CHAPTER 1
INTRODUCTION

1.1 Introduction

Wealth of humankind is closely related to energy. The progress and the welfare of a society have always relied on supply of energy in convenient form. This has led to positive developments to advance technology for energy utilization but also to conflict over limited resources.

Total generation of electrical energy in 2009 was 20093.6TWh. Approximately 14% of this electricity was produced with 438 nuclear power plants, while electricity produced using fossil fuel amounted to 68%. Nuclear power and fossil fuels accounted for 82% of the whole electricity production, while this generation has been criticized heavily. The major problem of the nuclear power industry is waste management and safety related issues, while coal is a huge source of greenhouse gas emissions and air pollution. Both can therefore be seen as non-sustainable energy forms. In the case of coal fired power plant, this assessment is easy to do: it emits huge amounts of unwanted gases in to the atmosphere, uses vast amounts of nonrenewable resources (coal) to produce electricity and has rather low efficiency per kilogram of coal. On the other hand.[1]
nuclear power may or may not be looked at as non-sustainable, depending on the type of the power plant and the choices in fuel cycle. The concern of this paper is first to introduce the nuclear power plant and fuel cycle principles to the reader and then assess the sustainability of the nuclear power plant.

The Structure of this dissertation is as follows; in first chapter most important aspects of nuclear physics for nuclear plant technology are explained. In the second chapter the source-end of nuclear fuel cycle is introduced. Current and future technologies are presented in third chapter with reasonable detail. The most problematic question is addressed in the fourth chapter, which is devoted to the nuclear waste management. [2]

1.2 Background

A nuclear power plant is a thermal power station in which the heat source is a nuclear reactor. As is typical in all conventional thermal power stations the heat is used to generate steam which drives a steam turbine connected to a generator which produces electricity.

Nuclear power has been used in a wide variety of applications for decades. Most people are at least vaguely familiar with the existence of nuclear power plants for civil utilities and aboard naval vessels, but perhaps not so familiar with the details surrounding them. Beyond that is a whole class of nuclear-based, electricity-producing devices that are sometimes called atomic batteries, which are used on spacecraft and are relatively unknown to the public at large.

1.3 Objectives

- To Know, Electrical power generation using high technology in nuclear power reactor.
- This will also induce high technology in power sector.
- The operation of different sections of Nuclear power plants.

1.4 Methodology

Collection of data from different books and internet.

1.5 Basic Block Diagram of Nuclear power plant.

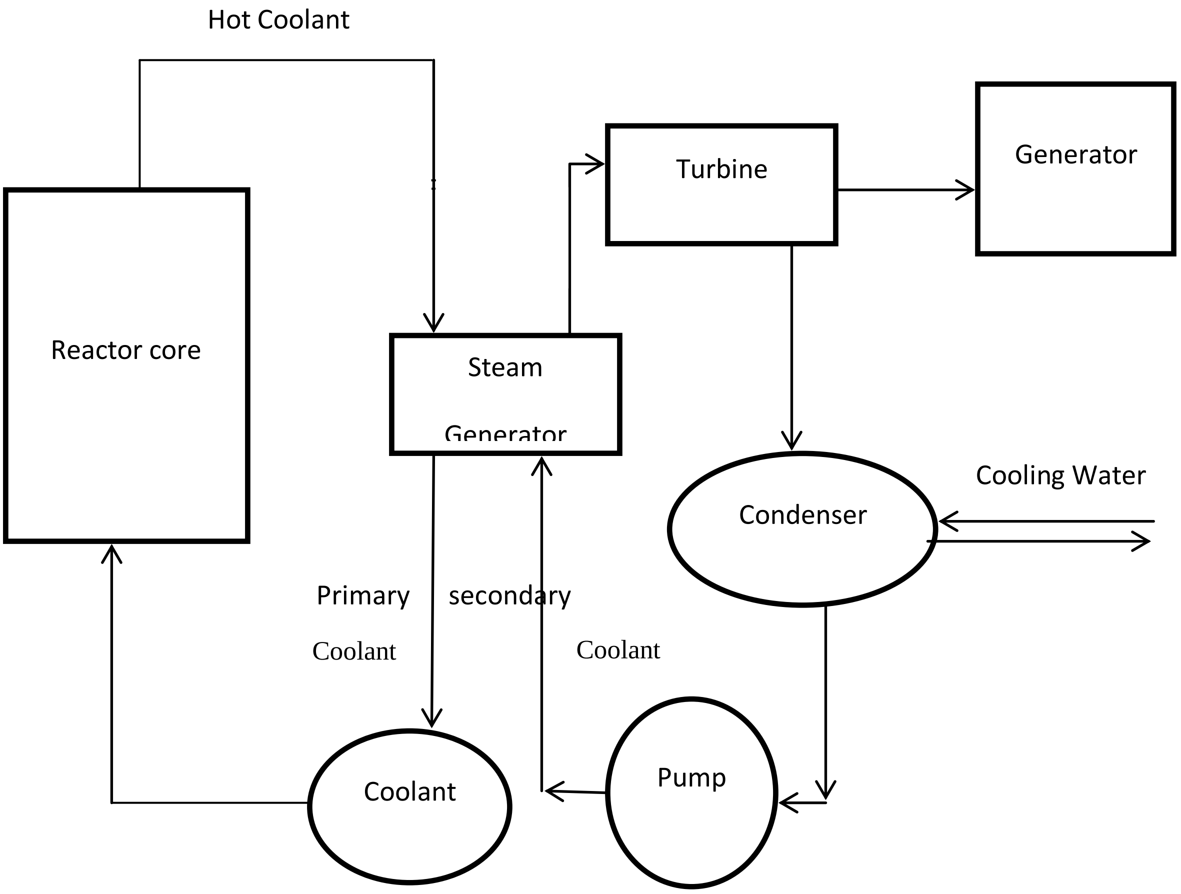


Fig: Block Diagram of Nuclear Power Plant

(In steam generator primary & secondary circuit are physically saperated but thermaly connected)

