1. Nuclear Power

Nuclear power generation utilizes nuclear power which created by the nuclear fission. The nuclear fission in which a **neutron** strikes the nucleus of a uranium atom and is absorbed. The absorption of the neutron makes the nucleus unstable, causing it to split into two atoms of lighter elements, for example,

$n + {}^{235}U \rightarrow {}^{93}Kr + {}^{141}Ba + 2n + 195\ MeV$,

and release heat and new neutrons. The heat is used to produce electricity while the neutrons potentially can be absorbed by other atoms of uranium, resulting in more nuclear fissions. This continuing process of fissioning is called a **chain reaction**. It is sustained because, for every atom of uranium fissioned by a neutron, new neutrons are released to continue the process.

The produced energy was origin from the **meson** which acts as the binding power combining the **proton** and neutron in the atom. A ${}^{235}U$ nuclear fission produces the power of $3.2\ 10^{-11}$ J, whereas the combustion of a molecule carbon (C) produces the power of $6.4\ 10^{-19}$ J.

NOTE: 1 **eV** is the obtaining power when a particle having 1 **elementary electric charge** is accelerated between 1 V potential difference in vacuum. 1 kg= $5.609545\ 10^{26}$ MeV, 1 eV= $1.602\ 10^{-19}$ J.

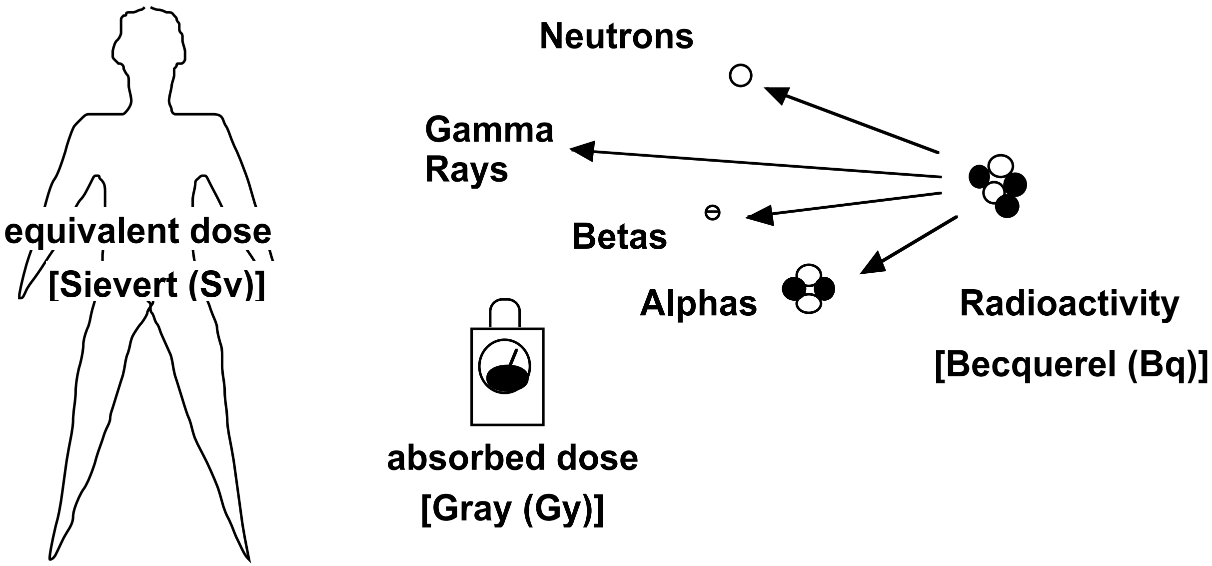
2. Basic Terms

a. Radioactivity

Radioactivity is the spontaneous transformation of an unstable atom and often results in the emission of radiation. This process is referred to as a transformation, a decay or a disintegrations of an atom.

b. Dose

In a general sense, Dose is a measure of the amount of energy from an ionizing radiation deposited in a mass of some material. Dose is affected by the type of radiation, the amount of radiation and the physical properties of the material itself. Specifically, we can talk about absorbed dose in tissue, or material like silicon. Other common doses are the effective and equivalent doses, which are adjusted to allow the comparison of different tissues or types of radiation. Absorbed doses are normally measured in units of grays (rads), and effective and equivalent doses in sieverts (rems).



