



# Nuclear Reactors: How They Work

## Fission Process and Control

In nuclear power reactors, energy is produced by the *nuclear fission* process in which uranium atoms are split into two major atoms, called fission products, with significant heat generation. A nuclear reactor system is controlled to ensure that the fission process is a sustained nuclear *chain reaction* (see Fig. 1) that neither declines nor increases with operation time, i.e., it is at steady-state. Control rods are employed to ensure that the nuclear process is controlled appropriately for safe and smooth operation. Should the need arise, such as in an emergency or planned power shut-off, the control rods are inserted to shut down the fission process.

## Heat Production and Removal and Power Production

The heat produced during reactor operation is removed by a flowing coolant, e.g. water, and the heat is then converted into mechanical energy for driving the turbine-generator used in producing power to the electric-energy grid. Different engineering design approaches are used for doing this in the different reactor systems deployed worldwide and include the use of loops, pumps, valves, heat exchangers and/or steam generators. Other than the use of the nuclear fission process, the engineering systems used in nuclear reactors are similar to those at other types of large power generating stations.

Most of the nuclear products from the fission process emit radiation and transform into other materials via the radioactive decay process. This process is accompanied by a significant amount of heating (different from the fission power). When the reactor is shut down by inserting the control rods, the power drops to about 6% to 8% of its operating level, all due to heating from radioactive decay. Consequently, reactor cooling systems and backup systems are designed such that the reactor is cooled appropriately during both operating (fission power) and shutdown (decay heat) states, to ensure that the fuel and cladding are not overheated. Over time, the radioactive materials emit less and less radiation and heat.

Reactor plants use various levels of redundancy to ensure adequate cooling under all plausible normal and off-normal conditions. This includes the use of primary cooling systems, backup systems, and, in the case of the newest plant designs, passive safety cooling systems. Provision is also made for battery-driven systems, under conditions when those primary means of cooling are inactive. Collectively, these systems are designed to withstand impacting engineering initiators and natural initiators such as earthquakes and tsunamis.

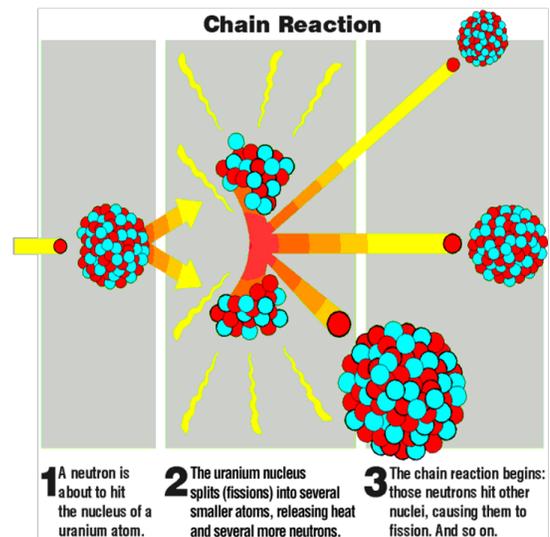


Figure 1. Nuclear Chain Reaction

## Containment of Radiation and Sources

A primary distinction between the nuclear and other power generation systems is the radiation that is produced during the nuclear process, which arises from products of the nuclear process, e.g., the fission products, heavy metals like plutonium, and nuclear particles such as gamma rays, neutrons, protons, and electrons. This necessitates shielding the environment from the reactor. As a result, attention is paid to shielding as part of reactor design. Additionally, various levels of radiation containment are employed in nuclear systems. Three primary barriers, called defense-in-depth, are included in most commercial reactor designs: (1) the fuel cladding that contains the nuclear fuel, (2) the reactor metallic vessel that contains the fuel-cladding, and (3) the *primary* containment structure that encloses vessel.

## Worldwide Nuclear Power Systems

Worldwide, nearly all nuclear power production comes from water-cooled reactor systems. The 99 nuclear reactor units currently operating in the United States generate about 20% of the country's electricity capacity and are light-water cooled reactors (LWRs) of the pressurized-water reactor (PWR, see Fig. 2) and boiling-water reactor (BWR, see Fig. 3) types.

Other water-cooled reactor systems are utilized in some other countries, such as the heavy-water-cooled CANDU systems used in Canada (also India, Republic of Korea (but also PWRs), and Romania), and the VVER systems used in Russia and former soviet-bloc countries and Finland (similar to the PWRs). In the United Kingdom, gas-cooled reactors have been deployed for electricity production.

In the commercial nuclear power reactors utilized worldwide, enriched-uranium dioxide (UOX) fuel is used. The uranium constituent is about 3-5% U-235 and the balance is U-238; these are the isotopes of uranium that are found in nature, but with the content of U-235 boosted by the enrichment process. In some reactors in Europe, predominantly in France, and some in Japan, mixed uranium-plutonium oxide (MOX) fuel is also being used. The UOX and MOX fuels behave very similarly in the commercial plants. These fuel materials are contained in zirconium-alloy cladding tubes, and these tubes are constituents of a fuel assembly (over 60 tubes in BWRs and over 225 tubes in PWRs). About 200 to 650 assemblies are in a nuclear reactor.

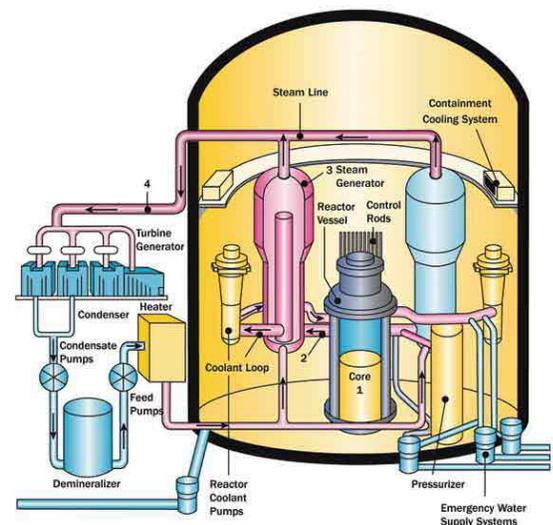


Figure 2. Schematic of PWR

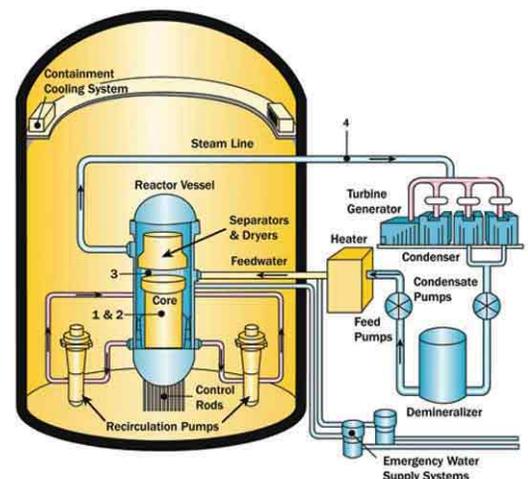


Figure 3. Schematic of BWR