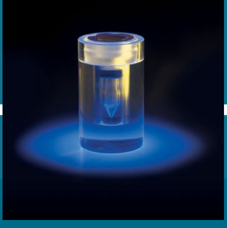
NUCLEAR MATERIALS



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. Work includes reviewing applications for and issuing new licenses, license renewals, and amendments to existing licenses. The NRC also regularly conducts health, safety, and security inspections.

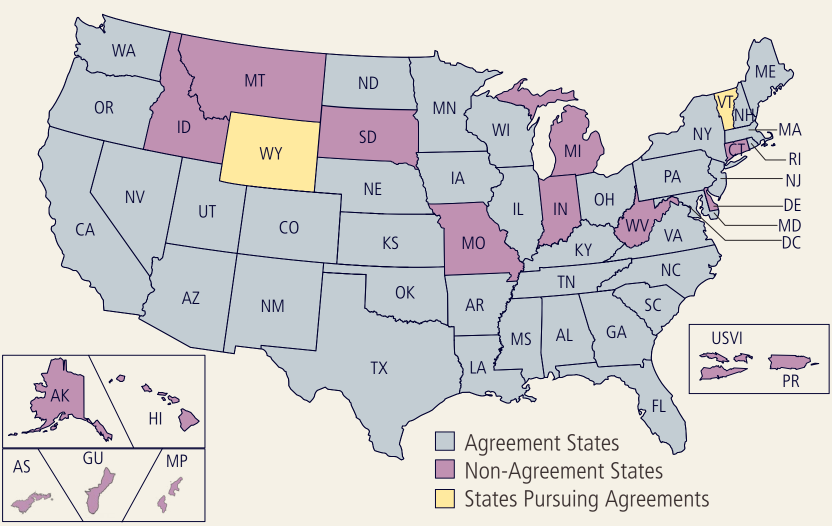
Materials Licenses

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

States have the option to regulate certain radioactive materials under agreements with the NRC. Those that do are called Agreement States (see Figure 25. Agreement States). These States develop regulations and appoint 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.

Radioactive materials, or radionuclides, are used for many purposes. They are used in civilian and military industrial applications; basic and applied research; the manufacture of consumer products; academic studies; and medical diagnosis, treatment, and research. They can be produced in a reactor or an accelerator—a machine that propels charged particles. The NRC does not regulate accelerators but does license the use of radioactive materials produced in accelerators.

Figure 25. Agreement States



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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 and diagnoses. 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 the Advisory Committee on the Medical Uses of Isotopes. This expert committee includes scientists, physicians, and other health care professionals who have experience with medical radionuclides.

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.

Photo courtesy: Sirtex

Photo courtesy: Nordion

Samples from two manufacturers of yttrium-90 (Y-90), SIR-Spheres® (left) andTheraSphere® (right). Vial containing millions of Y-90 microspheres used to treat liver cancers.

Radiation Therapy

Doctors also use radioactive 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.

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.

The 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 at right, 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.

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

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, blood, and wood flooring, to gamma radiation. This process can be used to eliminate harmful 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 illustrations 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. However, 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.

Truck carries transport package for research reactor fuel.

Material Security

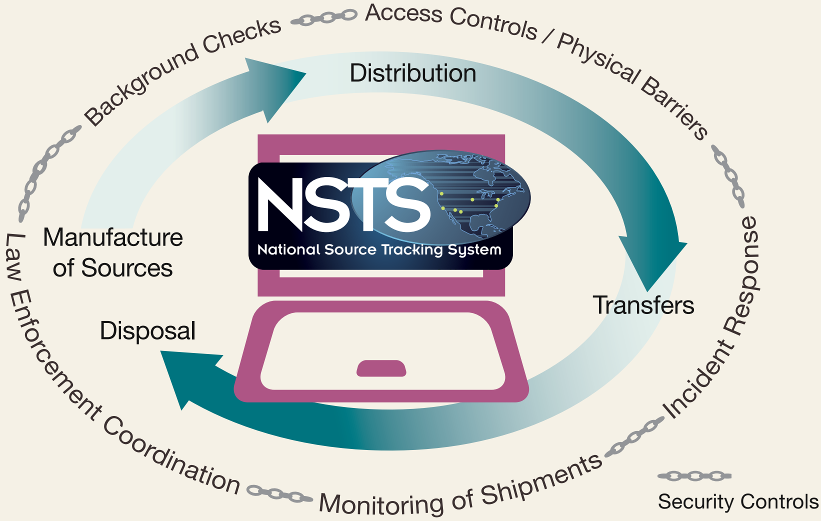
To monitor the manufacture, distribution, and ownership of the most high-risk sources, the NRC set up the National Source Tracking System (NSTS) in January 2009. Licensees use this secure Web-based system to enter information on the receipt or transfer of tracked radioactive sources (see Figure 26. Life-Cycle Approach to Source Security). The NRC and the Agreement States use the system to monitor where high-risk sources are made, shipped, and used.

