U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

Regulating Nuclear Fuel

Cover Photos:

Top: Inspecting fuel pellets.

Middle top: Inspecting a bracket for a fuel assembly.

Middle Bottom: Barrell of uranium-oxide powder.

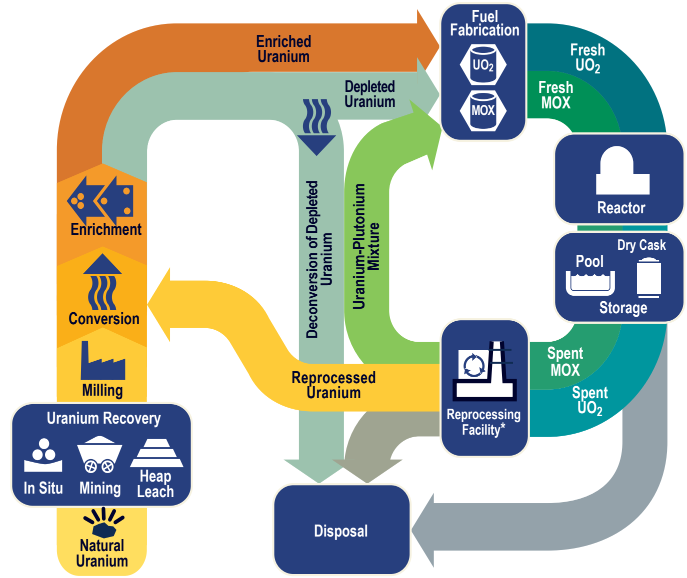
Bottom: A close up view of the HALEU cascade centrifuges
Photo courtesy of Centrus Energy Corp.

REGULATING NUCLEAR FUEL

The nuclear fuel cycle is the process of removing uranium from the ground, converting it into nuclear fuel for use in commercial power reactors, and managing its storage and ultimate disposal as waste.

The U.S. Nuclear Regulatory Commission (NRC), an independent Federal agency, is responsible for setting regulatory safety standards and for oversight of much of the fuel cycle. This booklet focuses on the NRC's responsibilities in the early part of the fuel cycle—from the processing of uranium through fabrication of fuel for use in a nuclear power plant.

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 nuclear fuel cycle begins when uranium is removed from the ground and its form is altered. This typically is done using one of two methods:

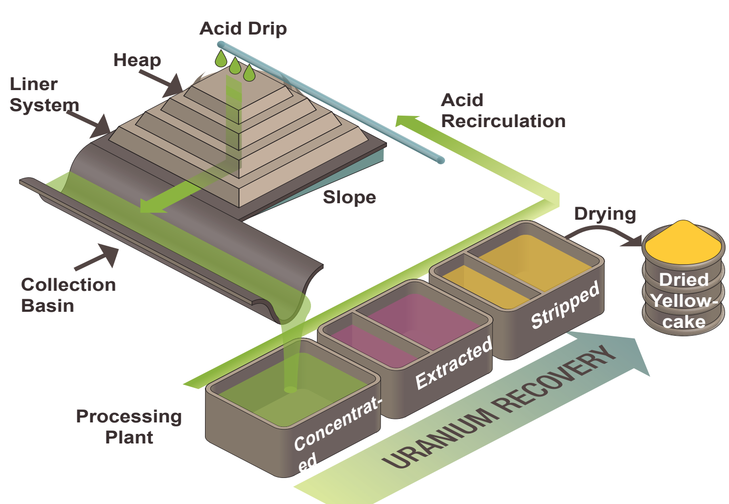
- Conventional milling extracts uranium from ore excavated in deep underground shafts or shallow open pits (ie., mines); the ore is crushed and chemically treated to extract the uranium.
- In situ recovery (ISR) injects a liquid solution into the ore underground; the solution leaches uranium from the rock and is then pumped to the surface and processed.

The NRC becomes involved when the ore is altered or processed— in other words, at the conventional mill or the ISR facility. The NRC does not regulate conventional mines. The NRC regulates ISR facilities, uranium mills, and the disposal of tailings in certain States, while State agencies regulate these activities in so-called "Agreement States"—States that have entered into an agreement with the NRC to regulate certain nuclear materials.

A conventional mill takes uranium ore removed from a mine and crushes it. A chemical process then extracts the uranium from the crushed rock, creating a powdery compound called uranium oxide, or "yellowcake." Yellowcake becomes the basis of nuclear fuel.

