Regulating Nuclear Fuel

U.S. Nuclear Regulatory Commission

Cover Photo: Irradiated fuel assembly and reactor core.
Courtesy of Framatome ANP, Inc.

First Page Background Photo: Switching Yard. Courtesy of USEC.

REGULATING NUCLEAR FUEL

The nuclear fuel cycle covers the entire process of mining uranium, to turning it into fuel, to using it in a nuclear power plant to produce electricity, and finally, to disposing of "spent," or used nuclear fuel, in a special repository.

This booklet focuses on the responsibilities of the U.S. Nuclear Regulatory Commission (NRC) in the first part of the fuel cycle—the mining of uranium and its conversion and enrichment into a form that is used in a nuclear power plant to produce electricity.

Uranium Mining and Milling

The nuclear fuel cycle begins when uranium ore is extracted from the ground. Two types of uranium mines are in use today: conventional mines and in-situ "leaching" facilities. The Office of Surface Mining, the U.S. Department of the Interior, and individual States, regulate mining. The NRC regulates in-situ leaching 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 NRC to regulate certain nuclear materials.

In a conventional mine, uranium is removed from deep underground shafts or shallow open pits. The rock is then crushed at a uranium mill, where an extraction process concentrates the uranium into a compound called "yellowcake." The remainder of the crushed rock is placed in a "tailings" pile. Mill tailings are fine-grained, sandy waste materials left over from uranium processing and must be disposed of in special facilities because of their residual concentration of radium. This residual radium decays to produce radon. Radon is 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.

Production well service at Ria Algom Smith Ranch in-situ leaching facility in Wyoming

Uranium can also be "leached" out of the ground by pumping a water solution through wells to dissolve the uranium in the ore. The uranium is then pumped to the surface in a liquid solution. About 20 such in-situ leach facilities operate in the United States. The NRC regulates several such facilities in the Western states and conducts routine annual inspections to ensure that they are operated safely. Safety violations at these sites have been few and relatively minor.

Acid "heap leach" processes have also been used at conventional mills to extract uranium from ore, and ion-exchange procedures have been used to separate uranium from the liquid extract. Acid leach operations involve placing uncrushed ore on a pad and dissolving the uranium in an acid bath. The uranium-rich liquid is then processed through an ion-exchange circuit to separate the uranium from the liquid. The ion-exchange method is similar at both conventional mills and in-situ leach facilities.

Quality control test on mill tailings cover at L-Bar site in New Mexico

The International Uranium Corporation's White Mesa mill in Blanding, Utah, is the only conventional mill processing uranium ore into yellowcake at this time. Several other mills may resume operation in the future. Uranium mills are located mostly in the western United States, where deposits of uranium are more plentiful.

Many NRC-licensed uranium mills have shut down, and owners have already started cleaning up the sites to the point where 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. Other sites accept waste from in-situ leach facilities.

Aerial view of Atlas mill tailings site near Moab, Utah, with Colorado River in background

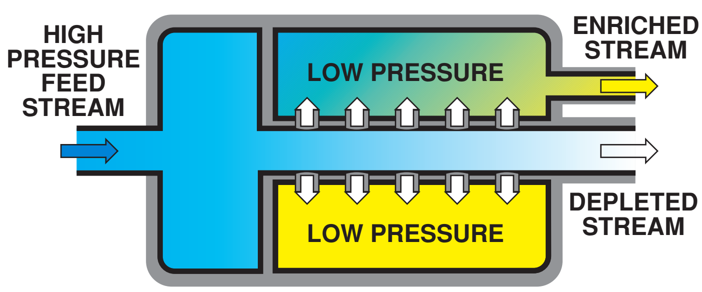
After the uranium is processed into yellowcake at a mill, it is sent to a facility to be converted into uranium hexafluoride (UF_6). The only conversion facility in the United States is located in Metropolis, Illinois. The UF_6 is solid under normal temperatures and pressure, but becomes a liquid at higher temperatures. It may produce a gas from a solid or liquid state. The material is then sent to one of the country's two gaseous diffusion plants to enrich its uranium concentration.