Sources tracked in the system are known as Category 1 and Category 2 sources. They have the potential to cause permanent injury and even death if they are not handled safely and securely, in compliance with NRC requirements. The majority of these sources are cobalt-60.

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 (DHS) 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.

Figure 26. Life-Cycle Approach to Source Security



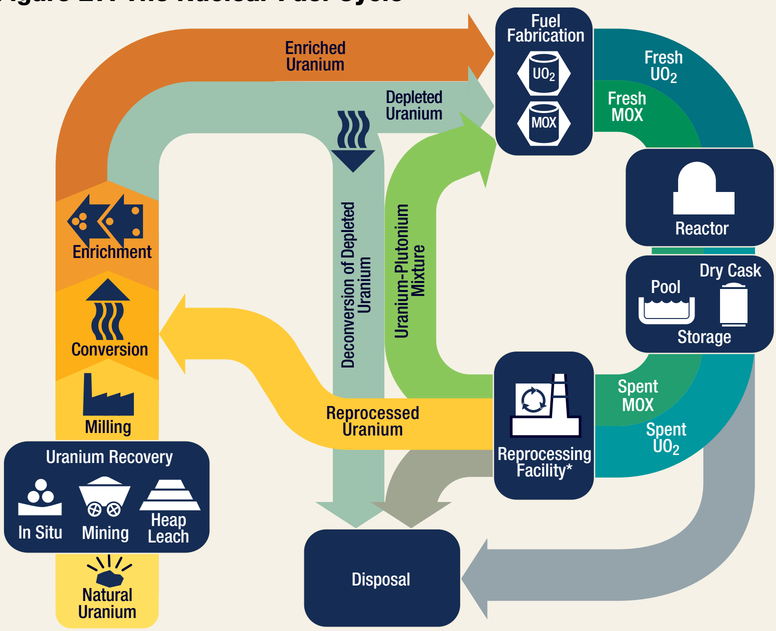
Nuclear Fuel Cycle

The typical nuclear fuel cycle uses uranium in different chemical and physical forms. Figure 27. The Nuclear Fuel Cycle illustrates the stages, which include 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.

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 facilities, and heap leach facilities. Once this processing is done, the uranium is in a powder form known as yellowcake, which is packed into 55-gallon (208-liter) drums and transported to a fuel cycle facility for further processing. The NRC has an established regulatory framework for uranium recovery facilities. This framework ensures they are licensed, operated, decommissioned, and monitored to protect the public and the environment.

Figure 27. 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.

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

In situ recovery 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 28. The In Situ Uranium Recovery Process).

