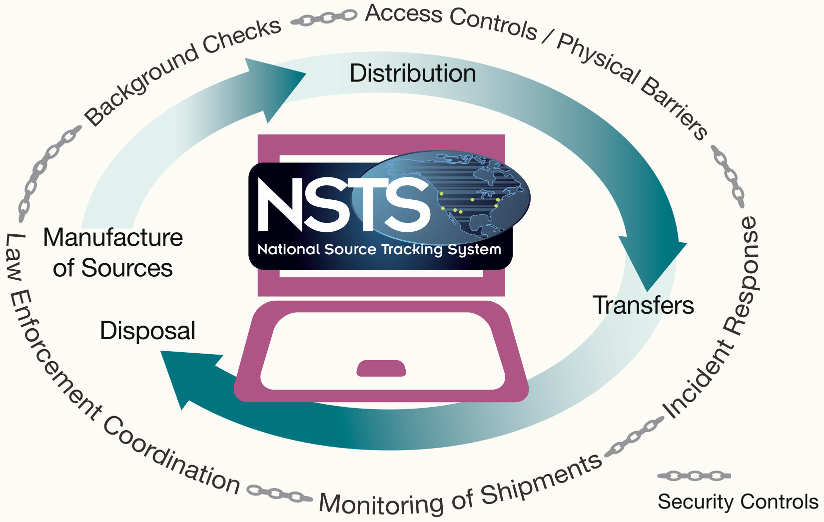
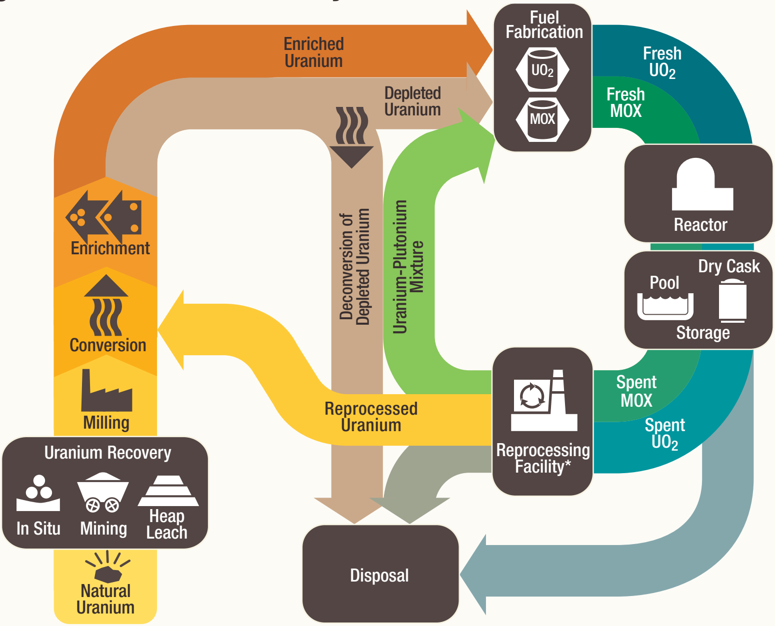


Figure 29. The Nuclear Fuel Cycle



* Reprocessing of spent nuclear fuel, including mixed-oxide (MOX) fuel is not practiced in the United States.
Note: The NRC has no regulatory role in mining uranium.

Uranium Recovery

The NRC does not regulate conventional mining but does regulate the processing of uranium ore, known as milling. This processing can be done at three types of uranium recovery facilities: conventional mills, in situ recovery (ISR) facilities, and heap leach facilities. The NRC has a well-established regulatory framework for uranium recovery facilities. This framework ensures they are licensed, operated, decommissioned, and monitored to protect the public and the environment.

Conventional Uranium Mill

A conventional uranium mill is a chemical plant that extracts uranium from ore. Most conventional mills are located away from population centers and within about 30 miles (50 kilometers) of a uranium mine.

In a conventional mill, the process of uranium extraction from ore begins when ore is hauled to the mill and crushed. Sulfuric acid dissolves and removes 90 to 95 percent of the uranium from the ore. The uranium is then separated from the solution, concentrated, and dried to form yellowcake.