The "heap leach" process has also been used at conventional mills to extract uranium from ore. Heap leach operations involve placing ore on a pad and dissolving the uranium using acid to percolate through the ore. The uranium-rich liquid is then recovered and processed to create yellowcake.

The Heap Leach Uranium Recovery Process



A barrel of dried yellowcake.

Once yellowcake is extracted from the crushed rock, the remaining waste material, known as “mill tailings,” is hazardous because of its residual concentration of radium. Radium decays to produce radon, a radioactive gas that has been linked by some researchers to an increased incidence of lung cancer when present in confined areas such as homes or mines. Mill tailings are disposed of in special facilities called “tailings piles,” designed to block radon from reaching the environment.

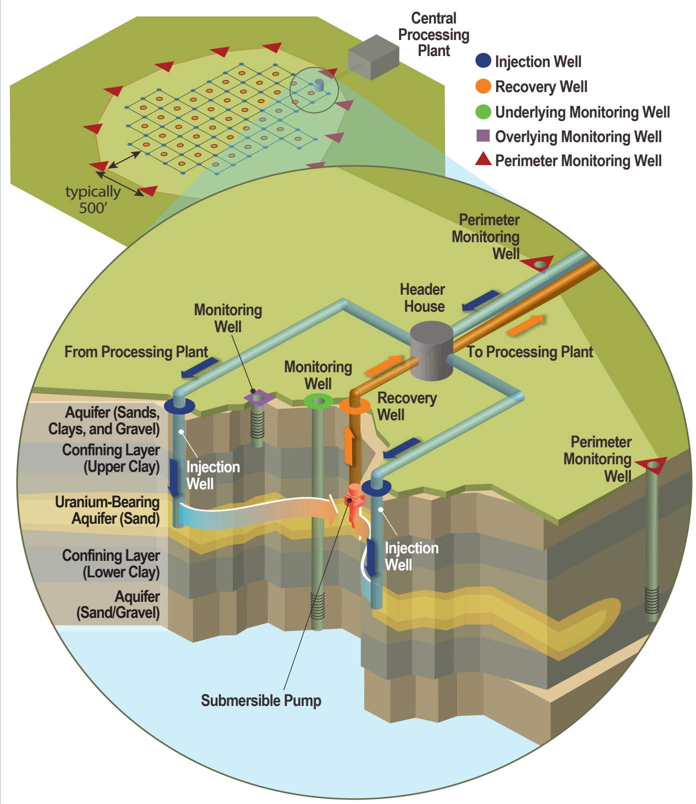
The International Uranium Corporation’s White Mesa Mill in Blanding, Utah, is currently the only active conventional mill. White Mesa is regulated by Utah, an Agreement State.

In the ISR process, uranium is recovered by pumping a water solution, known as lixiviant, through wells to dissolve the uranium ore in place. The uranium solution is then pumped to the surface and processed to create yellowcake. About 20 such ISR facilities operate in the United States, three of which are directly regulated by the NRC and others by Agreement States.

Many NRC-licensed conventional uranium mills have shut down, and owners are cleaning or have completed cleaning up the sites to the point at which they can be declared safe by the NRC. At these sites, clay is compacted on top of the tailings pile as a barrier to prevent radon from escaping into the atmosphere and to reduce the amount of water that seeps into the waste. The embankments are then covered with soil, rock, or other materials to prevent erosion. Ground water cleanup occurred at most of these sites and is ongoing at others. No tailings are produced at ISR facilities, but ground water cleanup is still required before the site is declared safe by the NRC.

The NRC conducts routine inspections to ensure that all operating facilities and those being cleaned up are protective of public health and safety, and the environment.

In Situ Uranium Recovery Process

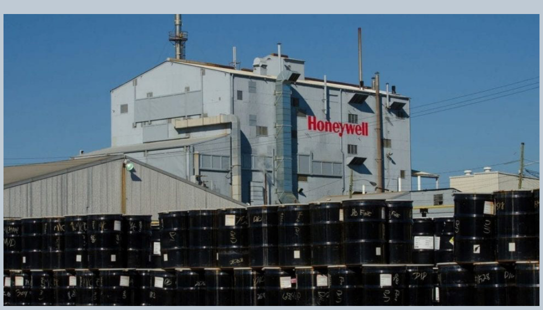


Conversion

Yellowcake is shipped from a mill or an ISR facility to a uranium conversion plant. There, the yellowcake is processed with fluorine to create uranium hexafluoride (UF6). The UF6 is a gas that is then cooled to a liquid and drained into 14-ton (14-tonne) storage and transport cylinders. As the UF6 cools over the course of five days, it solidifies. The cylinder full of solid UF6 can then be shipped to an enrichment plant.

