FACT SHEET

Nuclear Fuel Production: A Four-Step Process

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Key Facts

- Nuclear power plants use uranium as fuel to produce electricity. But before its use in a nuclear reactor, a series of processing steps must convert mined uranium ore into ceramic pellets, which are loaded into fuel rods.

- Natural uranium contains two different forms, or isotopes: U-238 and U-235. U-235 is fissionable, which means its atoms can be split, releasing large amounts of energy. Natural uranium consists of more than 99 percent U-238 and less than 1 percent U-235. Before uranium can be used as a fuel, an "enrichment" process must increase its U-235 content to between 3 percent and 5 percent.

- The United States uses about 53 million pounds of uranium oxide each year to fuel its 104 nuclear power reactors. Domestic uranium production in 2007 met less than 10 percent of the nation's requirements; imports supplied the remainder. Uranium from the dismantling of nuclear weapons has become an increasingly important supply source as well.

- Both federal and state agencies regulate uranium fuel production. Strict standards designed to protect public health and safety, as well as the environment, govern all fuel production activities.

From Ore to Pellets: A Multi-Step Process

A nuclear power plant, like most other types of power plants, generates electricity by boiling water into steam that drives a turbine generator. Splitting uranium atoms—the fission process—creates heat to boil the water.

Before its use in a reactor, uranium must undergo four processing steps to convert it from an ore to solid ceramic fuel pellets: mining and milling, conversion, enrichment, and fabrication. The resulting pellets are loaded into fuel rods. When grouped, the rods form bundles, or "fuel assemblies," for insertion into the reactor.

Mining and Milling: From Ore to 'Yellowcake'

Uranium miners employ several techniques: surface or "open pit" mining, underground mining, and *in-situ* leach mining, which involves using liquids to recover minerals from underground ore. Uranium also can be a byproduct of other mineral processing operations.

Ore mined from open-pit and underground mines travels to a conventional mill, where it is crushed, ground and leached to dissolve the uranium. Solvents or ion exchange processing removes the uranium. The resulting uranium oxide, or "yellowcake," is filtered, dried and packaged.

In-situ leach mining involves the injection of carbonated water through specially drilled wells into an ore body several hundred feet underground. The injected solutions penetrate the ore deposits and dissolve the uranium. This process brings the uranium-bearing solution to the surface, where the uranium is extracted and the leach solutions are again injected into the ore body.

Most U.S. uranium reserves are found in Arizona, Colorado, New Mexico, Texas, Utah and Wyoming. Primary U.S. uranium production in 2007 came from one U.S. mill and five *in-situ* leach plants.

Total U.S. uranium production from all sources in 2007 was 4.5 million pounds of uranium oxide, slightly higher than in 2006. Worldwide production in 2007 was about 108 million pounds. That same year, U.S. utilities purchased 33 percent of their uranium from Russia, 23 percent from Australia, 21 percent from Canada, 8 percent from the United States, 6 percent from Namibia, and the remaining 9 percent from several other countries.

Conversion: Yellowcake To Uranium Hexafluoride

The uranium oxide, or yellowcake, requires further processing before its use as a fuel. In the next step, the uranium oxide goes to a conversion plant, which removes impurities and chemically converts the material to uranium hexafluoride. The compound is heated to become a gas then loaded into cylinders, where it cools and condenses into a solid.

One of the world's five commercial conversion plants is in the United States. The others are in Canada, France, Russia and the United Kingdom.

ConverDyn Inc. operates the U.S. conversion plant in Metropolis, Ill. The facility has a production capacity of approximately 17,600 metric tons uranium (MTU) per year of uranium hexafluoride. The company is expanding the plant to produce 23,000 MTU by 2020. U.S. annual demand for conversion is approximately 20,000 MTU per year.

Annual world requirements for conversion as of 2007 are approximately 60,000 MTU. The world's conversion plants currently have a total maximum capacity of about 66,000 MTU. In 2007, roughly 40,000 MTU were produced. Although inventory drawdowns—in addition to recycling—supplied the remainder of 2007 world uranium requirements, those inventories are expected to provide smaller portions of requirements in the future.

Enrichment: Boosting The Fuel's Potency

Natural uranium contains two different forms, or isotopes, of uranium; one (U-238) is heavier than the other (U-235). The lighter U-235 is "fissionable" and makes up less than 1 percent of uranium by weight. U-238 accounts for more than 99 percent of uranium by weight.

To make uranium usable as a fuel, its U-235 content must increase to between 3 percent and 5 percent by weight through a process called enrichment.

Utilities can buy uranium and have it converted and enriched, or they can buy uranium already enriched. Uranium producers sell enrichment services in "separative work units," or SWUs. An SWU is a measure of the amount of energy needed to raise the concentration of U-235 to a specified level.

There are three ways to enrich uranium: gaseous diffusion, gas centrifuge and laser enrichment. The gaseous diffusion enrichment process is the only method now used in the United States.

USEC Inc. currently is the only U.S. provider of enrichment services. The Energy Policy Act of 1992 established the United States Enrichment Corp., a government-owned corporation, to take over the U.S. Department of Energy's uranium enrichment services business. The corporation was privatized as USEC Inc. in 1998.

USEC supplies approximately 50 percent of U.S. market needs. The company also serves as the U.S. executive agent for the U.S.-Russian High-Enriched Uranium Agreement, also known as "Megatons to Megawatts." Under this program, uranium from Russian weapons is converted for sale and use in commercial reactors. The weapons material represents slightly more than 100 million SWUs of enrichment services and will be available through 2013.