Natural uranium is composed mainly of three isotopes: U-234, U-235 and U- 238. To be used for nuclear fission in most U.S. reactors, the concentration of the U-235 isotope must be increased. Natural uranium contains less than 1 percent of U-235. To increase the percentage of U-235, the uranium must be "enriched" to about 4 to 5 percent. Enriched uranium is produced in the United States using the gaseous diffusion method.

Gaseous Diffusion

First, the solid UF_6 sent from the conversion facility is heated to form a liquid. The gas that is "boiled" off is then used in the gaseous diffusion process. While in a gaseous state, the lighter molecules of U-235 are separated from the heavier molecules of U-238 by forcing them through a membrane with tiny openings. Because the U-235 is lighter, it moves through the membrane more easily, and the two gases can then be separated, increasing the concentration of U-235, thereby "enriching" the uranium. The gas that escapes through the membrane is then slightly enriched in the lighter isotope. The gas retained by the membrane is slightly "depleted" in U-235 while the concentration of U-238 increases.

Gaseous Diffusion Stage



The enriched gas condenses into a liquid, solidifies, and is transported to a fuel fabrication facility where it can be converted into reactor fuel.

Two gaseous diffusion plants currently operate in the United States, one at Portsmouth, Ohio, and the other at Paducah, Kentucky. The Portsmouth plant closed enrichment operations in 2001, but is still being used for shipping and transfer operations. Both plants are operated by the United States Enrichment Corporation (USEC) under leases with the U.S. Department of Energy. The Paducah facility is located in the northwestern corner of Kentucky about 10 miles west of Paducah, Kentucky, and 3 miles south of the Ohio River. The Portsmouth facility is located in south central Ohio, approximately 70 miles south of Columbus, Ohio.

A large pump house at the Paducah uranium enrichment plant circulates cooling water between the enrichment process buildings and cooling towers

Photo courtesy of USEC.

The Energy Policy Act of 1992 established USEC and authorized the NRC to regulate the health and safety aspects of the gaseous diffusion plants. After a rigorous safety review, the two plants came under NRC regulation on March 3, 1997[1]. These facilities have the capacity to supply a majority share of the United States' nuclear power market, while also supplying a significant portion of the world's nuclear power market. The remainder is provided by other countries. The NRC has two full-time resident inspectors at each site. Also, specialized inspections are conducted using personnel from NRC headquarters in Maryland and the NRC Regional office in Lisle, Illinois.

Photo courtesy of USEC.

The control room at the Paducah uranium enrichment plant is the center of all plant activity. From here, operators can monitor and control all enrichment operations on the plant site

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[1]The gaseous diffusion plants are the only "certified" facilities under NRC oversight. The term originated from the Energy Policy Act that transferred the uranium enrichment function from the Department of Energy to a government corporation, which became a private company in 1998. Certification consists of a review of safety and safeguards for the plants against the NRC regulations.

Fabrication

Fabrication is the final step in the process used to produce uranium fuel. It begins with the conversion of enriched uranium hexafluoride (UF_6) gas to a uranium dioxide solid. Nuclear fuel must maintain both its chemical and physical properties under the extreme conditions of heat and radiation present inside an operating reactor vessel. Fabrication of commercial light-water reactor fuel consists of three basic steps:

1. the chemical conversion of UF_6 to uranium dioxide (UO_2) powder;
2. the ceramic process that converts uranium oxide powder to small pellets; and
3. the mechanical process that loads the fuel pellets into rods and constructs finished fuel assemblies.

After the UF_6 is chemically converted to UO_2 , the powder is blended, milled, and pressed into ceramic fuel pellets about the size of a fingertip. The pellets are stacked into long tubes made of material called “cladding” (such as zirconium alloys) and, after careful inspection, the resulting fuel rods are bundled into fuel assemblies for use in reactors. The cladding material provides one of multiple barriers to contain the radioactive fission products produced during the nuclear chain reaction.