1.6 Terminology

The protons and neutrons (nucleons) constitute the nucleus (size & mass). The fundamental charged particle in the nucleus is called proton, while the charge of proton is positive. The number of protons in the atom is depicted with the letter (A=Atomic number i.e # of proton) The simplest atom, hydrogen, has only 1 proton (Z=Mass number i.e # of P+N), but it is not charged by nature. Hence, there has to be some other particle outside of the nucleus to nullify the charge. This particle is electron; very small (mproton = 1837 melectron), negatively charged particle in an orbit around the nucleus. The neutron is a neutral particle in the nucleus and therefore it is not affected by the Coulomb forces, which is a very important feature of the neutron. A neutron weighs slightly more than a proton, but the difference (0,1%) is so small that it can be disregarded. [3]

The weight of the atom, the total mass number (number of nucleons, protons and neutrons, in the nucleus), is referred to by the letter A. For a hydrogen atom, this is also 1 (A=1). Indicating specific nuclear species, notation of ${}_Z^AX_N$ could be used. However, most of the time notation ${}^AX$ is used, for example ${}^{235}U$.

The difference between hydrogen ${}^1H$, Deuterium ${}^2H$ and Tritium ${}^3H$ is the neutron count. Atoms with the same number of protons, but different neutron number, are said to be isotopes. Isotopes share the chemical properties, but their nuclear properties are different. For example, uranium has 10 different isotopes (mass numbers from 232 to 241). Many of these isotopes can be only made through nuclear reactions and they decay quickly towards more stable form. These isotopes are called radioisotopes.

1.7 Units and dimensions

Useful length in the nuclear level is a fathometer (fm), which is 10^{-15} m (Suppers & Storvick, 2007). Diameters range from 1 fm for a proton, and neutron, to 7 fm of the heaviest nuclei (Suppes & Storvick, 2007). By contrast, the average diameter of atom is close to 2×10^{-10} m, more than 25,000 times the size of nucleus, while most of this space is taken up by the electron orbit. (Suppes & Storvick, 2007). (Krane, 1988)

Time scales in the nuclear world vary greatly. Some nuclei decay to form another nucleus on the time order of 10^{-20} seconds. There are however vast number of nuclei with lifetimes of minutes or hours, but sometimes lifetimes can be more than millions of years or longer for stable elements. [4]

Energies in the nuclear level are measured with million electron volts (MeV), where 1 eV is the energy gained by single unit of electronic charge when accelerated through a potential difference of one volt.

The unified atomic mass unit, u, is the measurement of mass in the nuclear level. It is defined so that 12C weights 12 u, making one nucleon weigh 1 u. When reactions and decays are analyzed, it is easier to have mass energies to work with, rather than mass itself. This is done by using Einstein's famous,

$$E=mc^2$$

Here E=Energy in evg, m =mass in gus,c =velocity of light=3×10^{8} m/sec

When using unified mass units the conversion can be done using factor of 1 u = 931.502 MeV. (Krane, 1988) [5]

1.8 Forces in the nucleus

The proton is a charged particle and therefore under influence of the Coulomb force. Every nucleus should “explode” due to the Coulomb force, but there is a force which holds it together.

This force is called nuclear force and it affects every nucleon in the nucleus. As neutrons have no charge, they are strongly pulled towards each other by the nuclear force, without any counteracting force. They act as glue to the nucleus, holding it together. The nuclear force is very strong, but it also acts over very short distance; about 1 fm. As the nuclear force has very short range, it is possible to disintegrate the nucleus if enough energy is inserted into it. This property of nucleus is used when fission of nucleus is induced. (Krane, 1988)
Coulomb potential can be calculated with equation

$$V(r) = \frac{1}{4\pi\varepsilon_0} \frac{Q_1 \times Q_2}{r} \qquad (2)$$

which gives the result of 1.44MeV in case of potential between two protons. Nuclear force has to nullify this force to keep the nucleus together.

The binding energy of a nucleus is the difference in mass energies between a nucleus and its individual building parts (neutrons and protons). If proton and electron masses are grouped together, binding energy can be written as

$$B = [Zm(1H) + N_{mn} - m(aX)]c^2 \qquad (3).$$

For example, this calculation done for uranium-238 would result a reading of 623 MeV, which is about 7.6 MeV per nucleon. For comparison, the result for iron (Fe-56) is 250 MeV. When the nuclear force is greater than the Coulomb force, the atom is stable. The nuclear force increases linearly with A, but Coulomb force increases faster, close to Z^2. Hence, the ratio of nucleons, protons and neutrons, determines the stability of the nucleus. In Figure 1.1, proton number is plotted against neutron number, showing stable atoms in black and radioactive atoms in grey. [6]

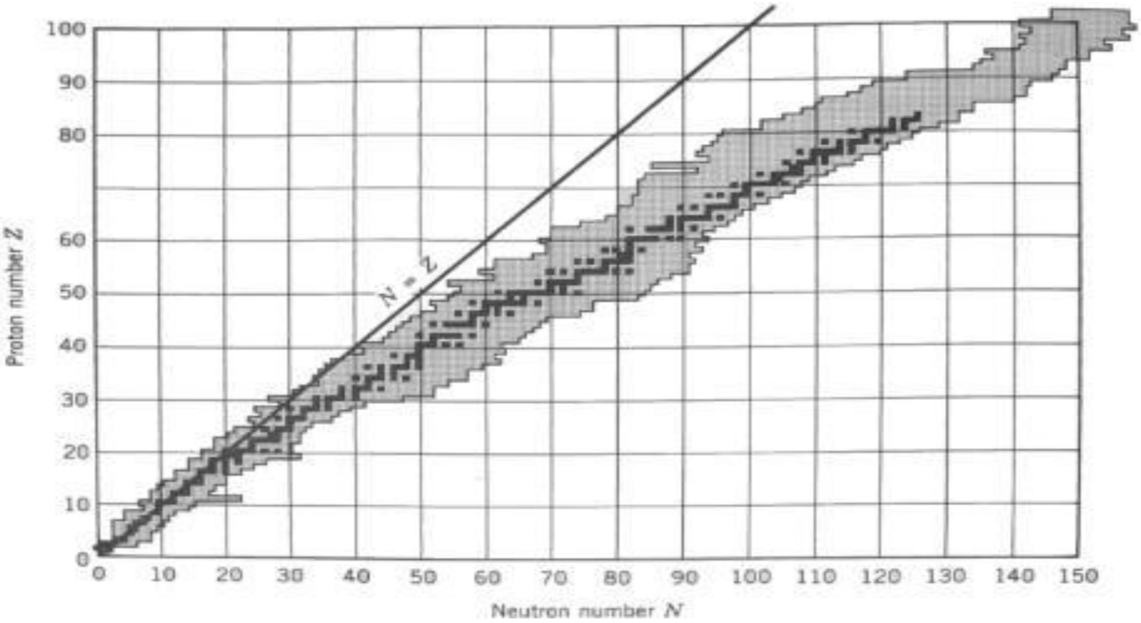


Figure 1.1: Stable and radioactive atoms (Krane, 1988)

