Uranium and the History of Nuclear Energy

What is Uranium?

Uranium is a naturally occurring radioactive element, that is very hard and heavy and is classified as a metal. It is also one of the few elements that is easily fissioned. It is the fuel used by nuclear power plants.

Uranium was formed when the Earth was created and is found in rocks all over the world. Rocks that contain a lot of uranium are called uranium ore, or **pitchblende**. Uranium, although abundant, is a nonrenewable energy source.

Three forms or isotopes of uranium are found in nature, uranium-234, uranium-235, and uranium-238. These numbers refer to the number of neutrons and protons in each atom. Uranium-235 is the form commonly used for energy production because, unlike the other isotopes, the nucleus splits easily when bombarded by a neutron. During fission, the uranium-235 atom absorbs a bombarding neutron, causing its nucleus to split apart into two atoms of lighter mass.

At the same time, the fission reaction releases energy as heat and radiation, as well as releasing more neutrons. The newly released neutrons go on to bombard other uranium atoms, and the process repeats itself over and over. This is called a **chain reaction**.

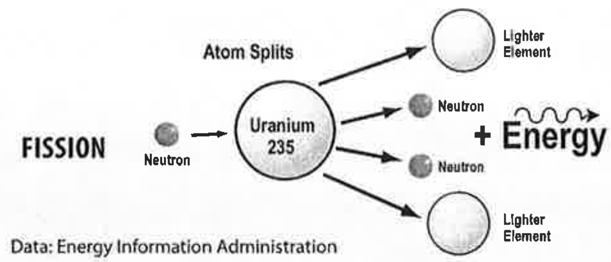
Uranium at a Glance, 2013

Classification:
- nonrenewable

Major Uses:
- electricity

U.S. Energy Consumption:
- 8.268 Q
- 8.47%

U.S. Energy Production:
- 8.268 Q
- 10.09%



Data: Energy Information Administration

History of Nuclear Energy

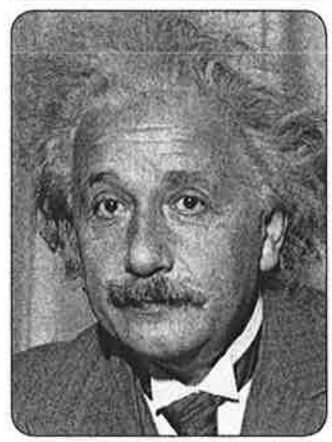
Nuclear reactions have occurred in the Earth's crust since the beginning of time. However, man's working knowledge of nuclear energy occupies a very small portion of Earth's history. This knowledge was started by a chain of events beginning in 1895 with the experiments of German physicist Wilhelm Roentgen. He was working with gas discharge tubes and discovered that the tubes caused certain materials to glow in the dark. Shadows of the bones of his fingers were recorded on cardboard coated with barium. He named the energy given off by these gas discharge tubes x-rays.

In 1896, Henri Becquerel, a French scientist, accidentally discovered that a uranium compound left in the dark near a photographic plate produced an image on the plate. Marie Curie, a student of Becquerel's, and her husband Pierre, a professor of physics, continued to investigate these emissions from uranium and named them **radioactivity.** Two years later, the Curies announced that they had discovered two radioactive elements in the ore pitchblende, polonium (named for Marie Curie's native country of Poland), and radium.

Scientific work related to radioactivity continued throughout the early to middle twentieth century. In England, Ernest Rutherford identified two different types of radiation given off by uranium atoms, alpha rays and beta rays (streams of alpha and beta particles). Rutherford's experiments with radiation showed that a radioactive element changes into a different element when it gives off alpha or beta particles. This change in an element is called **transmutation**.

MARIE CURIE

ALBERT EINSTEIN



Other significant events included the discovery of the electron by J. J. Thompson and Rutherford's observation that almost all of the mass and all of the positive charge of an atom were contained in its tiny nucleus. The general structure of an atom containing protons and neutrons in the nucleus and electrons outside the nucleus was completed in 1932 with the discovery of the neutron by James Chadwick.