Dose equivalent (HT) means the product of the absorbed dose in tissue, quality factor, and all other necessary modifying factors at the location of interest. The units of dose equivalent are the rem and sievert (Sv). 1 Sv = 100 rem.

Effective dose equivalent (HE) is the sum of the products of the dose equivalent to the organ or tissue (HT) and the weighting factors (WT) applicable to each of the body organs or tissues that are irradiated (HE = WTHT).

c. Common Types of Radiation

! **Gamma Rays**

Gamma rays are electromagnetic waves or photons emitted from the nucleus (center) of an atom.

! **Betas**

A beta is a high speed particle, identical to an electron, that is emitted from the nucleus of an atom

! **Alphas**

An alpha is a particle emitted from the nucleus of an atom, that contains two protons and two neutrons. It is identical to the nucleus of a Helium atom, without the electrons.

! **Neutrons**

Neutrons are neutral particles that are normally contained in the nucleus of all atoms and may be removed by various interactions or processes like collision and fission

! **X rays**

X Rays are electromagnetic waves or photons not emitted from the nucleus, but normally emitted by energy changes in electrons. These energy changes are either in electron orbital shells that surround an atom or in the process of slowing down such as in an X-ray machine.

d. Common Unit

! **Gray (Gy)**

The gray is a unit used to measure a quantity called **absorbed dose**. This relates to the amount of energy actually absorbed in some material, and is used for any type of radiation and any material. One gray is equal to **one joule** of energy deposited in one kg of a material. The unit gray can be used for any type of radiation, but it does not describe the biological effects of the different radiations. Absorbed dose is often expressed in terms of hundredths of a gray, or centi-grays. One gray is equivalent to 100 rads.

! **Sievert (Sv)**

The sievert is a unit used to derive a quantity called **equivalent dose**. This relates the absorbed dose in human tissue to the effective biological damage of the radiation. Not all radiation has the same biological effect, even for the same amount of absorbed dose. Equivalent dose is often expressed in terms of millionths of a sievert, or micro-sievert. To determine equivalent dose (Sv), you multiply absorbed dose (Gy) by a quality factor (Q) that is unique to the type of incident radiation. One sievert is equivalent to 100 rem.

! **Becquerel (Bq)**

The Becquerel is a unit used to measure a **radioactivity**. One Becquerel is that quantity of a radioactive material that will have 1 transformations in one second. Often radioactivity is expressed in larger units like: thousands (kBq), one millions (MBq) or even billions (GBq) of a becquerels. As a result of having one Becquerel being equal to one transformation per second, there are 3.7×10^{10} Bq in one **curie**.

e. Common Policy of the Nuclear Power Generation Industry

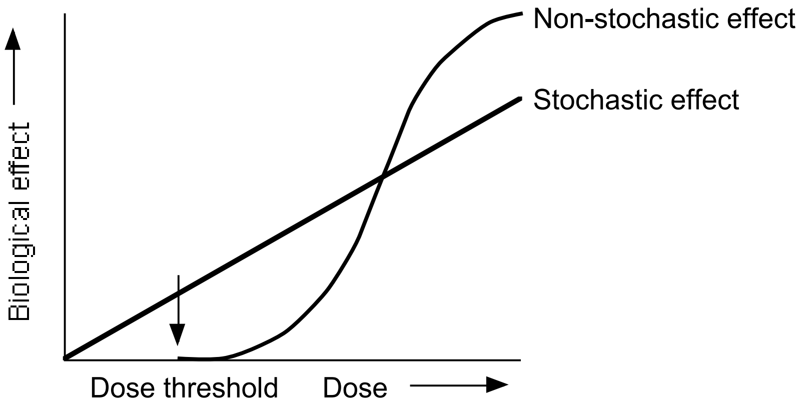
There are two types of biological effect of the dose, stochastic effect and non-stochastic effect.

! **Stochastic effects**

Stochastic effects are effects that occur on a random basis with its effect being independent of the size of dose. The effect typically has **no threshold** and is based on probabilities, with the chances of seeing the effect increasing with dose. Cancer is a stochastic effect. Genetic influence of dose is also stochastic effect, and it follows the consideration on the public dose.

