





3

NUCLEAR  
MATERIALS





# 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 it does not regulate x-ray machines or other devices that produce radiation without using radioactive materials.

## *Medical*

The NRC and Agreement States license hospitals, physicians, veterinarians, health physicists, and radiopharmacists 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 Advisory Committee on the Medical Uses of Isotopes advises the NRC staff on policy and technical issues that arise in the regulation of the medical uses of radioactive material in diagnosis and therapy. 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.

## *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:

- *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.*
- *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 (2.54 centimeters) from the target area.*
- *Therapeutic radiopharmaceuticals deliver a large radiation dose inside the body. A variety of radioactive materials can be given to patients and will concentrate in different regions or organ systems.*

## *Academic*

The NRC and the Agreement States issue 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. For example, gas chromatography devices are used to analyze air pollutants, blood alcohol content, essential oils, and food products. They are also 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 within 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 materials at construction sites. Gauges may be fixed or portable.

A 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 density, flow rate, level, thickness, 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 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 is a portable device 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, 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, or an electron beam.

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 when not in use. 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 the DOT's safety regulations.

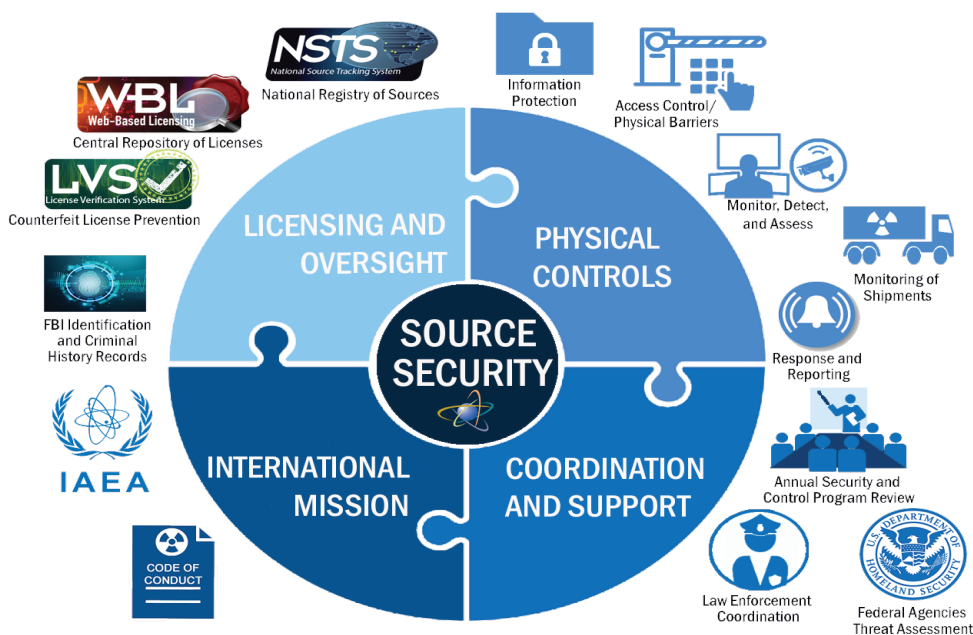
## MATERIALS SECURITY

To monitor the manufacture, distribution, and possession of the most high-risk sources, the NRC set up the National Source Tracking System in January 2009. 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.

Licensees use this secure web-based system to enter information on the receipt or transfer of tracked radioactive sources (see Figure 26. NRC 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 NRC and the Agreement States have increased controls on the most safety-significant 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 the 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.