In 1905, Albert Einstein theorized that mass and energy are interchangeable. According to his theory, mass can be converted into energy and energy can be converted into mass. The relationship between the mass and energy of matter is calculated by the equation $E = mc^2$. It took over thirty years for scientists to prove Einstein's theory correct, but this led to the understanding that large amounts of energy could be released from radioactive materials.

Uranium and the History of Nuclear Energy

In 1938 two German chemists, Otto Hahn and Fritz Strassmann, found that when uranium was bombarded with neutrons, the element barium (a much lighter element) was produced. An Austrian physicist, Lise Meitner, and her nephew, Otto Frisch, first explained nuclear fission, a process in which the nucleus splits into two nuclei of approximately equal masses. Using Einstein's equation, they calculated that this fission released a tremendous amount of energy. Immediately, the world's scientific community recognized the importance of the discovery. With the coming of World War II, the race was on to see which nation could unleash the power of the atom and create the most powerful weapon ever imagined.

The first controlled nuclear fission occurred in 1941 at the University of Chicago under the guidance of Leo Szilard and Enrico Fermi. Graphite blocks (a "pile" of graphite) were stacked on the floor of the Stagg Field squash court. Natural uranium was inserted among the graphite blocks. Using natural uranium, the scientists were able to produce the first controlled nuclear chain reaction. A chain reaction requires the correct amount of nuclear fuel (**critical mass**) to sustain the reaction, neutrons of the proper speed (energy), and a way to control the number of neutrons available for fission. The first large scale reactors were built in 1944 in Hanford, Washington, to produce plutonium for nuclear weapons.

On July 16, 1945, all of the theory about nuclear energy became reality. The first release of nuclear energy from an atom bomb occurred with the Trinity Test in south central New Mexico. The explosion was dramatic and demonstrated the huge amounts of energy stored in uranium. Enough nuclear fuel for two more atomic bombs was available. The bombs were immediately shipped to the Pacific for use against Japan. Many scientists and U.S. politicians hoped the bombs would end World War II without requiring an invasion of the islands of Japan.

On August 6, 1945, the B-29 Enola Gay took off from its airbase on the small pacific island Tinian. The bomber carried and dropped a uranium atomic bomb that exploded 1,900 feet above the city of Hiroshima, Japan. Hiroshima was a city of 300,000 civilians and an important military center for Japan. The effects of the bomb were devastating. People and animals closest to the explosion died instantly, and nearly every structure within one mile of ground zero was destroyed. Fires started and consumed the city; those who survived the initial blast were injured or later died from effects of the radiation. In the end, about half of the city's population was dead or injured.

Japan was asked to surrender immediately after the Hiroshima explosion, but chose not do so. So, on August 9, 1945, a plutonium atomic bomb was dropped on the industrial city of Nagasaki with results similar to those of Hiroshima. On August 10, some in the Japanese government started the process of surrender. On August 14th, Japan's surrender was officially declared, and was accepted by the United States and allies on August 15, 1945. The tremendous energy inside the tiny nucleus of the atom helped end the deadliest war in history.

At the end of World War II, nuclear energy was seen as very destructive; however, scientists started work to harness and use nuclear energy for peaceful purposes. The first use of nuclear power to generate electricity occurred in December 1951 at a reactor in Idaho. In 1954, a nuclear reactor in Obninsk, Russia, was the first connected to an electricity grid. The Nautilus, the world's first submarine powered by a nuclear reactor, was placed into service by the U.S. Navy in 1954. In 1957, the first commercial nuclear reactor to produce electricity went on-line at Shippingport, Pennsylvania. Other nuclear plants of different designs soon followed.

In 1946 the Atomic Energy Commission (AEC) was the first agency assigned the task of regulating nuclear activity. In 1974 the AEC was replaced by the **Nuclear Regulatory Commission** (NRC), which was established by Congress as part of the Energy Reorganization Act. The NRC's primary responsibility is to protect public health and safety. To accomplish this the NRC has oversight of reactor and materials safety, waste management, license renewal of existing reactors, materials licensing, and the evaluation of new nuclear power plant applications.