A nucleus that has the "wrong" ratio of protons and neutrons has to change. Fission is one way for the nucleus to change the ratio and move closer to a more stable form. Another possible way is to decay through emission, which is discussed with greater detail in later chapters. (Krane, 1988)

In a fission process, as an atom splits to form two new atoms, it goes from more loosely bound nucleus to two more tightly bound nuclei. The most tightly bound nucleus is Iron (Fe), which has the highest energy level per nucleon. In Figure 1.2 the binding energy per nucleon is plotted against the mass number to form curve of binding energy.

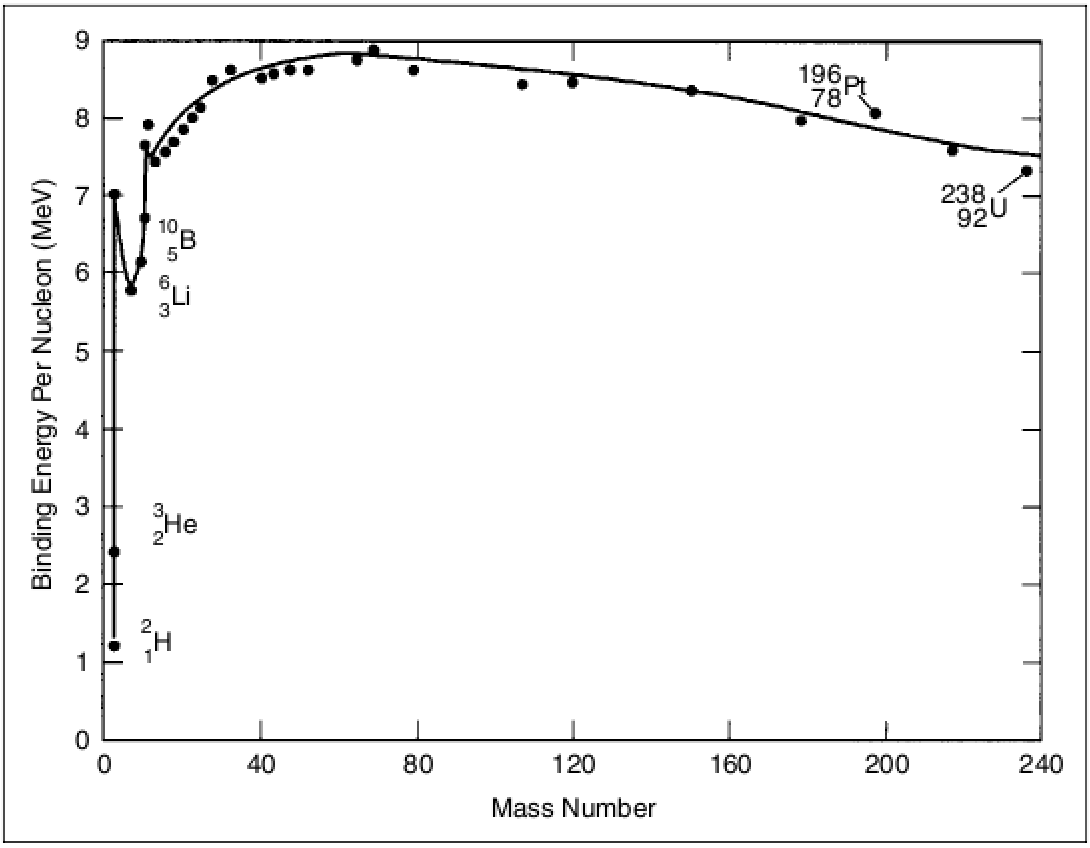


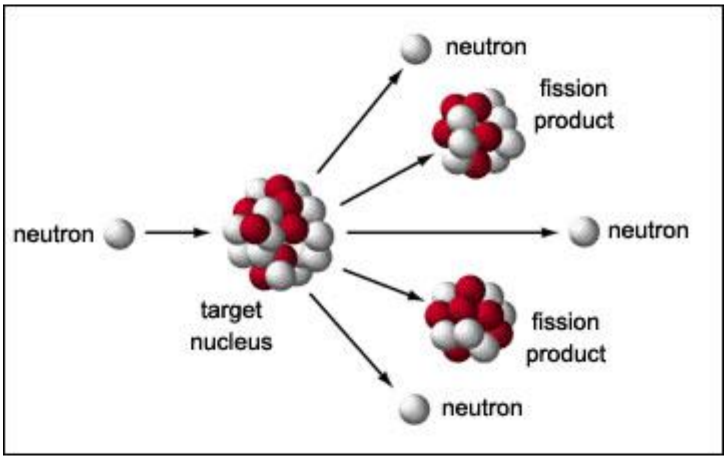
Figure 1.2, curve of binding energy (Krane, 1988)

From Figure 1.2 few things can be seen:

1) The most tightly bound atoms are around mass number 56.
2) By moving towards this mass number, energy can be released.
3) The amount of energy released is the difference between energy per nucleon: if two hydrogen atoms with mass number 2 would undergo fusion, the energy release would be very big compared to the size of the atoms.
4) The energy release from fission of uranium-235 to two more tightly bound atoms does not seem to have huge potential when compared to fusion. However, as it will be seen, the energy released from one fission process with uranium-235 is very large due to large number of nucleons.[7]

1.9 Fission

When a nucleus fissions, it splits into several smaller fragments. These fragments, or fission products, are about equal to half the original mass. Two or three neutrons are also emitted.