In Situ Recovery

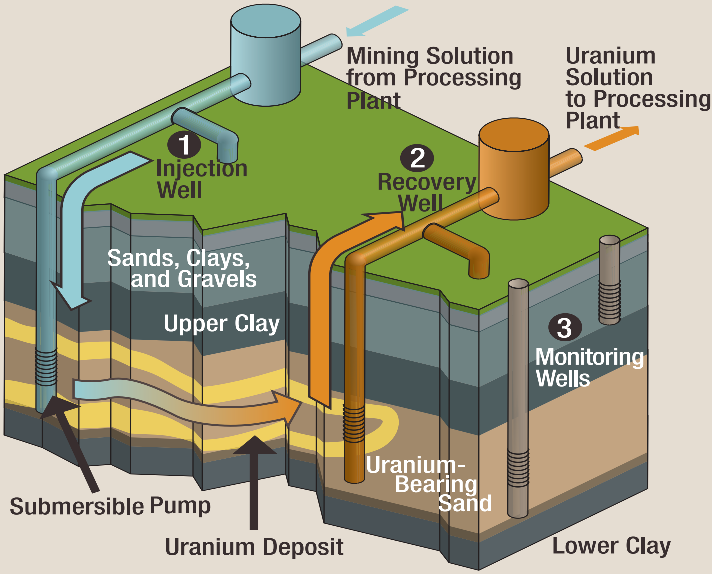
There are 21 uranium recovery sites licensed by the NRC—12 are conventional mills and nine are ISR facilities. Of these 21 facilities, 11 are in various stages of decommissioning and one is in standby status with the potential to restart in the future.

ISR is another way to extract uranium—in this case, directly from underground ore. In situ facilities recover uranium from ores that cannot be processed economically using 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 into the ore to dissolve the uranium. The solution is then pumped out of the rock and the uranium separated to form yellowcake (see Figure 30: The In Situ Uranium Recovery Process). The United States has 17 ISR facilities. Of these facilities, the NRC licenses nine and Agreement States license the rest.

Heap Leach Facility

Heap leach facilities also extract uranium from ore. At these facilities, the ore is placed in piles or heaps on top of liners. The liners prevent uranium and other chemicals from moving into the ground. Sulfuric acid is dripped onto the heap and dissolves uranium as it moves through the ore.

Figure 30. The In Situ Uranium Recovery Process



Injection wells (1) pump a chemical solution—typically ground water 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.

In situ recovery mining is an extraction method of obtaining uranium ore, in Crow Butte, NB.

Uranium solution drains into collection basins, where it is piped to a processing plant. At the plant, uranium is extracted, concentrated, and dried to form yellowcake. The NRC has no licensed heap leach facilities.

See Glossary for definition and illustration of heap leach recovery process.

Uranium Recovery Facilities

The NRC expects as many as 12 applications to build new uranium recovery facilities and to expand or restart existing facilities in the next few years. As of April 2015, the agency had received seven applications for new facilities and eight applications to expand or restart an existing facility.

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, and Oregon, and in the Agreement States of Texas, Colorado, and Utah (see Figure 31: Locations of NRC-Licensed Uranium Recovery Facility Sites, and Table 1: Locations of NRC-Licensed Uranium Recovery Facilities).

The NRC works closely with stakeholders, including Native American Tribal governments, to address their concerns with licensing new uranium recovery facilities. The NRC is also responsible for the following actions:

- inspecting and overseeing both active and inactive uranium recovery facilities
- ensuring the safe management of mill tailings (waste) at facilities required by the NRC to be located and designed to minimize radon release and disturbance by weather or seismic activity
- enforcing requirements to ensure cleanup of active and closed uranium recovery facilities
- applying stringent financial requirements to ensure funds are available for decommissioning
- making sure licensees follow requirements for underground disposal of mill tailings and provide liners for tailings impoundments
- monitoring to prevent ground water contamination
- monitoring and overseeing decommissioned facilities

See Glossary for more information on mill tailings.