! **Non-stochastic effect**

Non-stochastic effects are effects that can be related directly to the dose received. It typically has a threshold, below which the effect will not occur. A skin burn from radiation is a non-stochastic effect.

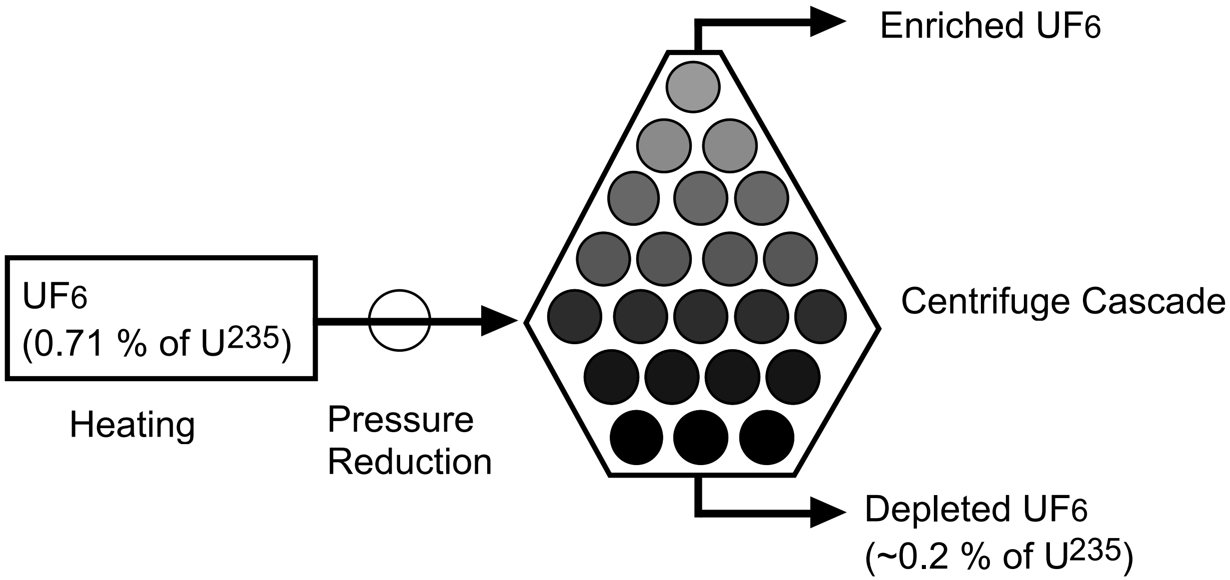


! **ALARA** (as low as is reasonably achievable) :

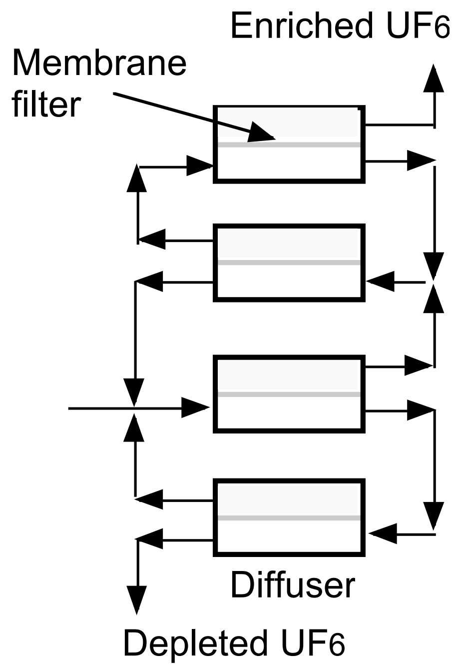
means making every reasonable effort to maintain exposures to radiation as far below the dose limits as is practical consistent with the purpose for which the licensed activity is undertaken, taking into account the state of technology, the economics of improvements in relation to state of technology, the economics of improvements in relation to benefits to the public health and safety, and other societal and socioeconomic considerations, and in relation to utilization of nuclear energy and licensed materials in the public interest.

f. Nuclear fuel - Uranium enrichment

In the enrichment plant the UF6 are put into a heating chamber in order to vaporize the UF6. After pressure reduction by control valves and restrictors, the UF6 is fed into the cascades, where it is divided into two output streams by the centrifuges. One is enriched in U-235 and the other depleted in U-235. The separation effect is expressed in Separative Work Units (SWUs or kgSW or tSW) calculated by a standard formula. The higher the U-235 content of the enriched uranium and the lower the U-235 content of the depleted uranium, the more SWUs are required. Following is the centrifuge type enrichment plant model.