Nuclear Fission

The sum of the masses of these fragments is less than the original mass. This 'missing' mass (about 0.1 percent of the original mass) has been converted into energy according to Einstein's equation.

Fission can occur when a nucleus of a heavy atom captures a neutron, or it can happen spontaneously.About 200 mev energy is released per fission.

1.9 .1Thermal and fast fission

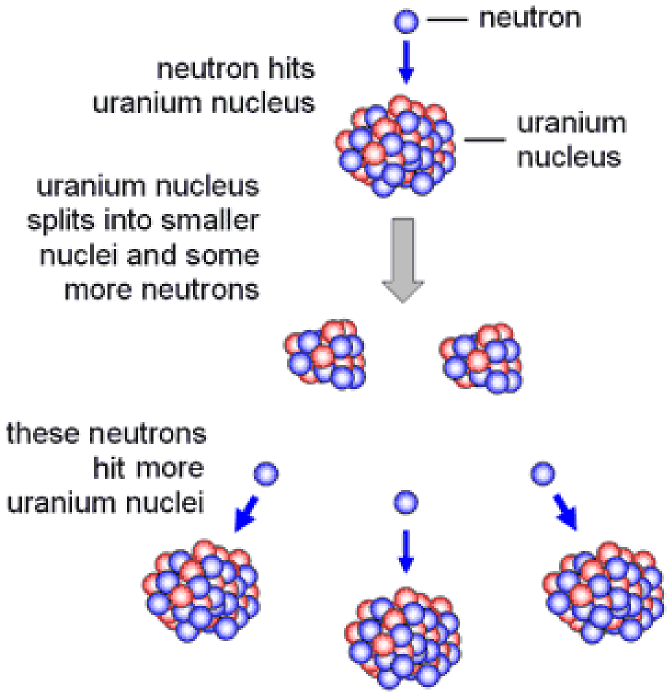
Nuclear reactors use a type of nuclear reaction called nuclear fission. Another type of nuclear reaction - nuclear fusion - happens in the Sun and other stars. Nuclear power reactors use a reaction called nuclear fission. Two isotopes in common use as nuclear fuels are uranium-235 and plutonium-239.

Fission is another word for splitting. The process of splitting a nucleus is called nuclear fission. Uranium or plutonium isotopes are normally used as the fuel in nuclear reactors, because their atoms have relatively large nuclei that are easy to split, especially when hit by neutrons.

When a uranium-235 or plutonium-239 nucleus is hit by a neutron, the following happens:

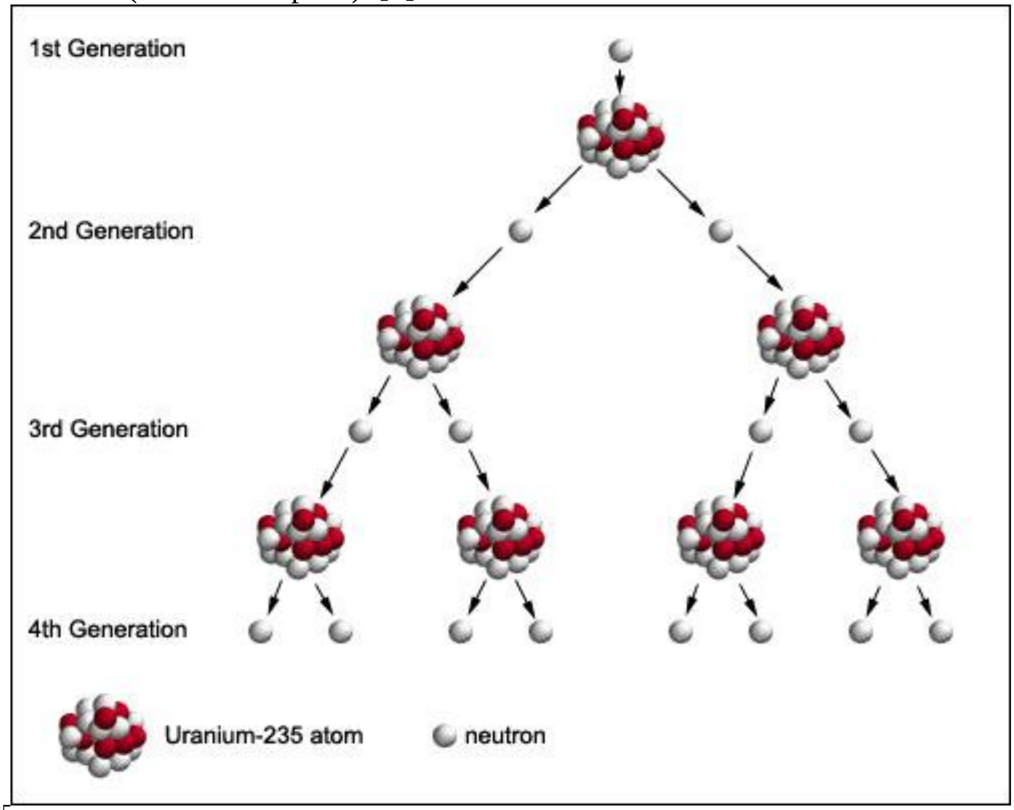
1. the nucleus splits into two smaller nuclei, which are radioactive
2. two or three more neutrons are released
3. some energy is released

The additional neutrons released may also hit other uranium or plutonium nuclei and cause them to split. Even more neutrons are then released, which in turn can split more nuclei. This is called a chain reaction. The chain reaction in nuclear reactors is controlled to stop it going too fast.


neutron
neutron hits
uranium nucleus
uranium
nucleus
uranium nucleus
splits into smaller
nuclei and some
more neutrons
these neutrons
hit more
uranium nuclei

1.9.2 Fission Chain Reaction

A chain reaction refers to a process in which neutrons released in fission produce an additional fission in at least one further nucleus. This nucleus in turn produces neutrons, and the process repeats. The process may be controlled (nuclear power) or uncontrolled (nuclear weapons). [8]



U^{235} + n → fission + 2 or 3 n + 200 MeV

If each neutron releases two more neutrons, then the number of fissions doubles each generation. In that case, in 10 generations there are 1,024 fissions and in 80 generations about 6 x 10^{23} (a mole) fissions.