Three companies—USEC, Louisiana Energy Services (LES) and AREVA—are building or plan to build new gas centrifuge enrichment facilities in the United States. The LES facility will be based in New Mexico, the AREVA facility is planned for Idaho, and USEC's new facility will be located in Ohio. USEC's existing facility is based in Kentucky.

LES is owned by Urenco, a British-Dutch-German consortium that enriches uranium in Europe. AREVA is based in France.

A fourth company, GE Hitachi Nuclear Energy, plans to build a facility in Wilmington, N.C., that will use a laser process for enrichment.

Three other major commercial enrichment service producers operate facilities in France, Germany, the Netherlands, Russia and the U.K.

Fabrication: Precisely Tailoring Uranium Fuel

After enrichment, a fuel fabricator converts enriched uranium hexafluoride into uranium dioxide powder and presses it into fuel pellets. The fabricator loads the ceramic pellets into long tubes, or "fuel rods," made of a noncorrosive material, usually a zirconium alloy. Once grouped together into a bundle, these fuel rods form a fuel assembly.

Fuel assemblies, though similar, are designed to meet the specific requirements of each nuclear reactor. To ensure that each assembly performs to design criteria over its lifetime, fuel fabricators employ stringent quality-control measures throughout the production process.

Although nuclear reactors differ somewhat from one utility to another, a typical large pressurized water reactor contains 193 fuel assemblies composed of about 51,000 fuel rods containing more than 18 million uranium dioxide fuel pellets.

A fuel assembly's life in a reactor is 36 to 54 months, after which the majority of the U-235 has fissioned and there is an inadequate amount to support the chain reaction. Operators then remove the fuel from the reactor through refueling, which normally replaces about one-quarter to one-third of the fuel assemblies with new fuel every 18 to 24 months.

Three U.S. companies offer fabrication services: AREVA NP Inc., which operates facilities in Lynchburg, Va., and Richland, Wash.; GE Hitachi Nuclear Energy in Wilmington, N.C.; and Westinghouse Electric in Columbia, S.C. These companies essentially meet all U.S. fabrication demand.

Protecting the Public And the Environment

Activities involved in uranium fuel production are subject to strict standards designed to protect public health and safety as well as the environment.

Controls on Mining. Regardless of the method used to recover uranium, mining companies must comply with a host of local, state and federal regulations.

For some time, news reports have examined radiation exposure of some U.S. underground uranium miners at federal facilities during the 1950s and 1960s. But miners producing uranium for use in the nation's commercial nuclear power plants always have worked under conditions that protect their health and safety, as well as that of the general public.

Radon—a gas that occurs naturally in all soils throughout the world—can be hazardous in any underground mine if concentrations of the gas are high.

Extraction of uranium ores by *in-situ* mining does not allow the buildup of radon gas, resulting in greater worker health and safety. Thick, impermeable covers minimize the release of radon from mill tailing impoundments. Mill tailings are the waste rock that remains after the milling process is complete.

Regulators apply research by key agencies, such as the International Commission on Radiological Protection, to set radiation exposure limits for uranium workers. Regulations also are in place to ensure that no significant increase in environmental radiation occurs. These regulations cover such activities as surface mining and reclamation, dam safety, water rights, and water quality.

The regulations clearly work: The U.S. Environmental Protection Agency has concluded that radiation levels in uranium mining communities are essentially the same as levels in other communities in the same geologic area.

Safe Disposal of Mill Tailings. Uranium milling is subject to strict regulation as well. The moderate amounts of radioactivity in tailings also are carefully controlled. The mill tailings remain in impoundment sites designed to account for such factors as geology, seismic activity, groundwater levels and potential flooding.

Recovery of uranium by *in-situ* leach mining, the method principally in use in the United States, does not generate tailings. To protect the public, *in-situ* mine operators continually remove minor quantities of radioactive waste over the mine's operating life.

During the operation of the uranium mill, people and all wildlife are prohibited from the tailings impoundment area. When milling operations cease, the impoundment area is reclaimed and permanently isolated from the environment.

This involves sealing the area with a soil and rock cover at least 10 feet thick. The surface, after being planted with native vegetation, then returns to its pre-mining environment. These reclamation procedures effectively reduce radon emissions from tailings to the levels of natural soils in the area.

The uranium industry must also ensure safe water quality under the Clean Water Act. The water released at any point during mining or milling must meet strict standards and generally is of better quality than the water found naturally in the area.

Clay and special artificial liners seal the tailings disposal area after reclamation, thereby preventing seepage.

Regulating Fuel Processing Activities. The U.S. Nuclear Regulatory Commission licenses and inspects all plants that convert yellowcake into uranium hexafluoride. Although natural uranium poses little radiation danger to humans, it is chemically toxic and subject to close regulation when used for commercial purposes.

The nation's enrichment facilities must comply with all federal and state environmental statutes. In lieu of a license from the NRC, USEC has obtained a certificate of compliance from the NRC. The agency oversees enrichment facilities in the United States. The NRC has issued the licenses for USEC's new facility and LES's facility.

U.S. fuel fabrication plants are subject to regulation at both the state and federal levels. The NRC is the primary regulator.

This fact sheet is also available at www.nei.org, *where it is updated periodically.*