As of 2013, 100 nuclear reactors are operating in 62 plants in the United States. Two new reactors are being built at an existing plant in Georgia and are expected to come online in 2017 and 2018. 437 nuclear reactors are generating power throughout the world. Following the Fukushima Daiichi incident in Japan in 2011 (see page 36), several countries have voted to scale back or phase out nuclear generation in the coming years. These countries include Germany, Switzerland, and Italy. Since the Fukushima Daiichi incident Japan has reduced its nuclear power production by 89%.

Despite the success of peaceful uses of nuclear power, some people remain hesitant about increasing usage of nuclear energy because of its potential to be used in non-peaceful ways—**nuclear proliferation**.

Lise Meitner

Lise Meitner was head of physics at the Keiser Wilhelm Institute in Germany and worked closely with radiochemist, Otto Hahn. When Nazis came to power in 1933, many Jewish scientists left. Meitner, who was Jewish by birth, stayed to continue her work at the Institute. In 1938 she was forced to move to Sweden for her safety.

Meitner and Hahn continued corresponding about their research. Hahn wrote to Meitner perplexed that bombarding a uranium nucleus produced barium. Meitner discussed Hahn's findings with her nephew, Otto Frisch. They interpreted Hahn and Strassmann's results as nuclear fission, explaining that a large amount of energy is released when the nucleus splits.

Meitner was offered a position working on the Manhattan Project, but refused to be a part in the making of a bomb. In 1944, without acknowledgement of Meitner's work, Hahn was awarded the Nobel Prize for Chemistry for the discovery of nuclear fission.

Nuclear Accidents

Three events that have influenced people's perception of nuclear energy are the accidents at Three Mile Island in Pennsylvania, Chernobyl in the Ukraine (former Soviet Union), and Fukushima in Japan.

Three Mile Island

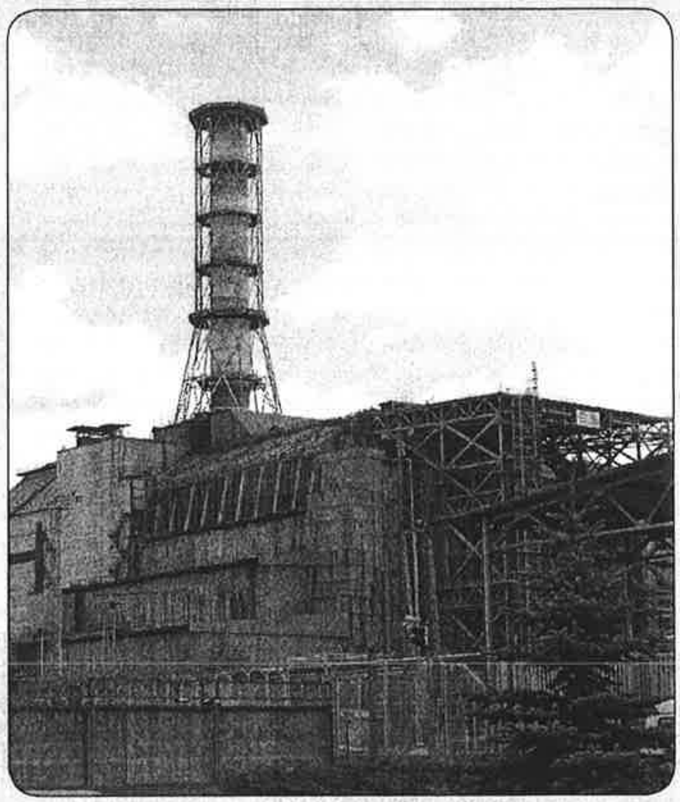
In 1979 there was an accident at the Three Mile Island (TMI) reactor. In the morning, feed-water pumps that moved coolant into one of the reactors stopped running. As designed, the turbine and reactor automatically shut down, but an automatic valve that should have closed after relieving pressure inside of the reactor stayed open. This caused coolant to flow out of the reactor and the reactor overheated, and the nuclear fuel started to melt. By evening, the reactor core was stabilized. Over the next few days there were additional dilemmas, including the release of some radioactive gas into the atmosphere, which led to a voluntary evacuation of pregnant women and pre-school aged children who lived within a five mile radius of the plant.

The accident at TMI has been the most serious in U.S. commercial nuclear power plant history, however there were no serious injuries and only small amounts of radiation were measured off-site.