Energy Released From Each Fission

165 MeV ~ kinetic energy of fission products
7 MeV ~ gamma rays
6 MeV ~ kinetic energy of the neutrons
7 MeV ~ energy from fission products
6 MeV ~ gamma rays from fission products
9 MeV ~ anti-neutrinos from fission products
200 MeV

1 MeV (million electron volts) = 1.609 x 10^{-13} joules

1.9.3 Fission energies

In its natural state, energy has to be added to the nucleus to produce fission. In the case of the uranium-235, 6.2 MeV has to be added to uranium-236 to have a fission process. Table 1.1 shows the threshold energy and the amount of energy that one neutron brings into different materials. [9]

Table 1.1: Threshold energies (Krane, 1988)

Material	Threshold energy	Energy added by neutron	Difference
Thorium-232	7.5 MeV	5.4 MeV	-2.1 MeV
Uranium-238	7.0 MeV	5.5 MeV	-1.5 MeV
Uranium-235	6.2 MeV	6.5 MeV	+0.3 MeV
Uranium-233	6.0 MeV	7.0 MeV	+1.0 MeV
Plutonium-239	5.0 MeV	6.6 MeV	+1.6 MeV

Naturally, materials which have positive difference are fissile materials. (U.S Department of Energy, 1993)

1.9.4 Fission products

As induced fission occurs, the atom disintegrates into two smaller pieces. It would be expected that both of these fission products to have similar A, but this is not the case. The fission product mass distribution is closer to 2/3 and 1/3. The average sizes of fission products are therefore A1 = 95 and A2 = 140. This distribution, which has major implications for the composition of nuclear waste, is shown in Figure 1.3. [10]

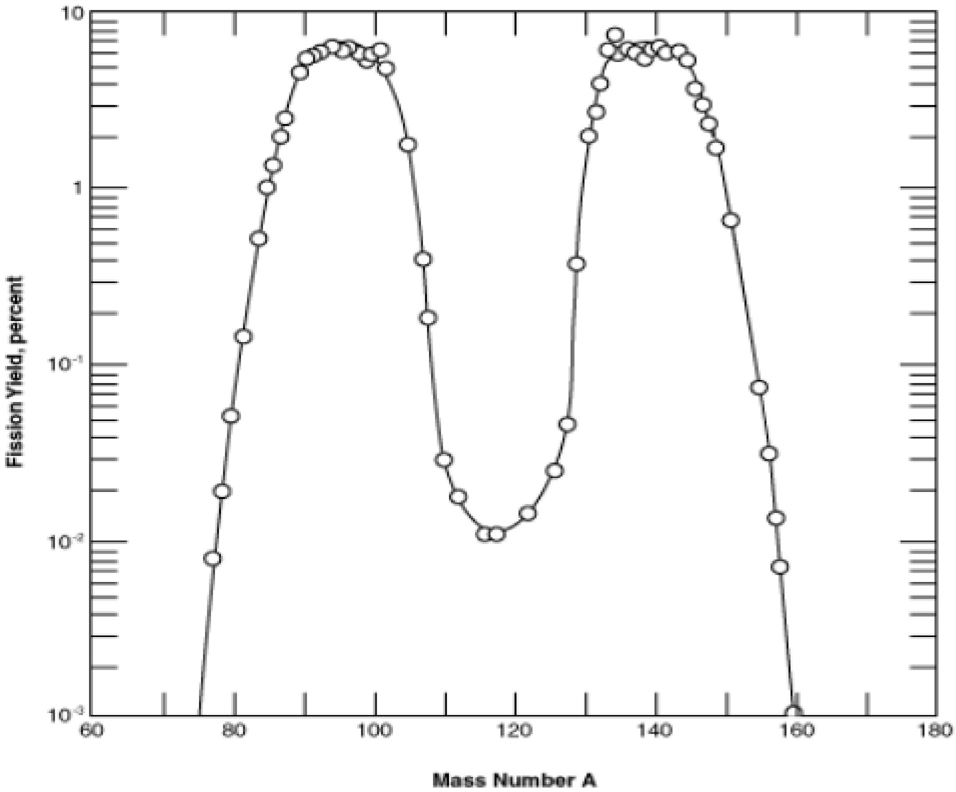


Figure 1.3: Distribution of fission products (Krane, 1988)

As it is seen from Figure 1.3, the two peaked distribution has to be symmetric: for every light particle coming out of the fission-process, there has to be a heavy particle. It is known that two peaked distribution of the fission products is property of low-energy fission. In high energy induced fission processes, the masses of products from fission seem to have a single peaked distribution. (Krane, 1988)

CHAPTER 2
OPERATION AND CONTROL OF NUCLEAR POWER PLANT

The physics of operating a nuclear reactor is explained in Nuclear Reactor Physics.

Just as many conventional thermal power stations generate electricity by harnessing the thermal energy released from burning fossil fuels, nuclear power plants convert the thermal energy released from nuclear fission.

2.1 Reactor details

All nuclear reactors are devices designed to maintain a chain reaction producing a steady flow of neutrons generated by the fission of heavy nuclei. They are, however, differentiated either by their purpose or by their design features. In terms of purpose, they are either research reactors or power reactors.

Research reactors are operated at universities and research centres in many countries, including some where no nuclear power reactors are operated. These reactors generate neutrons for multiple purposes, including producing radiopharmaceuticals for medical diagnosis and therapy, testing materials and conducting basic research.

Power reactors are usually found in nuclear power plants. Dedicated to generating heat mainly for electricity production, they are operated in more than 30 countries (see Nuclear Power Reactors). Their lesser uses are drinking water or district water production. In the form of smaller units, they also power ships.

Differentiating nuclear reactors according to their design features is especially pertinent when referring to nuclear power reactors (see Types of Nuclear Power Reactors).