Heap Leach Facility

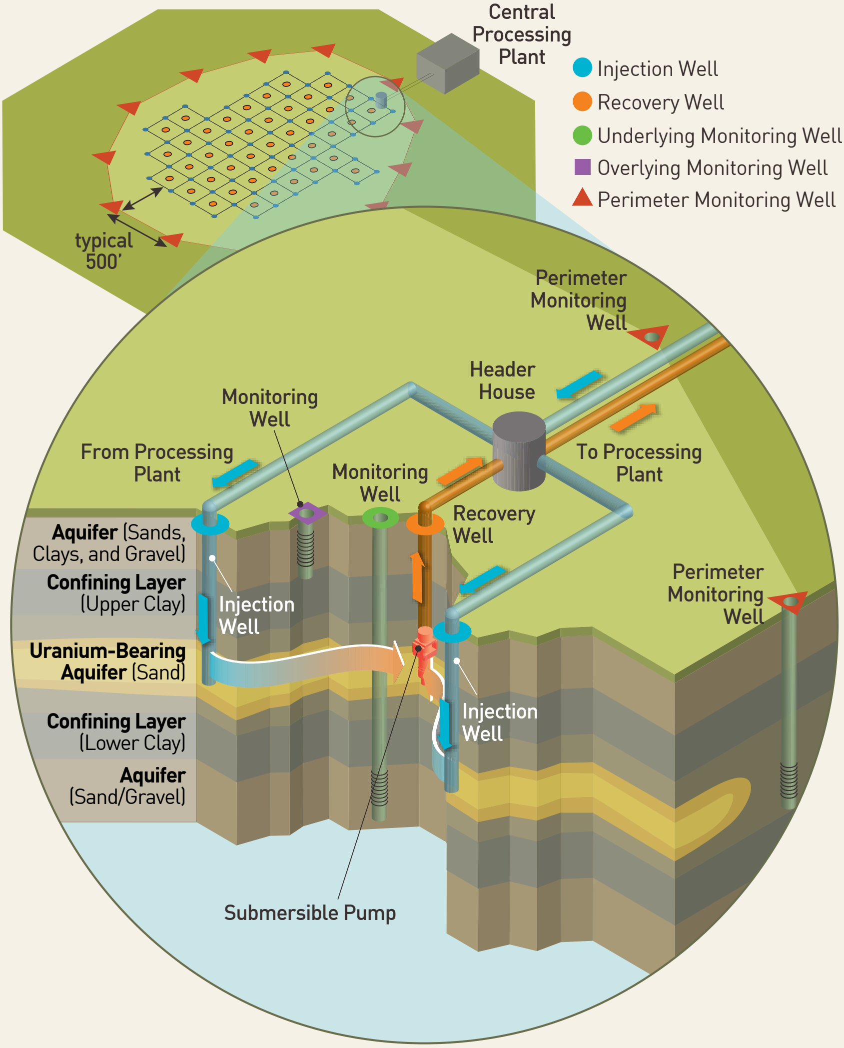
Heap leach facilities also extract uranium from ore. At these facilities, the ore is placed in piles or heaps on top of liners. The liners prevent uranium and other chemicals from moving into the ground. Sulfuric acid is dripped onto the heap and dissolves uranium as it moves through the ore. Uranium 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 does not currently license any heap leach facilities.

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

Licensing Uranium Recovery Facilities

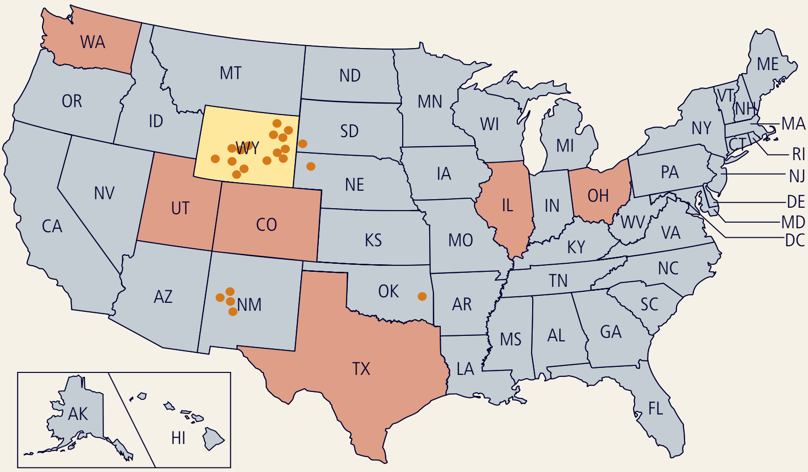
The NRC continues to receive applications to build new uranium recovery facilities and to expand or restart existing facilities. The current status of applications can be found on the NRC's Web site (see the Web Link Index). Existing facilities and new potential sites are located in Wyoming, New Mexico, Nebraska, South Dakota, and Oregon and in the Agreement States of Texas, Colorado, and Utah (see Figure 29. Locations of NRC-Licensed Uranium Recovery Facility Sites).

Figure 28. The In Situ Uranium Recovery Process



Injection wells ● pump a solution of native ground water, typically mixed with oxygen or hydrogen peroxide and sodium bicarbonate ore carbon dioxide into the aquifer (ground water) 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 ●, all controlled by the header house. From there, the solution is sent to the processing plant. Monitoring wells ● ■ ▲ are checked regularly to ensure the injection solution is not escaping from the wellfield. Confining layers keep ground water from moving from one aquifer to another.