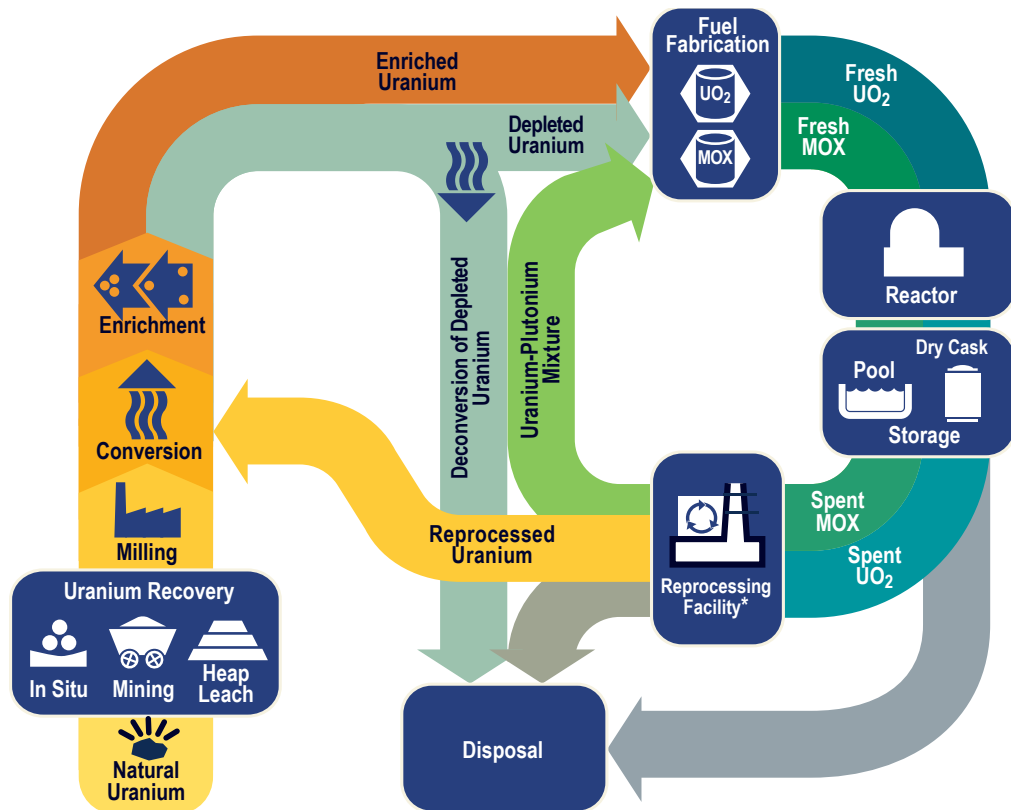
*Figure 26. NRC Approach to Source Security*



# 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 reactors. Uranium is recovered or extracted from ore, converted, and enriched. Then the enriched uranium is manufactured into pellets, which are placed into fuel assemblies to power nuclear reactors. Uranium is recovered or extracted from ore, converted, and enriched. Then the enriched uranium is manufactured into pellets, which are placed into fuel assemblies to power nuclear reactors.

*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.

## 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 the milling is completed, 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.