Following final assembly operations, the completed fuel assembly (about 12 feet long) is washed, inspected, and finally stored in a special rack until it is ready for shipment to a nuclear power plant site.

Nuclear Fuel Fabrication

Fuel fabrication facilities mechanically and chemically process the enriched uranium into nuclear reactor fuel. The NRC licenses seven commercial nuclear fuel fabrication facilities in the United States:

Westinghouse Electric Company LLC
Hematite, Missouri
(ceased conversion and removed all UF_6 from the site as of March 31, 2001)

Framatome ANP, Inc.
Lynchburg, Virginia
Richland, Washington

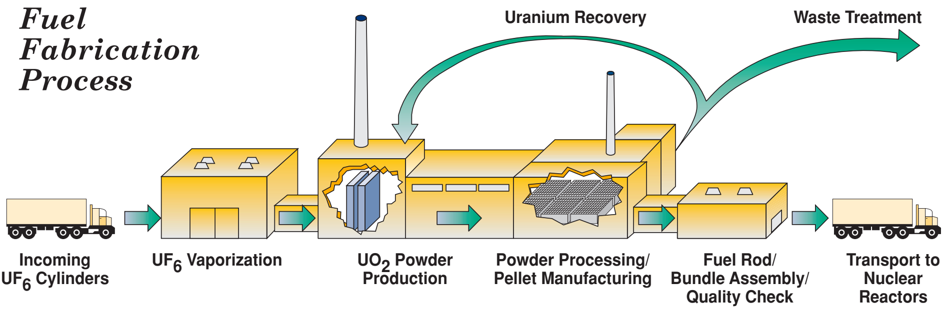
BWX Technologies, Inc.
Lynchburg, Virginia

Global Nuclear Fuels–Americas LLC
Wilmington, North Carolina

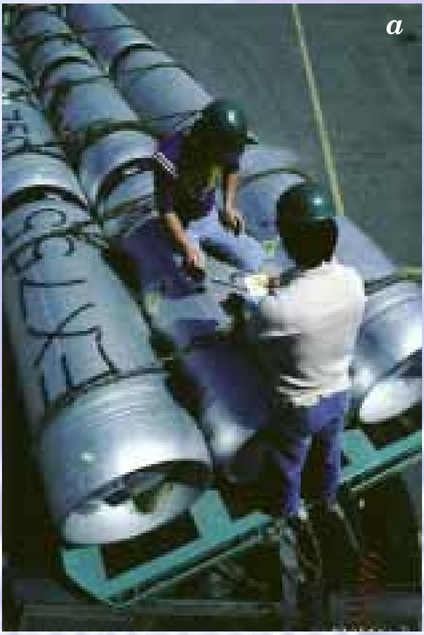
Nuclear Fuel Services, Inc.
Erwin, Tennessee

Westinghouse Electric Company LLC
Columbia, South Carolina

Fuel Fabrication Process



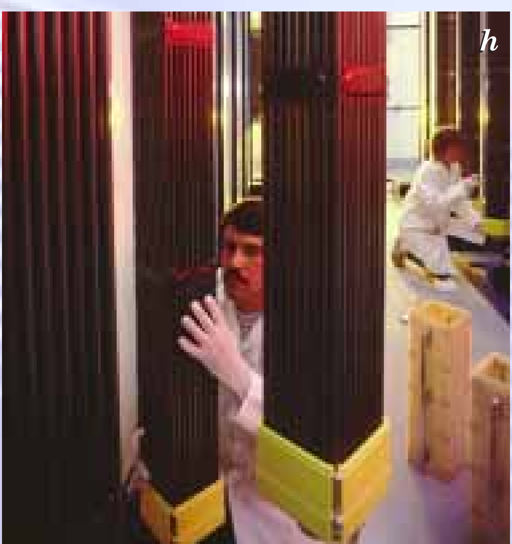
Photos courtesy of Framatome ANP, Inc.



