Introduction

Nuclear fission occurs because of the absorption of neutron by fissile material. Neutrons are released by nuclear fission, and since the number of neutrons released is sufficiently greater than 1, a chain reaction can be established. This allows, in turn, for energy to be extracted from the process. The amount of extracted energy can be adjusted by controlling the number of neutrons. The higher the power density is raised, the greater the economic efficiency of the reactor. The energy is extracted usually as heat via the coolant circulating in the reactor core. Finding the most efficient way to extract the energy is a critical issue. The higher the coolant output temperature is raised, the greater the energy conversion efficiency of the reactor.

“Transport Equation and Diffusion Equation”, is a basis of “Reactor Analysis”. This field addresses the neutron transport including changes of neutron characteristics. Discovery of the Neutron, Nuclear Fission and Invention of the Nuclear Reactor Technology generally progresses gradually by the accumulation of basic knowledge and technological developments. In contrast, nuclear engineering was born with the unexpected discovery of neutrons and nuclear fission, leading to a sudden development of the technology.

The neutron was discovered by Chadwick in 1932. This particle had previously been observed by Irene and Frederic Joliot-Curie. However, they interpreted the particle as being a high energy γ-ray. Considering that the Joliot-Curies were excellent scientists and later received a Nobel Prize, it can be understood how difficult it was to predict the neutron at that time. The discovery of neutrons clarified the basic structure of the atomic nucleus (often referred to as simply the “nucleus”), which consists of protons and neutrons. At the same time, the discovery of neutrons provided an extremely effective technology for producing nuclear reactions. Since the nucleus is very small, it is necessary to bring reacting nuclei close to each other in order to cause a nuclear reaction. Since the nucleus has a positive charge, a very large amount of energy is required to bring the nuclei close enough so that a reaction can take place. However, the neutron has no electric charge; thus, it can easily be brought close to a nucleus. Fermi clarified the effectiveness of this method by carrying out numerous nuclear reactions using neutrons, for which he received a Nobel Prize, and discovered that many nuclei can easily react with neutrons if the neutrons are moderated.
Progress in nuclear physics

1808 Dalton: Atomic theory
1876 Goldstein: Cathode rays
1891 Stoney: Prediction of electrons
1895 Roentgen: X-rays
1896 Becquerel: Radioactivity
1897 Thomson: Cathode rays = electrons
1898 Rutherford: $\alpha$-rays and $\beta$-rays
1900 Planck: Quantum theory
1905 Einstein: Special relativity theory
1911 Rutherford: Atomic model
1912 Thomson: Isotope
1914-1918 World War 1
1919 Aston: Mass spectrometer
1921 Harkins: Prediction of neutrons
1930 Bothe: Be ($\alpha$, ?)
1932 Irene and Frederic Joliot-Curie: Be ($\alpha$, $\gamma$) Chadwick: Neutron discovery
1934 Fermi: Delayed neutrons Szilard: Chain reaction
1939-1945 World War 2 1939 Hahn, Strassman, Meitner: Discovery of nuclear fission
1942 Fermi: CP–1 made critical
1944 First plutonium production reactor made critical (Hanford, USA)
1945 Test of atomic bomb (USA)
1945 Natural uranium heavy water research reactor (ZEEP) made critical (Canada)
1946 Fast reactor (Clementine) made critical (USA)
1950 Swimming pool reactor (BSR) made critical (USA)
1951 Experimental fast breeder reactor (EBR-1) made critical and generates power (USA)
1953 Test of hydrogen bomb (USSR) “Atoms for Peace” Initiative (United Nations, USA)
1954 Launch of the nuclear submarine “Nautilus” (USA) Graphite-moderated water-cooled power reactor (AM-1) generates power (USSR) Nuclear fission was discovered by Hahn, Strassman, and Meitner in 1939.
Fission should have taken place in Fermi’s experiments. The fact that Fermi did not notice this reaction indicates that nuclear fission is an unpredictable phenomenon. In 1942, Fermi created a critical pile after learning about nuclear fission and achieved a chain reaction of nuclear fission. The output power of the reaction was close to nil, however, this can be considered the first nuclear reactor made by a human being. We can understand how the discovery of the neutron and nuclear fission was unexpected. This is very similar to the case of X-rays, where several X-ray generators were put on the market in the year following the discovery of X-rays by Roentgen in 1895, and X-rays began to be used not only in the laboratory but also for practical applications such as for the treatment of cancer and for hair removal. However, it is not the case that a nuclear reactor can be built simply by causing fissions by bombarding nuclei with neutrons. The following conditions have to be satisfied for nuclear fission reactions. (As it turned out, these conditions could be satisfied within one year after the discovery of nuclear fission.)

① Exoergic reaction ② Sustainable as a chain reaction ③ Controllable Details of these conditions

It was obvious to the researchers of that time that a nuclear reaction can generate approximately one million times the energy of a chemical reaction. The above-mentioned first nuclear reactor was built by Fermi under a plutonium production project for atomic bombs. In a nuclear reactor, radioactive material is rapidly formed. Therefore, nuclear reactors have the following unique and difficult issues, which did not have to be considered for other power generators.

① Safety ② Waste ③ Nuclear proliferation

The first nuclear reactor was built in the middle of World War II in the military research and development program known as the Manhattan Project. Its products were the atomic bombs using enriched uranium and plutonium. One of the reasons for this war was to secure energy sources. After the war, the energy problem remained a big issue. Thus, large-scale development of nuclear engineering was started in preparation for the exhaustion of fossil fuels. Light-water reactors, which were put into practical use in nuclear submarines, were established in many countries. These reactors are not a solution to the energy problem, since they can utilize less than 1% of natural uranium. Fast reactors, on the other hand, can use almost 100% of natural uranium. However, after new energy resources were discovered and the depletion of resources became remote, the development of fast reactors, which were considered the solution to the energy problem at the time, met a world-wide setback. Now the problem of the global environment is at the fore, and nuclear engineering, which does not generate carbon dioxide, is being reconsidered. Nuclear engineering is an excellent technology by which tremendous amounts of energy is generated from a small amount of fuel. In addition to power generation, numerous applications are expected in the future. As well as being used in energy generation, neutrons are expected to be widely used as a medium in nuclear reactions.