Location of United States Reactors

In 2017, there were ninety-nine working nuclear reactors in the United States. The majority of these reactors are on the eastern side of the country. Each reactor site houses between one and three reactors. The average age of these nuclear reactors is approximately thirty-six years. Each year, reactor units are rigorously inspected for safety. Also, reactors that cannot meet safety measures or are not able to be upgraded will be placed on shut-down. These reactors will eventually be closed forever or decommissioned.

![Map of working United States commercial reactors](https://upload.wikimedia.org/wikipedia/commons/thumb/4/4f/Working_Nuclear_Reactors_Map.png/220px-Working_Nuclear_Reactors_Map.png)


How a Nuclear Reactor Works

In the United States, nuclear reactors use LEU (low enriched) U-235 as fuel. After mining, uranium is purified to a level no greater than 4%. The fuel undergoes a continuous, controlled fissionable reaction. Click on the video below to see the inner workings of a typical nuclear reactor.
Video \(\PageIndex{1}\): Nuclear Energy Explained: Risk or Opportunity. Anything with the word nuclear next to it usually comes with a fair bit of misunderstanding. Hopefully, this video demystifies the process of how nuclear fuels are turned into electricity and how we can use them in combination with renewables to reduce greenhouse gas emissions and the effects on the climate that comes with high levels of them.

Components of a Reactor

Chain reactions of fissionable materials can be controlled and sustained without an explosion in a nuclear reactor. Any nuclear reactor that produces power via the fission of uranium or plutonium by bombardment with neutrons must have at least five components: nuclear fuel consisting of fissionable material, a nuclear moderator, reactor coolant, control rods, and a shield and containment system.

The reactor works by separating the fissionable nuclear material such that a critical mass cannot be formed, controlling both the flux and absorption of neutrons to allow shutting down the fission reactions. In a nuclear reactor used for the production of electricity, the energy released by fission reactions is trapped as thermal energy and used to boil water and produce steam. The steam is used to turn a turbine, which powers a generator for the production of electricity.
Figure \(\PageIndex{2}\): A Light-Water Nuclear Fission Reactor for the Production of Electric Power. The fuel rods are made of a corrosion-resistant alloy that encases the partially enriched uranium fuel; controlled fission of \(^{235}\text{U}\) in the fuel produces heat. Water surrounds the fuel rods and moderates the kinetic energy of the neutrons, slowing them to increase the probability that they will induce fission. Control rods that contain elements such as boron, cadmium, or hafnium, which are very effective at absorbing neutrons, are used to control the rate of the fission reaction. A heat exchanger is used to boil water in a secondary cooling system, creating steam to drive the turbine and produce electricity. The sizeable hyperbolic cooling tower, which is the most visible portion of the facility, condenses the steam in the secondary cooling circuit; it is often located at some distance from the actual reactor.

Nuclear Fuels

Naturally occurring uranium is composed almost totally of two uranium isotopes. It contains more than \(\frac{99}{\%}\) uranium-238 and less than \(\frac{1}{\%}\) uranium-235. It is the uranium-235. However, that is fissionable (will undergo fission). For uranium to be used as fuel in a fission reactor, the percentage of uranium-235 must be increased, usually to about \(\frac{3}{\%}\). (Uranium in which the \(\%\) content is more than \(\frac{1}{\%}\) is called enriched uranium.) The enriched UF\(_6\) gas is collected, cooled until it solidifies, and then taken to a fabrication facility where it is made into fuel assemblies. Each fuel assembly consists of fuel rods that contain many thimble-sized, ceramic-encased, enriched uranium (usually UO\(_2\)) fuel pellets. Modern nuclear reactors may contain as many as 10 million fuel pellets. The amount of energy in each of these pellets is equal to that in almost a ton of coal or 150 gallons of oil. Once the supply of \(\%\)-235 is acquired, it is placed in a series of long cylindrical tubes called fuel rods. These fuel cylinders are bundled together with control rods made of neutron-absorbing material. The amount of \(\%\)-235 in all the fuel rods taken together is adequate to carry on a chain reaction but is less than the critical mass. (In the United States, all public nuclear power plants contain less than a critical mass of \(\%\)-235 and therefore, could never produce a nuclear explosion.)
Nuclear Moderators

Neutrons produced by nuclear reactions move too fast to cause fission (Figure \(\PageIndex{4}\)). They must first be slowed to be absorbed by the fuel and produce additional nuclear reactions. A nuclear moderator is a substance that slows the neutrons to a speed that is low enough to cause fission. Early reactors used high-purity graphite as a moderator. Modern reactors in the US exclusively use light water (ordinary H\(_2\)O), whereas some reactors in other countries use other materials, such as carbon dioxide, beryllium, or graphite.