As with mining and milling, the primary risks associated with conversion are more chemical than radiological. The process to convert yellowcake to UF6 involves several volatile and soluble chemicals, including fluorine, hydrofluoric acid, and uranyl fluoride. These chemicals are harmful if inhaled. The process also uses hydrogen gas, which is flammable and potentially explosive. A nuclear reaction (criticality) is not possible at these facilities because the nuclear material consists of natural uranium that has not yet been enriched.

There is one commercial uranium conversion plant in the United States. The plant is Honeywell International Inc. Metropolis Works Uranium Conversion Facility, located in Metropolis, Illinois. After several years in “idle-ready” status, this plant resumed commercial operations in June 2023.



Honeywell International Inc. Metropolis Works Uranium Conversion Facility in Metropolis, Illinois.

Enrichment

Natural uranium consists of three isotopes: Uranium (U)-234, Uranium-235 and Uranium-238. The U-235 isotope is best suited for the fission process of splitting atoms to generate power; however, it is less that 1 percent of natural uranium. For uranium to be useful in reactor fuel, it must be "enriched" to a higher proportion of U-235. Current U.S. reactors use fuel enriched to about 4 to 5 percent U-235, while newer fuels for advanced reactor designs are likely to use higher enrichments. The two enrichment processes licensed for use in the United States: gas centrifuge and laser separation.

Centrifuge Technology

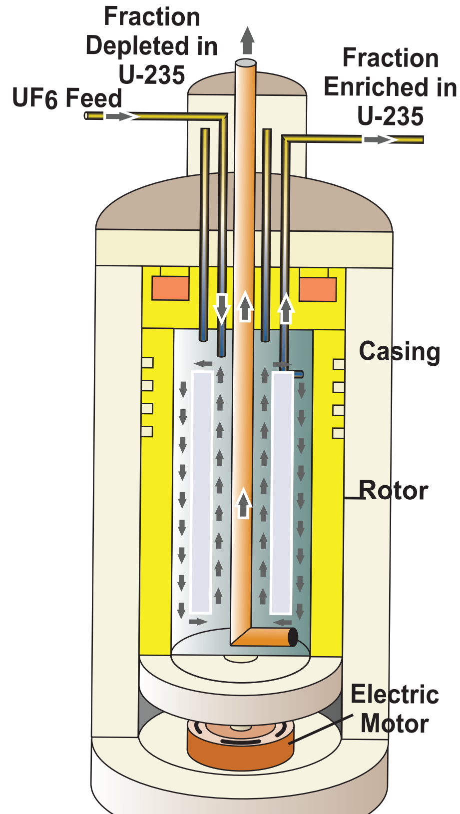
Gas centrifuge enrichment is the process currently used in the United States. UF6 gas is placed in a large cylinder and rotated at a high speed. This rotation creates a strong centrifugal force so that the heavier U-238 molecules move towards the outside of the cylinder. The lighter U-235 molecules collect closer to the center. This lighter stream, slightly enriched in U-235, is withdrawn and fed into the next centrifuge, the next higher stage. The heavier, slightly depleted stream (with a lower concentration of U-235) is recycled back into the next lower stage.

A gas centrifuge facility contains long lines of many rotating cylinders. These cylinders are connected in both series and parallel formations. Centrifuge machines are interconnected to form trains and cascades. At the final withdrawal point, the UF6 is enriched to the desired amount.

Two centrifuge plants are currently in operation in the United States: the URENCO USA facility in Eunice, New Mexico, and the Centrus Energy Corp. American Centrifuge Plant in Piketon, Ohio.

URENCO USA facility in Eunice, New Mexico.

Gas Centrifuge Process



Laser Enrichment

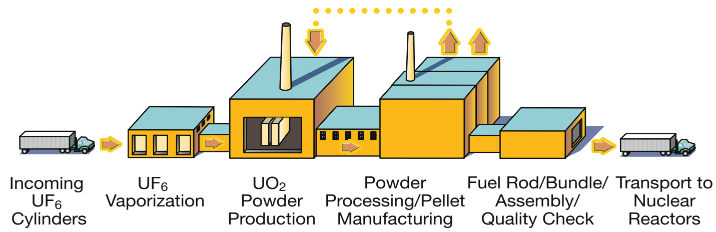
Uranium may also be enriched by separating isotopes with lasers. Molecules can be excited by laser light; this is called photoexcitation. Lasers can increase the energy in the electrons of a specific isotope, changing its properties and allowing it to be separated.