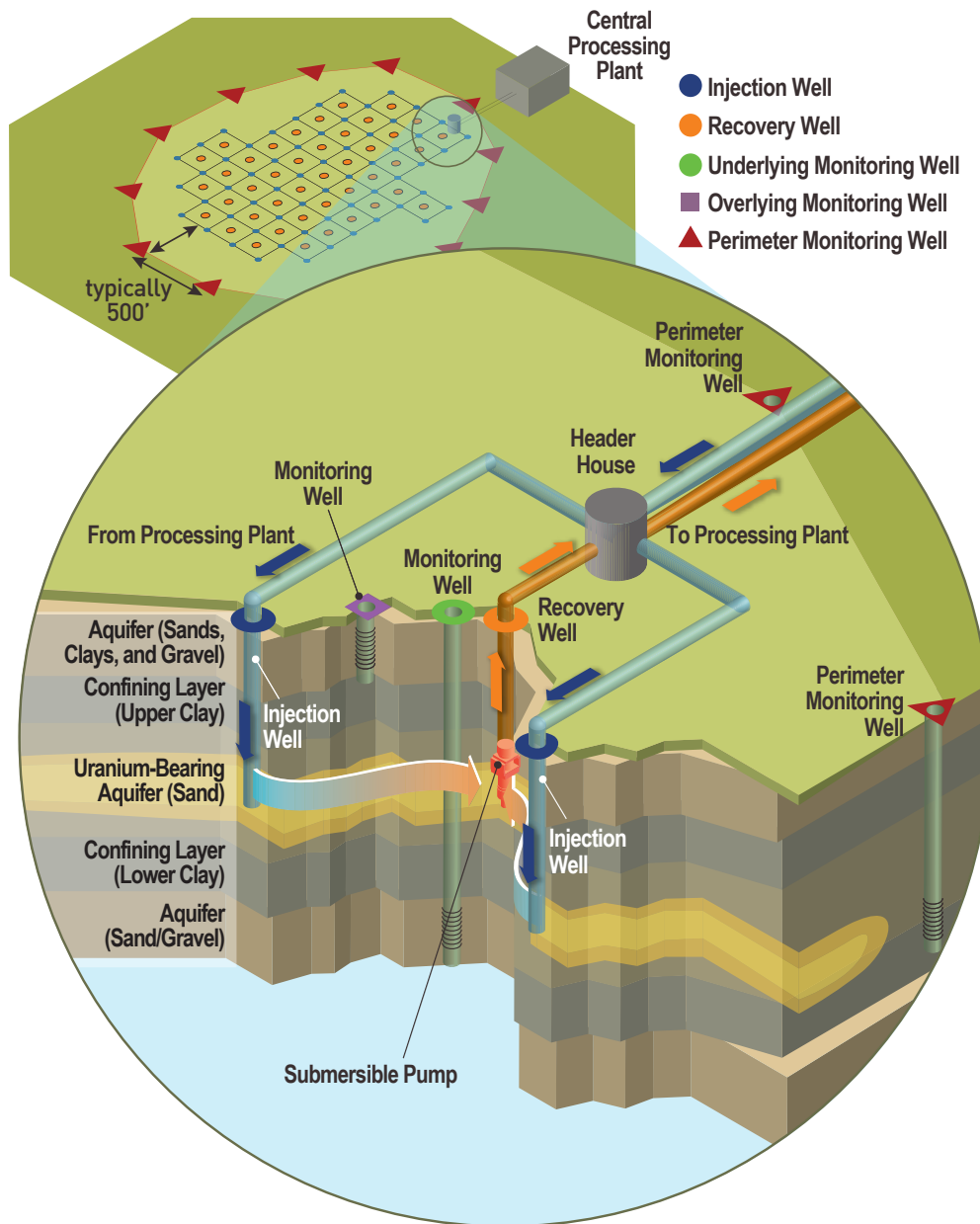
## Conventional Uranium Mill

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 this process, a solution of 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).

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 or 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.





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*
- *ensuring licensees monitor ground water for contamination*
- *providing oversight of decommissioned uranium recovery facilities*

## 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).

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  $UF_6$  gas is then cooled back into solid  $UF_6$  for shipment to a fuel fabrication facility.

Once at a fuel fabrication facility, the  $UF_6$  is mechanically and chemically processed back into a solid  $UO_2$  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.

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 these operations to ensure they are conducted safely.

### *Domestic Safeguards Program*

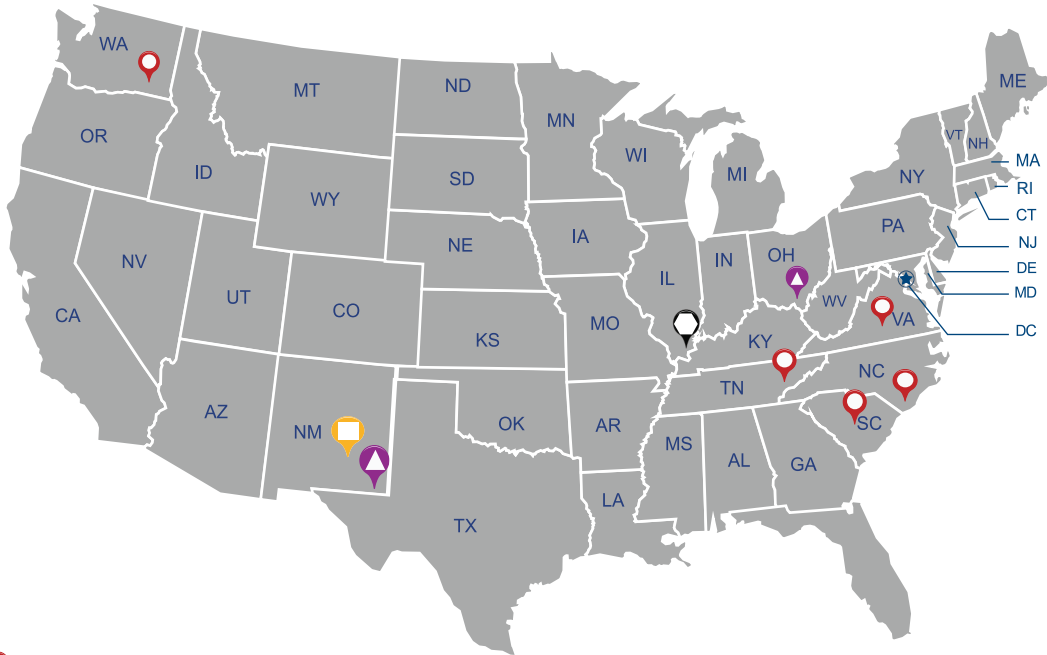
The NRC's domestic safeguards program for fuel cycle facilities and transportation is aimed at ensuring that special nuclear material (such as plutonium or enriched uranium) is not stolen and does not pose a risk to the public from sabotage or terrorism. Through licensing and inspections, the NRC verifies that licensees apply safeguards to protect special nuclear material.

The NRC and the 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. Material 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 inventories annually in the NMMSS database. **>>See Appendix K for major U.S. fuel cycle facility sites and go to the glossary on the NRC's website for a definition on the enrichment process.<<**