UF_6 is received in cylinders (a), converted to UO_2 powder (b), and pressed into fuel pellets, which must pass strict quality inspections (c) before columns of pellets are loaded into fuel rods (d)

All fuel components are built to exact specifications and are thoroughly inspected during the fabrication process (e, f, g)

Finished assemblies are inspected both before shipment (h) and upon arrival at the reactor site (i)



Possible Hazards

The most significant hazard at a uranium conversion facility exists at the stage where liquid UF_6 is stored and processed. When liquid UF_6 is released to the atmosphere, it reacts with the moisture in the air to form a dense vapor cloud that contains hydrogen fluoride (HF) gas, a non-radioactive, extremely toxic substance. In 1986, at the Sequoyah Fuels Corporation conversion facility in Gore, Oklahoma, an overfilled cylinder of UF_6 ruptured, resulting in a major release of hydrogen fluoride that killed a worker. This facility was later closed by its owner.

Since the enrichment facilities handle and process large amounts of UF_6, the same chemical hazards exist at an enrichment facility. In addition, the production of enriched uranium at enrichment facilities could potentially produce an inadvertent nuclear chain reaction, known as "criticality." Such an accident occurred in Tokaimura, Japan, in September, 1999. A criticality may release significant, localized amounts of radiation that can be harmful and even fatal to workers or people in the immediate vicinity, as was the case with two workers in Japan. The enriched uranium also requires that significant

Fuel Assembly Inspection

Photo courtesy of Framatome ANP, Inc.

security measures be taken to safeguard such material against theft or sabotage.

Since it's creation in 1995, an incident of this type has never occurred at an NRC-licensed facility. A potential criticality accident was averted in 1991 at the fuel fabrication facility in Wilmington, North Carolina. The incident began when liquid waste material was inadvertently transferred to a tank which, because of its configuration, type, and the amount of uranium it contained, led to the potential for a criticality accident. The former owner, General Electric, took steps to ensure the incident should not recur.

Fuel fabrication facilities have essentially the same types of hazards as enrichment facilities (i.e., radiological, chemical, and criticality hazards). Fuel fabrication facilities also have extensive security procedures to guard against the loss, theft, and diversion of enriched uranium. Fires can pose significant hazards at conversion, enrichment, and fuel fabrication facilities. NRC has regulations in place to protect against these safety hazards and security concerns. Regular inspections at fuel fabrication facilities enforce these regulations, ensuring safe operation.

All commercial fuel facilities in the United States are licensed or certified by the NRC. The licensing process begins with rigorous evaluation and safety checks, to ensure the facilities will be built and operated to NRC's strict regulations, 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.

Approximately 8 to 10 times per year NRC inspections are conducted at each fuel facility, from one of NRC's four regional offices or from its headquarters in Rockville, Maryland. The regional offices are located in King of Prussia, Pennsylvania; Atlanta, Georgia; Lisle, Illinois; and Arlington, Texas.

The exact number of inspections and their focus varies, depending on the relative safety and safeguards risks at each facility and its overall performance level. Resident inspectors, living nearby, perform daily inspections at the gaseous diffusion plants. The NRC also has resident inspectors at the BWXT fuel facility in Virginia and the Nuclear Fuel Services plant in Tennessee because those facilities handle material enriched at a higher level for national defense and other purposes.

NRC's inspections focus on those areas that are most important to safety and security, using objective measures of performance. In general, inspections may cover activities such as nuclear criticality control, chemical process, emergency preparedness, fire safety, and radiation safety. For those facilities that store or process higher enriched nuclear material, the NRC requires certain safeguards to protect such material from loss, theft, or diversion.

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 expected to resolve the problem and prevent recurrence. If the violation is of larger safety significance, NRC may levy a written Notice of Violation, or, in certain circumstances, a fine.

Framatome ANP, Inc. Fuel Fabrication Facility in Richland, Washington

Photos courtesy of Framatome ANP, Inc.

Inspection reports, correspondence, and other information about the performance of fuel cycle facilities are available to the public, both on the agency's document management system and at its Public Document Room in Rockville, Maryland.

Nuclear power currently supplies about 20 percent of our nation's electricity needs. Through rigorous adherence to 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.

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NUREG/BR-0280, Rev. 1
September 2001