Chernobyl

In the Ukraine, they rely heavily on nuclear power to generate electricity. In 1986, there were four reactors operating at the Chernobyl Power Complex with two more reactors under construction. On April 26, 1986, while conducting tests of Unit 4's reactor behavior at low power settings, plant operators turned off all of the automatic plant safety features. During the test the reactor became very unstable and there was a massive heat surge. Operators were unable to stop the surge and two steam explosions occurred. When air entered the reactor the graphite moderator burst into flames and the entire unit became engulfed in fire.

CHERNOBYL POWER PLANT



The damaged reactor number four of Chernobyl Nuclear Power Plant

The steam explosions, along with burning graphite used to moderate the reactor, released considerable amounts of radioactive material into the environment. Two workers died in the initial explosion and by July, 28 additional plant personnel and firefighters had also died. Between May 2-4, about 160,000 persons living close by the reactor were evacuated. During the next several years an additional 210,000 people were resettled from areas within an approximate 20 mile radius of the plant. Soon after the accident Unit 4 was encased in a cement structure allowing the other reactors nearby to continue operating.

Today about 1,000 people have unofficially returned to live within the contaminated zone. A "New Safe Confinement" structure is being built to more securely contain the radioactive materials that remain in Unit 4. The new structure will encompass Unit 4 and the existing concrete shelter. Scheduled to be completed in 2017, the structure will be 344' high, 492' long, and 843' wide. This is larger than six football fields.

Nuclear Accidents

Fukushima

On March 11, 2011, one of the largest earthquakes in recorded history occurred off the coast of Japan. This earthquake created a tsunami that killed nearly 20,000 people as it destroyed buildings, roads, bridges, and railways. When the earthquake occurred, the seismic instrumentation systems worked as designed and automatically shut down the reactors at the Fukushima Daiichi Nuclear Power Station. Fukushima lost off-site power due to the earthquake damaging transmission towers. This resulted in the emergency diesel generators automatically starting to maintain the cooling of the reactors and the spent fuel pools on site. When the tsunami arrived about 45 minutes later, it was estimated to be nearly 50 feet high—much taller than the 16' seawall constructed to protect the site. When the tsunami hit, all but one of the emergency diesel generators stopped working and DC power from batteries was lost due to the flooding that ensued. Both the emergency diesel generators and the batteries were located in the basement of the turbine building. Beyond that, four of the six reactor units were significantly damaged by the tsunami.

The loss of both AC power from the emergency diesel generators and DC power from the batteries disabled instrumentation needed to monitor and control the situation and disabled key systems needed to cool the reactor units and spent fuel pools. This resulted in damage, which is suspected to include the breech of reactor pressure vessels, leaks in primary containment vessels, and significant damage of nuclear fuel that was partially uncovered. Continued investigation will confirm exact damage as the reactor units and local areas are analyzed. Hydrogen is produced when uncovered zirconium fuel cladding reacts with water, which also resulted in two hydrogen explosions occurring in the upper part of certain reactor buildings.

Lessons Learned

Much was learned by nuclear engineers and operators from these accidents. Although the reactor of Unit 2 at TMI was destroyed, most radioactivity was contained as designed. No deaths or injuries occurred. Lessons from TMI have been incorporated into both evolutionary and passive nuclear plant designs.

While some Chernobyl-style reactors are still operating in Eastern Europe, they have been drastically improved. Training for nuclear plant operators in Eastern Europe has also been significantly improved with an emphasis on safety.

Nearly 20,000 people lost their lives due to the tsunami in Japan, while no deaths have been attributed to radiological causes from the Fukushima accident. Radioactive material was, however, released into the air and water as a result of the accident. The effects of this contamination on the flora and fauna will continue to be monitored and studied. The Fukushima accident will improve nuclear safety as power plant operators and regulators take a closer look at the potential of natural disasters, protecting backup emergency diesel generators and batteries from being disabled, ensuring back-up systems to cool reactors and spent fuel pools are redundant and robust, and modifying hardware to improve function during emergencies.

Nuclear energy remains a major source of electricity in the United States and around the globe. The safe operation of nuclear power plants is important to quality of life and to the health and safety of individuals worldwide.