Centrifuge Method



Gas diffusion Method

NOTE: The conventional enrichment plants adopt the gaseous diffusion process.

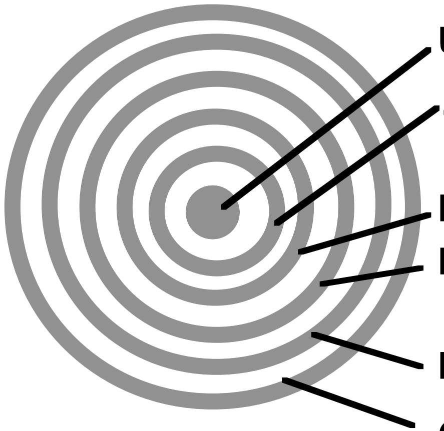
3. Characteristics of the Nuclear Power Plant

a. Steam conditions

The large value of the **specific power** (power per **working medium**) is one of the characteristics of the nuclear power. The specific power of the thermal power plant is about 10 kW/m^3, though, the value of the nuclear power plant is 1,300 kW/m^3 (BWR) or 1,900 kW/m^3 (PWR). Nuclear power plants show these high level of the power, however, the temperature of the working medium (water) is limited because of the nuclear fuel temperature limitation (300 ~ 400 degree C), and it introduces the **poor steam condition**. For this reason, the plant equipments such as turbine are relatively large comparing the thermal power plant which has comparable output power.

b. Radioacitivitiy isolation

The protection of **operators and residents** living near the plant from the radioactivity is the specific problem of the nuclear power plant. For this purpose, plant design adopts the **multiple protection** policy.



UO_2 pellet : adequate mechanical/thermal strength

Zircaloy fuel cladding pipe : corrosion resistance at the high-temperature

Pressure vessel : pressure resistance reactor vessel

Reactor containment : pressure resistance container of reactor and primary coolant system

Reactor building : shielding reinforced concrete building

Controlled area definition : controlling the entrance area considering annual dose (5 mSv)

NOTE: Background dose is 1~2 mSv

4. Nuclear Power Plant - Light Water Reactor

a. Characteristic safeties of light water reactor

The light water reactor which is using low enriched uranium dioxide has characteristic safeties for preventing the reactor runaway.

! **fuel rod safety**

Decreasing the reactivity when the temperature of the fuel rod increased by the Doppler effect

! **moderator safety**

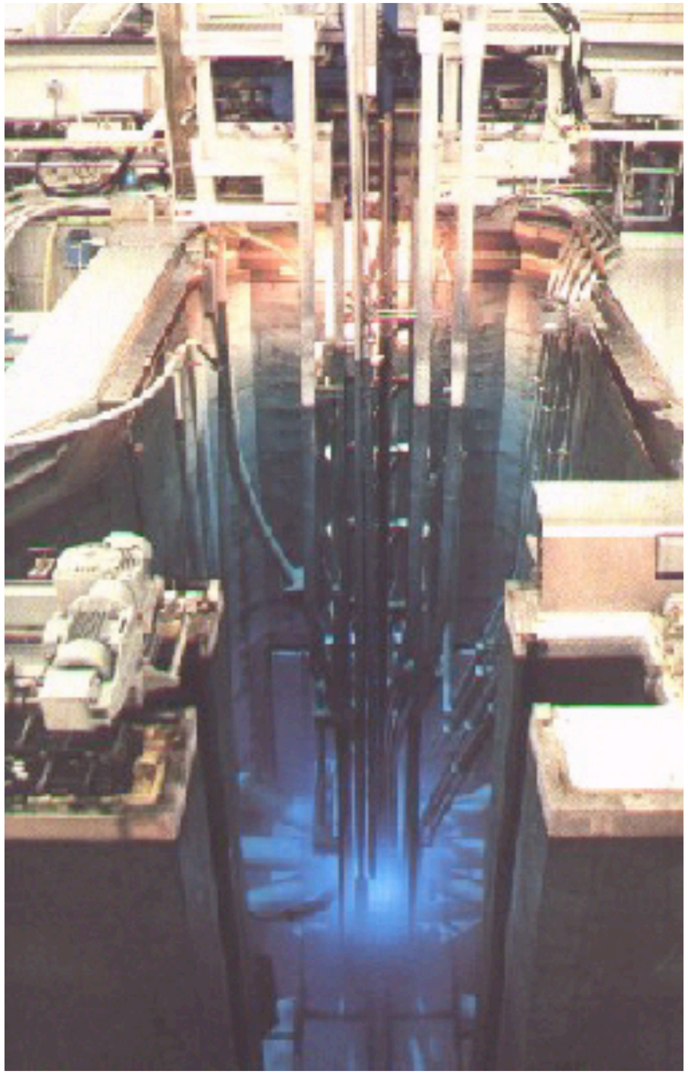
Decreasing the reactivity when the temperature of the moderator (water) increased