Figure 31. Locations of NRC-Licensed Uranium Recovery Facility Sites

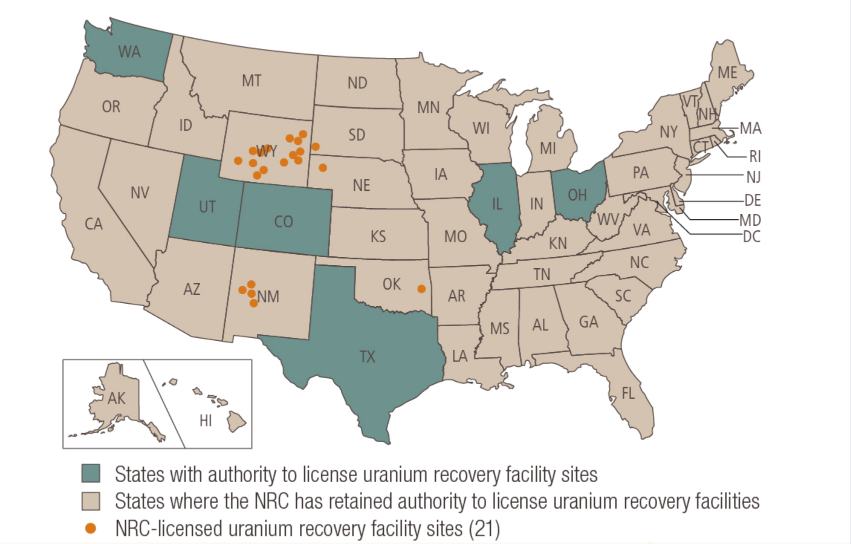


Table 1. Locations of NRC-Licensed Uranium Recovery Facilities

Licensee	Site Name, Location
In Situ Recovery Facilities	
Cameco Resources, Inc.	Crow Butte, NE*
Cameco Resources, Inc.	Smith Ranch and Highland, WY*
Hydro Resources, Inc.°	Crownpoint, NM
Lost Creek ISR, Inc.	Lost Creek, WY
Powertech USA	Dewey Burdock, SD
Strata Energy	Ross, WY
Uranerz Energy Corp.	Nichols Ranch, WY
Uranium One	Moore Ranch, WY
Uranium One	Willow Creek, 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 Co.°	Sweetwater, WY
Pathfinder Mines Corp.†	Lucky Mc, WY
Pathfinder Mines Corp.†	Shirley Basin, WY
Rio Algom Mining, LLC†	Ambrosia Lake, NM
Sequoyah Fuels Corp.†	Gore, OK
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 Resources Inc. has an operating license, but the facility has not yet been constructed. Kennecott Uranium Company has an operating license but is in "standby" mode.

Fuel Cycle Facilities

The NRC licenses all commercial fuel cycle facilities involved in conversion, enrichment, and fuel fabrication (see Figure 32: Locations of Fuel Cycle Facilities, and Figure 33: Enrichment Process, and Figure 34: Simplified Fuel Fabrication Process).

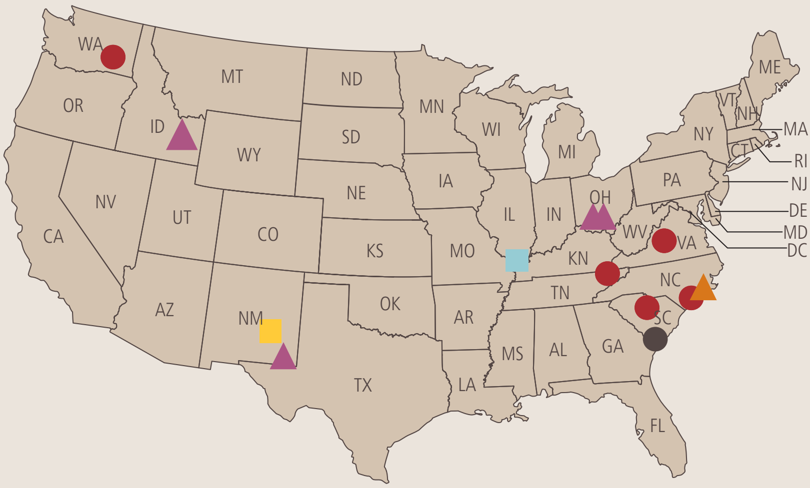
See Glossary for more information on enrichment processes

The NRC also routinely inspects their safety, safeguards, security, and environmental protection programs. On average, the NRC issues about 100 fuel cycle facility licensing actions per year, including amendments, renewals, new licenses, and safety and safeguards reviews.