Figure 29. 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
- Final Agreement State application received
- NRC-licensed uranium recovery facility sites (22)

Note: For the most recent information, go to the Dataset Index Web page at *https://www.nrc.gov/reading-rm/doc-collections/datasets/*.

The NRC takes into account the views of 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 that the NRC requires 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.

Fuel Cycle Facilities

The NRC licenses all commercial fuel cycle facilities involved in conversion, enrichment, and fuel fabrication (see Figure 30. Locations of NRC-Licensed Fuel Cycle Facilities, and Figure 31. Simplified Fuel Fabrication Process).

See Glossary for more information on enrichment processes.

The NRC reviews applications for licenses, license amendments, and renewals. The agency also routinely inspects licensees' safety, safeguards, security, and environmental protection programs.

These facilities turn the uranium that has been removed from ore and made into 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.

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.

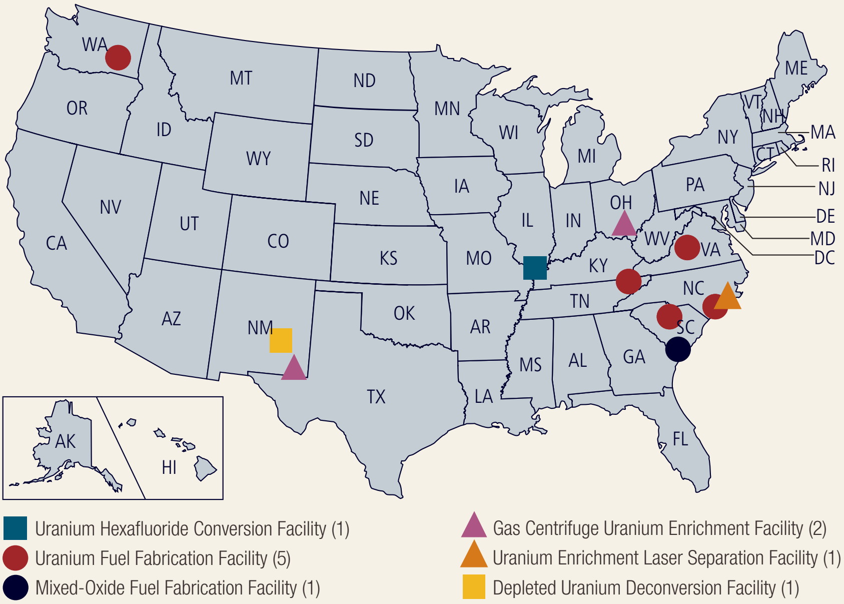
See Appendix M for major U.S. fuel cycle facility sites.

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.

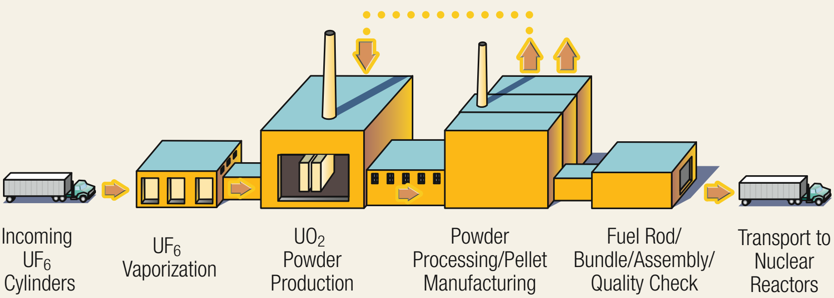
The NRC and DOE developed the Nuclear Materials Management and Safeguards System (NMMSS) to track transfers and inventories of special nuclear material, source material from abroad, and other material. The NRC has issued licenses authorizing facilities to possess special nuclear material in quantities ranging from a single pound to multiple tons. These licensees verify and document their inventories in the NMMSS database. The NRC and Agreement States have licensed 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.

Figure 30. Locations of NRC-Licensed Fuel Cycle Facilities



Note: There are no fuel cycle facilities in Alaska or Hawaii.
For the most recent information, go to the Dataset Index Web page at *https://www.nrc.gov/reading-rm/doc-collections/datasets/*.

Figure 31. 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