! **void safety**

Decreasing the reactivity when increasing the void with the increase of the output power

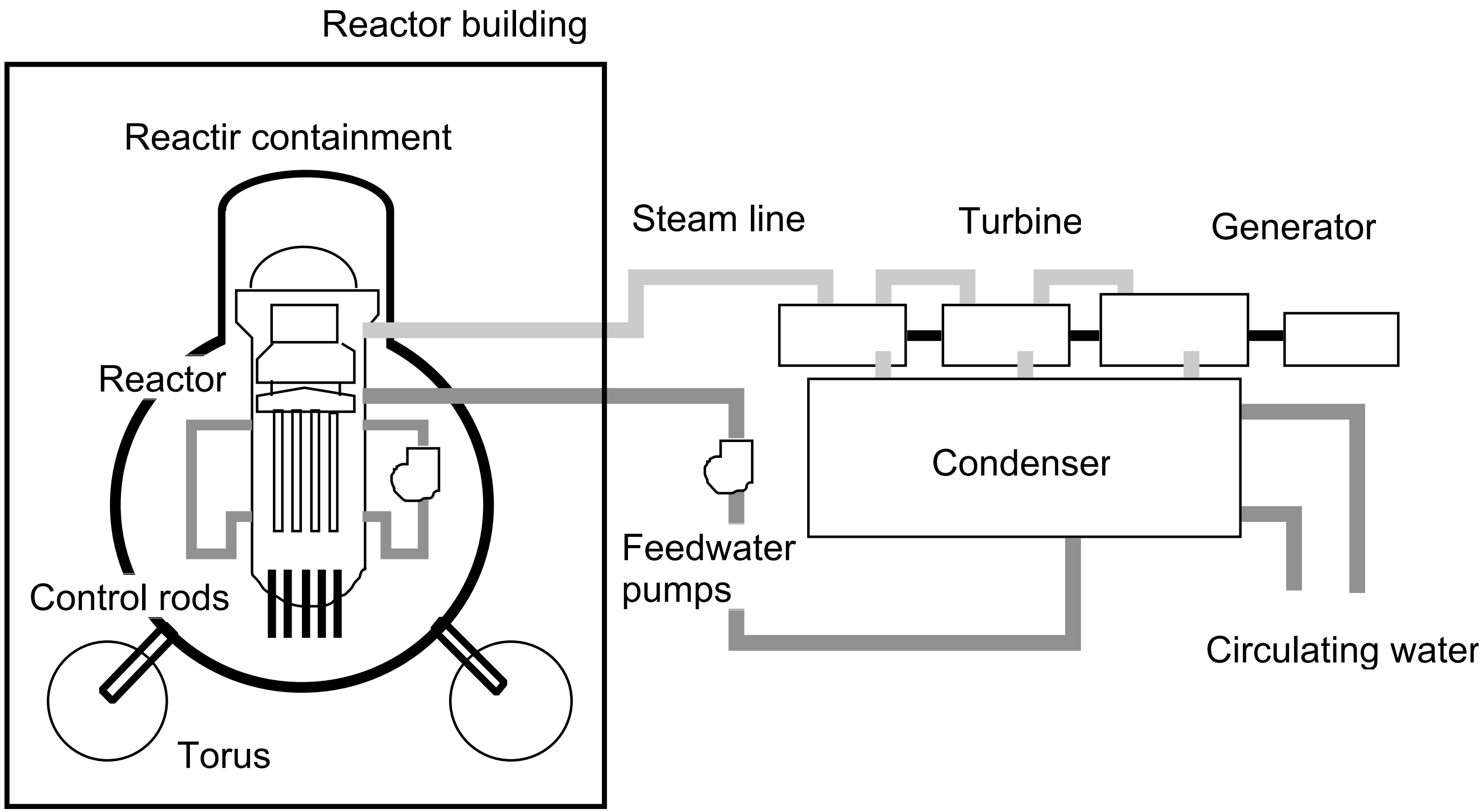
b. fuel conversion

In the reactor, ^{238}U is converted to ^{239}Pu absorbing 1 neutron. The