These facilities turn the uranium that has been removed from ore (as yellowcake) into fuel for nuclear reactors. In this process, the conversion facility converts yellowcake into uranium hexafluoride (UF_6). Next, an enrichment facility heats the solid UF_6 enough to turn it into a gas, which is "enriched," or processed, to increase the concentration of the isotope uranium-235.

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

Figure 32. Locations of Fuel Cycle Facilities



Uranium Hexafluoride Conversion Facility (1)
Uranium Fuel Fabrication Facility (5)
Mixed-Oxide Fuel Fabrication Facility (1)
Gas Centrifuge Uranium Enrichment Facility (4)
Laser Separation Enrichment Facility (1)
Uranium Hexafluoride Deconversion Facility (1)

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

Figure 33. Enrichment Process

Gas Centrifuge Process

The gas centrifuge process uses many rotating cylinders that are connected in long lines. Gas is placed in the cylinder, which spins at a high speed, creating a strong centrifugal force. Heavier gas molecules move to the cylinder wall, while lighter molecules collect near the center. The stream, now slightly enriched, is fed into the next cylinder. The depleted stream is recycled back into the previous cylinder.

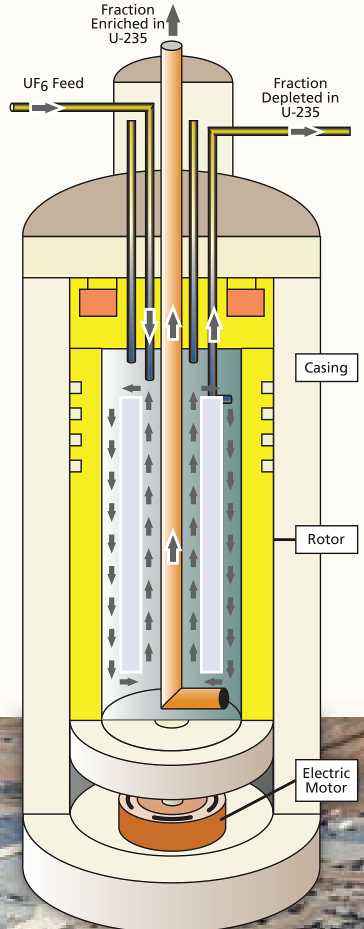
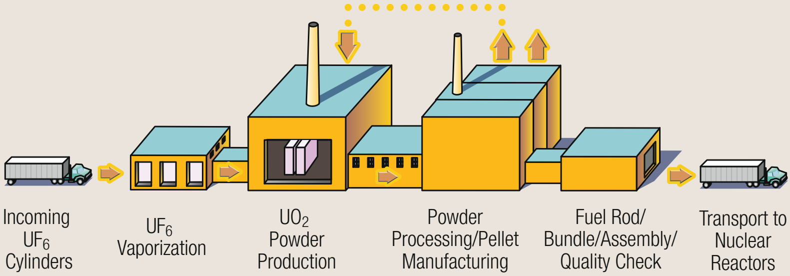


Photo courtesy: Louisiana Energy Services

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

Figure 34. 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

A worker displays a small ceramic fuel pellet.

The enriched uranium gas is mechanically and chemically processed back into a solid uranium dioxide (UO_2) powder. The powder is blended, milled, pressed, and fused into ceramic fuel pellets about the size of a fingertip. The pellets are stacked into tubes or rods that are about 14 feet (4.3 meters) long and made of material such as zirconium alloys; this material is referred to as cladding. These fuel rods are made to maintain both their chemical and physical properties under the extreme conditions of heat and radiation present inside an operating reactor.

After careful inspection, the 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. 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 and does not pose a risk to the public from sabotage or terrorism. Through licensing and inspections, the NRC verifies that licensees apply safeguards to protect special nuclear material.

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 authorizing some 180 facilities 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 Agreement States license several hundred additional sites that possess special nuclear material in smaller quantities. Licensees possessing small amounts of special nuclear material must confirm their inventory annually in the NMMSS database.

The Willow Creek Project site for in situ recovery is located in Wyoming.