\(\text{Figure } \PageIndex{4})\): The Magnox reactor is utilized by Russia and the United Kingdom. wikipedia/commons/thumb/1/10/Magnox_reactor_schematic.svg/2000px-Magnox_reactor_schematic.svg.png
Reactor Coolants

A nuclear reactor coolant is used to carry the heat produced by the fission reaction to an external boiler and turbine, where it is transformed into electricity. Two overlapping coolant loops are often used; this counteracts the transfer of radioactivity from the reactor to the primary coolant loop. All nuclear power plants in the US use light water as a coolant. Other coolants include molten sodium, lead, a lead-bismuth mixture, or molten salts.

Control Rods

Nuclear reactors use control rods (Figure \((\PageIndex{4})\)) to control the fission rate of the nuclear fuel by adjusting the number of slow neutrons present to keep the rate of the chain reaction at a safe level. Control rods are made of boron, cadmium, hafnium, or other elements that are able to absorb neutrons. Boron-10, for example, absorbs neutrons by a reaction that produces lithium-7 and alpha particles:

\[
\text{\ce{^10_5B + ^1_0n -> ^7_3Li + ^4_2He}}
\]

When control rod assemblies are inserted into the fuel element in the reactor core, they absorb a larger fraction of the slow neutrons, thereby slowing the rate of the fission reaction and decreasing the power produced. Conversely, if the control rods are removed, fewer neutrons are absorbed, and the fission rate and energy production increase. In an emergency, the chain reaction can be shut down by fully inserting all of the control rods into the nuclear core between the fuel rods.

*Figure \((\PageIndex{5})\): The nuclear reactor core shown in (a) contains the fuel and control rod assembly shown in (b). (credit: modification of work by E. Generalic, [http://glossary.periodni.com/glossar...en=control+rod](http://glossary.periodni.com/glossar...en=control+rod))
Shield and Containment System

During its operation, a nuclear reactor produces neutrons and other radiation. Even when shut down, the decay products are radioactive. In addition, an operating reactor is thermally very hot, and high pressures result from the circulation of water or another coolant through it. Thus, a reactor must withstand high temperatures and pressures, and must protect operating personnel from the radiation. Reactors are equipped with a containment system (or shield) that consists of three parts:

1. The reactor vessel, a steel shell that is 3–20-centimeters thick and, with the moderator, absorbs much of the radiation produced by the reactor
2. A main shield of 1–3 meters of high-density concrete
3. A personnel shield of lighter materials that protects operators from γ rays and X-rays

In addition, reactors are often covered with a steel or concrete dome that is designed to contain any radioactive materials might be released by a reactor accident.


Nuclear power plants are designed in such a way that they cannot form a supercritical mass of fissionable material and therefore cannot create a nuclear explosion. But as history has shown, failures of systems and safeguards can cause catastrophic accidents, including chemical explosions and nuclear meltdowns (damage to the reactor core from overheating).

Two Types of United States Commercial Reactors

In the United States, commercial reactors can be one of two types. Sixty-five reactors are pressurized water reactors (or PWRs). This type of reactor uses light water as a moderator and a coolant. The water in the reactor is kept under high pressures. This type of configuration does not allow water to boil. The water inside the reactor transfers its heat to the water in a steam generator. Then, steam is produced to aid in the production of electrical energy.
The other thirty-four commercial reactors are boiling water reactors (BWRs). These reactors also use light water as their moderator and coolant. Here, the water in the reactor is allowed to boil. This heated water goes directly to the turbine house which is separated from a generator. The radioactive water that goes through the turbine is contained inside the nuclear facility. Cooling this water with a condenser allows it to be returned into the reactor and used for coolant once again.

References


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