converted ^{239}Pu acts as the fuel.



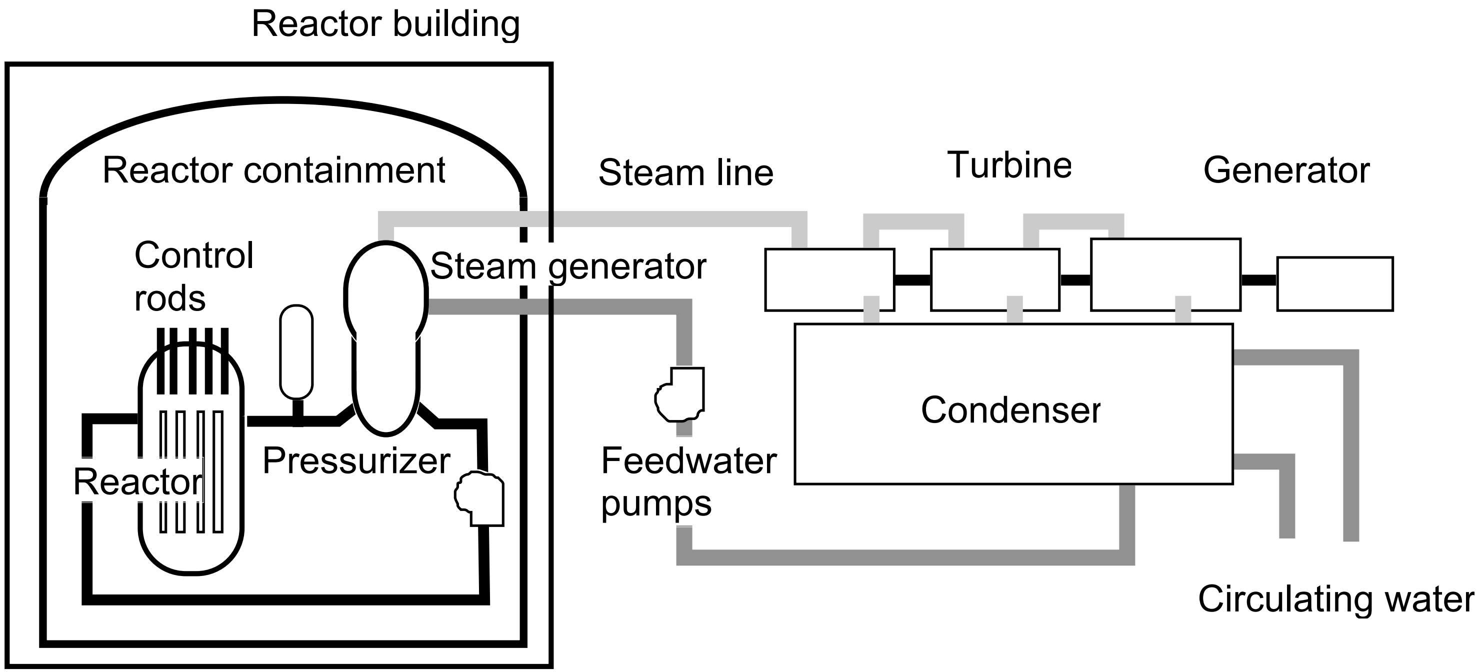
Delft nuclear reactor of the Delft University of Technology Interfacultair Reactor Institute

b. BWR



Boiling Water Reactor

c. PWR



Pressurized Water Reactor