Nuclear Power Reactors

There are many different types of power reactors. What is common to them all is that they produce thermal energy that can be used for its own sake or converted into mechanical energy and ultimately, in the vast majority of cases, into electrical energy.

In these reactors, the fission of heavy atomic nuclei, the most common of which is uranium-235, produces heat that is transferred to a fluid which acts as a coolant. During the fission process, bond energy is released and this first becomes noticeable as the kinetic energy of the fission products generated and that of the neutrons being released. Since these particles undergo intense deceleration in the solid nuclear fuel, the kinetic energy turns into heat energy.

In the case of reactors designed to generate electricity, to which the explanations below will now be restricted, the heated fluid can be gas, water or a liquid metal. The heat stored by the fluid is then used either directly (in the case of gas) or indirectly (in the case of water and liquid metals) to generate steam. The heated gas or the steam is then fed into a turbine driving an alternator.

Since, according to the laws of nature, heat cannot fully be converted into another form of energy, some of the heat is residual and is released into the environment. Releasing is either direct – e.g. into a river – or indirect, into the atmosphere via cooling towers. This practice is common to all thermal plants and is by no means limited to nuclear reactors which are only one type of thermal plant.

Types of Nuclear Power Reactors

Nuclear power reactors can be classified according to the type of fuel they use to generate heat.

Uranium–fuelled Reactors

The only natural element currently used for nuclear fission in reactors is uranium. Natural uranium is a highly energetic substance: one kilogram of it can generate as much energy as 10 tonnes of oil. Naturally occurring uranium comprises, almost entirely, two isotopes: U238 (99.283%) and U235 (0.711%). The former is not fissionable while the latter can be fissioned by thermal (i.e. slow) neutrons. As the neutrons emitted in a fission reaction are fast, reactors using U235 as fuel must have a means of slowing down these neutrons before they escape from the fuel. This function is performed by what is called a moderator, which, in the case of certain reactors (see table of **Reactor Types** below) simultaneously acts as a coolant. It is common practice to classify power reactors according to the nature of the coolant and the moderator plus, as the need may arise, other design characteristics. [11]

Reactor Type	Coolant	Moderator	Fuel	Comment
Pressurised water reactors (PWR, VVER)	Light water	Light water	Enriched uranium	Steam gener-ated in secondary loop
Boiling water reactors (BWR)	Light water	Light water	Enriched uranium	Steam from boiling water fed to turbine
Pressurised heavy water reactor (PHWR)	Heavy water	Heavy water	Natural uranium	
Gas-cooled reactors (Magnox, AGR, UNGG)	CO_2	Graphite	Natural or enriched uranium	
Light water graphite reactors (RBMK)	Press-urised boiling water	Graphite	Enriched uranium	Soviet design

PWRs and BWRs are the most commonly operated reactors in Organisation for Economic Cooperation and Development (OECD) countries. VVERs, designed in the former Soviet Union, are based on the same principles as PWRs. They use “light water”, i.e. regular water (H_2O) as opposed to “heavy water” (deuterium oxide D_2O). Moderation provided by light water is not sufficiently effective to permit the use of natural uranium. The fuel must be slightly enriched in U235 to make up for the losses of neutrons occurring during the chain reaction. On the other hand, heavy water is such an effective moderator that the chain reaction can be sustained without having to enrich the uranium. This combination of natural uranium and heavy water is used in PHWRs, which are found in a number of countries, including Canada, Korea, Romania and India.

Graphite-moderated, gas-cooled reactors, formerly operated in France and still operated in Great Britain, are not built any more in spite of some advantages.

RBMK-reactors (pressure-tube boiling-water reactors), which are cooled with light water and moderated with graphite, are now less commonly operated in some former Soviet Union bloc countries. Following the Chernobyl accident (26 April 1986) the construction of this reactor type ceased. The operating period of those units still in operation will be shortened. [12]

Plutonium-fuelled Reactors

Plutonium (Pu) is an artificial element produced in uranium-fuelled reactors as a by-product of the chain reaction. It is one hundred times more energetic than natural uranium; one gram of Pu can generate as much energy as one tonne of oil. As it needs fast neutrons in order to fission, moderating materials must be avoided to sustain the chain reaction in the best conditions. The current Plutonium-fuelled reactors, also called "fast" reactors, use liquid sodium which displays excellent thermal properties without adversely affecting the chain reaction. These types of reactors are in operation in France, Japan and the Commonwealth of Independent States (CIS).

Light Water Reactors

The Light Water Reactors category comprises pressurised water reactors (PWR, VVER) and boiling water reactors (BWR). Both of these use light water and hence enriched uranium. The light water they use combines the functions of moderator and coolant. This water flows through the reactor core, a zone containing a large array of fuel rods where it picks up the heat generated by the fission of the U235 present in the fuel rods. After the coolant has transferred the heat it has collected to a steam turbine, it is sent back to the reactor core, thus flowing in a loop, also called a primary circuit.

In order to transfer high-quality thermal energy to the turbine, it is necessary to reach temperatures of about 300 °C. It is the pressure at which the coolant flows through the reactor core that makes the distinction between PWRs and BWRs.

In PWRs, the pressure imparted to the coolant is sufficiently high to prevent it from boiling. The heat drawn from the fuel is transferred to the water of a secondary circuit through heat exchangers. The water of the secondary circuit is transformed into steam, which is fed into a turbine.