*Scan QR code for more to access  
the online NRC Glossary*

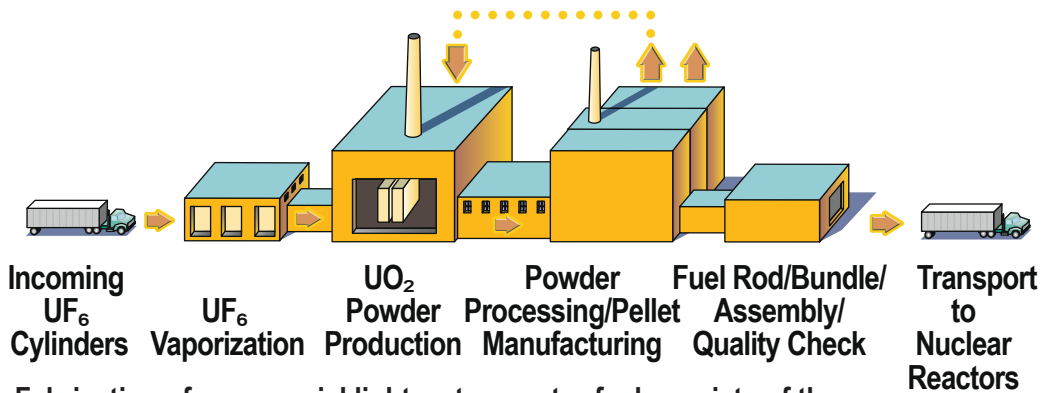
**Figure 30. Locations of NRC-Licensed Fuel Cycle Facilities**



-  Uranium Fuel Fabrication Facility (5)
-  Gas Centrifuge Uranium Enrichment Facility (2)
-  Depleted Uranium Deconversion Facility (1)
-  Uranium Hexafluoride Conversion Facility (1)

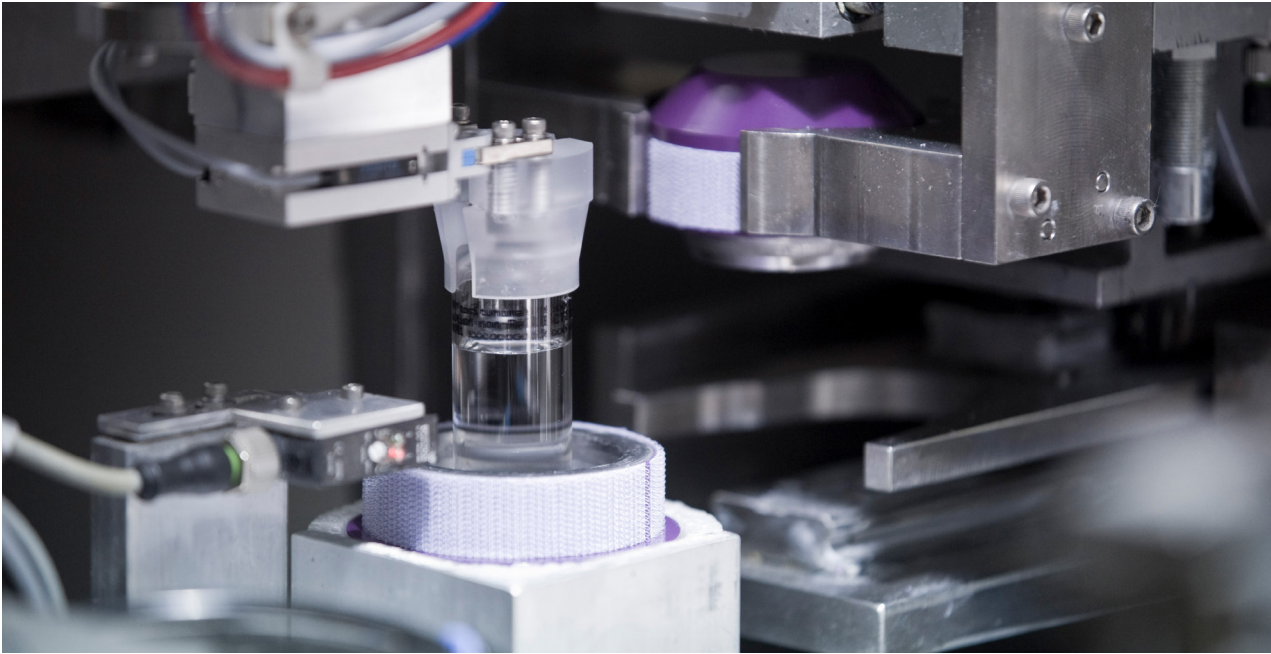
Note: Alaska and Hawaii are not pictured here and do not have sites. On September 30, 2022, the NRC issued a letter terminating the license for the GLE Laser Separation Enrichment Facility. For the most recent information, go to the NRC facility locator page at <https://www.nrc.gov/info-finder.html>.

**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<sub>6</sub> to UO<sub>2</sub> powder
2. a ceramic process that converts UO<sub>2</sub> powder to small ceramic pellets
3. a mechanical process that loads the fuel pellets into rods and constructs finished fuel assemblies



*A Bexxar Automated-Inspection unit placing a vial containing radiopharmaceutical into a lead pot. Photo courtesy of the Noridan Corporation.*



*A moisture density gauge indicates whether a foundation is suitable for constructing a building or roadway. Photo courtesy of the American Portable Nuclear Gauge Association.*