In general, this enrichment process uses three major systems: laser, optical, and separation module systems. The laser delivers a highly monochromatic light that ionizes a specific isotope of uranium, leaving other isotopes unaffected. The isotopes can then be separated. The laser separation technology currently under development is called Separation of Isotopes by Laser Excitation, or SILEX.

No laser separation uranium enrichment plants are currently operating in the United States. A company called Global Laser Enrichment (GLE) operates a test loop SILEX facility in Wilmington, North Carolina, and has announced plans to apply for a license to construct and operate a commercial SILEX facility in Paducah, Kentucky. The NRC issued GLE a license in 2012 for a commercial facility in Wilmington, but the company dropped those plans, and the license was terminated in 2020.

Fuel Fabrication

Fuel Fabrication Process



The final step in the production of nuclear fuel occurs at a fuel fabrication facility. Here the enriched UF6 is heated into a gas and chemically treated to form uranium dioxide (UO2) powder. The UO2 is then compressed into ceramic pellets about the size of a fingertip — these are the nuclear fuel. The pellets are loaded into long, thin metal rods (called “cladding”) typically made from zirconium alloys. The rods are then bundled into fuel assemblies, which are ready to be loaded into a reactor. The cladding material provides one of multiple barriers to contain the radioactive fission products created during the nuclear chain reaction. Fuel assemblies may contain up to 264 fuel rods and have dimensions of 5 to 9 inches (13 to 23 centimeters) square by about 12 to 14 feet (3.7 to 4.3 meters) long.

Primarily for security reasons, the NRC categorizes fuel fabrication facilities according to the enrichment level of the uranium they use. Two Category 1 fuel facilities are licensed to use highly enriched uranium (above 20 percent U-235). They produce fuel for the U.S. Naval Reactors program and down-blend highly enriched uranium with other uranium to produce low-enriched uranium reactor fuel. These Category 1 facilities are Nuclear Fuel Services in Erwin, Tennessee, and the BWXT Nuclear Operations Group plant in Lynchburg, Virginia.

The NRC currently licenses three three fuel fabrication plants processing low-enriched uranium:

(1) Global Nuclear Fuel-Americas in Wilmington, North Carolina

(2) Westinghouse Columbia Fuel Fabrication Facility in Columbia, South Carolina

(3) Framatome, Inc., in Richland, Washington

These facilities are called Category 3 fuel facilities.

(The Centrus Energy Corp. American Centrifuge Plant in Piketon, Ohio, is currently licensed to process uranium up to 19.75 percent enrichment. It is the only Category 2 fuel facility.)

Hazards

Fuel fabrication facilities generally pose a low safety risk to the public. Plant workers have a greater risk of being impacted by chemical, radiological, and criticality hazards. NRC regulations, including the use of the integrated safety analysis, intend to mitigate or reduce the chance of adverse events.

Global Nuclear Fuel-Americas in Wilmington, North Carolina. Photo Courtesy of GE Hitachi Nuclear Energy

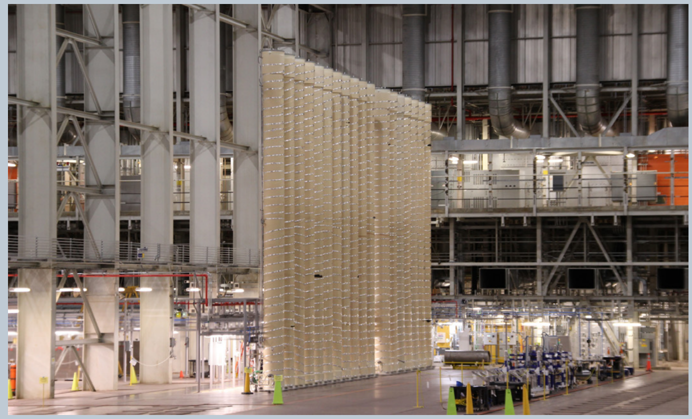
The Westinghouse Columbia Fuel Fabrication Facility in Columbia, South Carolina. Photo Courtesy of Westinghouse Electric Co.