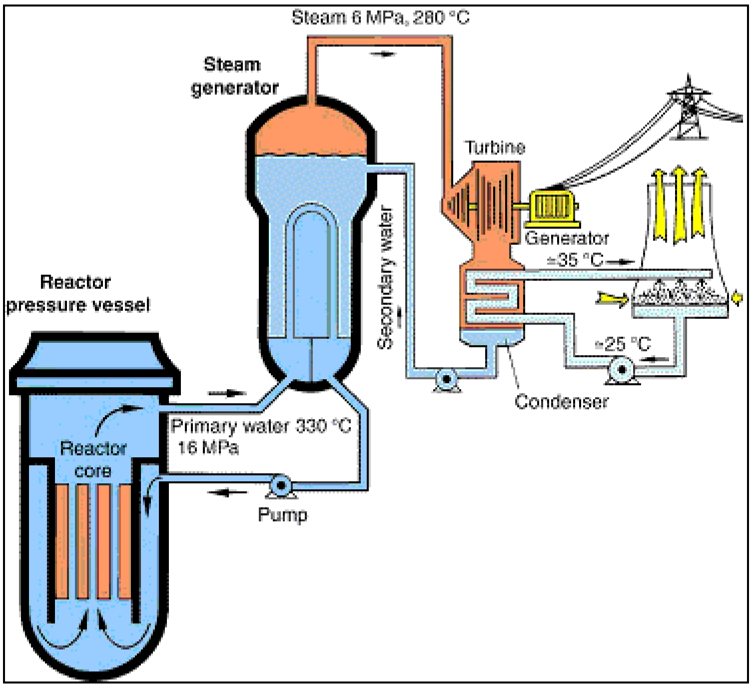
In BWRs, the pressure imparted to the coolant is sufficiently lower than in a PWR to allow it to boil. It is the steam resulting from this process that is fed into the turbine.

This basic difference between pressurised and boiling water dictates many of the design characteristics of the two types of light water reactors, as will be explained below.

Despite their differing designs, it must be noted that the two reactor types provide an equivalent level of safety.

Pressurised Water Reactors

The fission zone (fuel elements) is contained in a reactor pressure vessel under a pressure of 150 to 160 bar (15 to 16 MPa). The primary circuit connects the reactor pressure vessel to heat exchangers. The secondary side of these heat exchangers is at a pressure of about 60 bar (6 MPa) - low enough to allow the secondary water to boil. The heat exchangers are, therefore, actually steam generators. Via the secondary circuit, the steam is routed to a turbine driving an alternator. The steam coming out of the turbine is converted back into water by a condenser after having delivered a large amount of its energy to the turbine. It then returns to the steam generator. As the water driving the turbine (secondary circuit) is physically separated from the water used as reactor coolant (primary circuit), the turbine-alternator set can be housed in a turbine hall outside the reactor building.



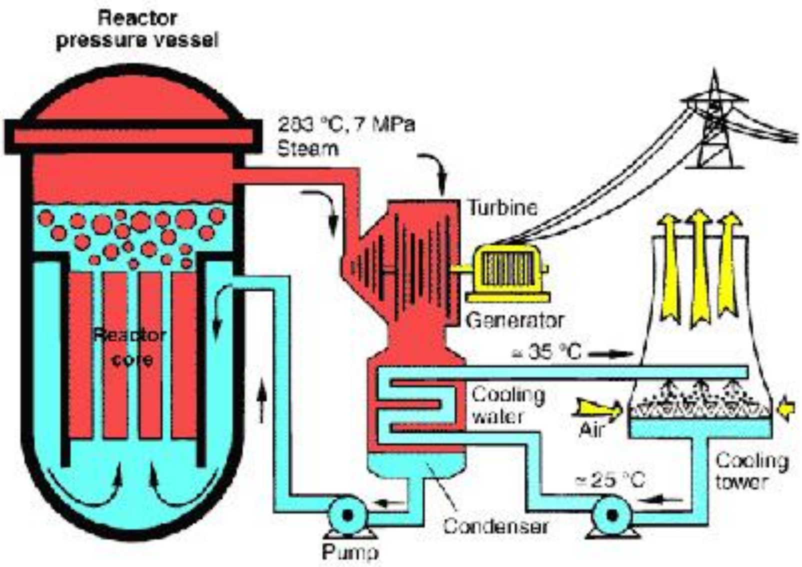
Nuclear power plant with pressurized water reactor

Boiling Water Reactors

The fission zone is contained in a reactor pressure vessel, at a pressure of about 70 bar (7 MPa). At the temperature reached (290 °C approximately), the water starts boiling and the resulting steam is produced directly in the reactor pressure vessel. After the separation of steam and water in the upper part of the reactor pressure vessel, the steam is routed directly to a turbine driving an alternator.

The steam coming out of the turbine is converted back into water by a condenser after having delivered a large amount of its energy to the turbine. It is then fed back into the primary cooling circuit where it absorbs new heat in the fission zone.

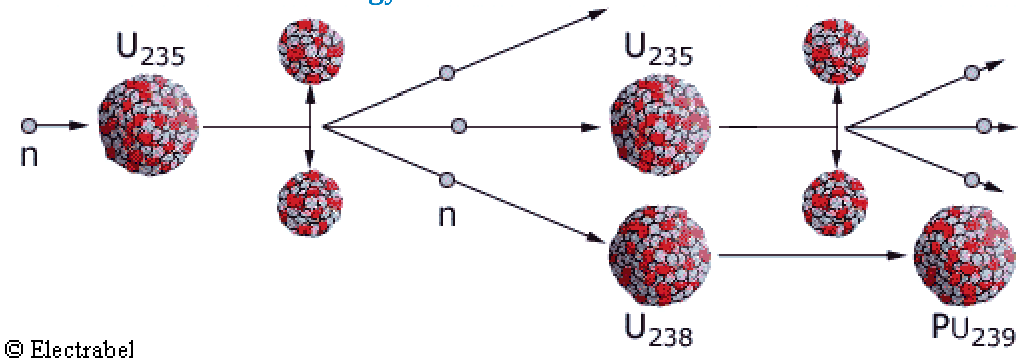
Since the steam produced in the fission zone is slightly radioactive, mainly due to short-lived activation products, the turbine is housed in the same reinforced building as the reactor.



Principle of a nuclear power plant with boiling water reactor

2.2 Fission process

From nuclear to thermal energy



When the nuclei of heavy atoms (such as uranium and plutonium) are split energy is released in the form of heat and radiation. Fission can be achieved by bombarding the nucleus with neutrons. A neutron will more easily hit a fissile uranium atom if its speed is slowed down.