Framatome, Inc. Fuel fabrication facility in Richland, Washington. Photo Courtesy of Framatome, Inc.

Developments in Nuclear Fuel

In recent years, the nuclear industry has been developing new types of fuel to perform more safely and efficiently in commercial reactors. So-called "accident tolerant fuels" have the potential to enhance safety at U.S. nuclear power plants through better performance during normal operation, transient conditions, and accident scenarios. These fuels are designed to make reactors more resistant to a nuclear accident while lowering the cost of electricity over the reactor's lifetime.

The industry is also developing new reactor designs that will use different fuels than current light-water reactors. These fuels will be able to use higher enrichment levels than the 5 percent typical in today's reactors. The NRC is working with the industry in anticipation of licensing high-assay low-enriched uranium, or HALEU, with enrichment levels up to 20 percent U-235. HALEU fuel is expected to allow for smaller reactor designs, longer reactor core operation, and more efficient fuel use. Today's reactor fleet may also use fuels with higher enrichment to extract more power from fuel and reduce radioactive waste.



Top: Ground floor view of the HALEU cascade.

Bottom: View of the machine controls electronics of the HALEU cascade demonstration program. Photos courtesy of Centrus Energy Corp.

Regulation, Licensing, Inspection, and Safety

All commercial fuel facilities in the United States are licensed by the NRC. The licensing process begins with rigorous evaluation and safety checks to ensure the facilities will be built and operated to the NRC's strict regulations and designed to ensure protection of the public and the environment. Other agencies, such as the Occupational Safety and Health Administration and Federal and State environmental protection agencies, also have key oversight roles at these facilities.

NRC inspectors conduct approximately 8 to 10 different inspections at each facility every year. The exact number of inspections and their focus varies, depending on the relative safety and safeguards risks at each facility. The NRC's inspections focus on areas most important to safety and security, using objective measures of performance. Inspections cover activities such as nuclear criticality control, chemical processes, emergency preparedness, fire safety, and radiation safety. To prevent loss, theft, or diversion of enriched nuclear material, the licensee's safeguards activities are also inspected. Full-time resident inspectors are stationed at the two Category 1 fuel fabrication facilities.

In 2019, the NRC formed a working group to conduct a holistic assessment of the fuel cycle oversight program. The assessment considered both domestic and international operating experience, risk insights, inspection data, and lessons learned. Based on the group's recommendations, the NRC in 2021 implemented the Smarter Fuel Cycle Inspection Program. This program further integrates risk-informed insights into fuel cycle inspections to ensure the appropriate focus is applied to areas most important to safety and security. This program improves the overall effectiveness and efficiency of fuel cycle facility inspections.

Violations of NRC requirements are evaluated to determine their impact on safety. If the violation is of low safety significance, it may be discussed with the licensee with no formal enforcement action taken. The licensee is required to resolve the problem and prevent recurrence. If the violation is of larger safety significance, the NRC may levy a written notice of violation or, in certain circumstances, a fine. Inspection reports, correspondence, and other information about the performance of fuel cycle facilities are available to the public, both in the agency's document management system and at its Public Document Room in Rockville, Maryland.

NRC inspectors at the URENCO USA centrifuge plant in Eunice, New Mexico.

Nuclear power currently supplies about 20 percent of U.S. electricity needs. Through rigorous adherence to the NRC's safety regulations, the agency is confident that the production of nuclear fuel is a safe and valuable contribution to the continued supply of nuclear power in the United States.

Environment and Regulation

The National Environmental Policy Act (NEPA) requires Federal agencies to consider the impacts of the proposed action as well as alternatives to the proposed action. The NRC complies with NEPA through its regulations in Title 10 of the *Code of Federal Regulations* Part 51, "Environmental Protection Regulations for Domestic Licensing and Related Regulatory Functions." Staff will prepare one of three types of NEPA documents— a categorical exclusion, an environmental assessment and finding of no significant impact, or an environmental impact statement and record of decision—depending on the nature of the action and its potential environmental impacts. The NRC's NEPA review analyzes the potential environmental impacts related to areas such as land use, water quality and use, air quality, ecology, socioeconomics, environmental justice, waste management, accidents, and public and occupational health. Some projects may also require consultation with State or Tribal agencies under the National Historic Preservation Act or the Endangered Species Act.

For more information on regulating nuclear fuel,
visit the NRC's website:

https://www.nrc.gov/materials/fuel-cycle-fac.html

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