Therefore, a moderator is required: a substance that acts like a brake upon the neutrons. [3]

The fissile nucleus will disintegrate into several fission fragments and in turn emit neutrons. These can react in new fission processes, causing a chain reaction. An enormous amount of radiation and kinetic energy is created when the fission fragments burst apart, and this energy is converted into heat: approximately 24.000.000 kWh (thermal) for 1 kg of uranium 235 (if all of the atoms are split). By way of comparison, burning 1 kg of coal produces 8 kWh of thermal energy (i.e. 3.000.000 times less).

Industrial fissile fuel, containing only some 3% of actually fissionable material, has about a 100.000 times more energy potential than coal.

After four years, the usable energy in the fuel will be depleted. The spent fuel is then replaced with fresh fuel, then, "reprocessed": this means that the residual uranium and plutonium that can be reused, is recovered. The spent fuel can also be conditioned and stored as high-grade radioactive waste.

2.3 Heat Generation

The reactor core generates heat in a number of ways:

- The kinetic energy of fission products is converted to thermal energy when these nuclei collide with nearby atoms.
- Some of the gamma rays produced during fission are absorbed by the reactor, their energy being converted to heat.
- Heat produced by the radioactive decay of fission products and materials that have been activated by neutron absorption. This decay heat source will remain for some time even after the reactor is shutdown.
- A kilogram of Uranium -235 converted via nuclear processes contains approximately three million times the energy of a kilogram of coal burned conventionally 7.2×10^{13} Joules per kilogram of uranium-235 versus 2.4×10^{7} Joules per kilogram of coal

2.4 Cooling

A nuclear reactor coolant - usually water but sometimes a gas or a liquid metal or molten salt - is circulated past the reactor core to absorb the heat that it generates. The heat is carried away from the reactor and is then used to generate steam. Most reactor systems employ a cooling system that is physically separate from the water that will be boiled to produce pressurized steam for the turbines, like the pressurized water reactor. But in some reactors the water for the steam turbines is boiled directly by the reactor core, for example the boiling water reactor.

2.5 Reactivity Control

The power output of the reactor is controlled by controlling how many neutrons are able to create more fission.

Control rods that are made of a nuclear poison are used to absorb neutrons. Absorbing more neutrons in a control rod means that there are fewer neutrons available to cause fission, so pushing the control rod deeper into the reactor will reduce its power output, and extracting the control rod will increase it.

In some reactors, the coolant also acts as a neutron moderator. A moderator increases the power of the reactor by causing the fast neutrons that are released from fission to lose energy and become thermal neutrons. Thermal neutrons are more likely than fast neutrons to cause fission, so more neutron moderation means more power output from the reactors. If the coolant is a moderator, then temperature changes can affect the density of the coolant/moderator and therefore change power output. A higher temperature coolant would be less dense, and therefore a less effective moderator.

2.6 Nuclear Reactor/Energy Generation

2.6.1 Resources

Nuclear Power for Energy Generation "Nuclear Reactor Concepts" Workshop Manual, NRC The Fission Process and Heat Production "Nuclear Reactor Concepts" Workshop Manual, NRC Boiling Water Reactor Systems "Nuclear Reactor Concepts" Workshop Manual, NRC Pressurized Water Reactor Systems "Nuclear Reactor Concepts" Workshop Manual, NRC.

2.6.2 Generalizing

The purpose of a nuclear power plant is to produce or release heat and boil water. It is designed to produce electricity. It should be noted that while there are significant differences, there are many similarities between nuclear power plants and other electrical generating facilities. Uranium is used for fuel in nuclear power plants to make electricity.

CHAPTER 3
NUCLEAR POWER REACTORS

3.1 Basic Concept of Nuclear Power Reactors

A nuclear reactor produces and controls the release of energy from splitting the atoms of certain elements. In a nuclear power reactor, the energy released is used as heat to make steam to generate electricity. (In a research reactor the main purpose is to utilise the actual neutrons produced in the core. In most naval reactors, steam drives a turbine directly for propulsion.)

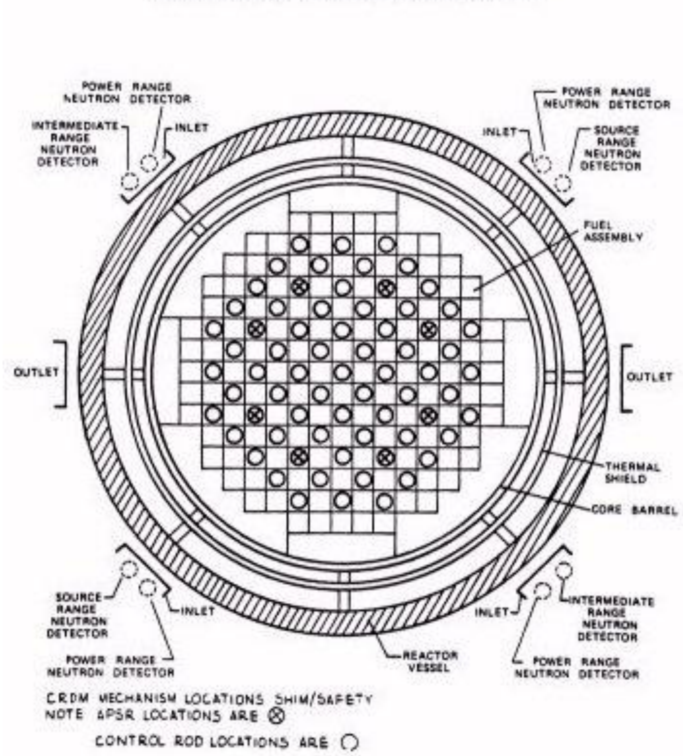
The principles for using nuclear power to produce electricity are the same for most types of reactor. The energy released from continuous fission of the atoms of the fuel is harnessed as heat in either a gas or water, and is used to produce steam. The steam is used to drive the turbines which produce electricity (as in most fossil fuel plants).

The world's first nuclear reactors operated naturally in a uranium deposit about two billion years ago. These were in rich uranium ore bodies and moderated by percolating rainwater. Those at Oklo in West Africa, each less than 100 kW thermal, together consumed about six tons of that uranium. [14]

Today, reactors derived from designs originally developed for propelling submarines and large naval ships generate about 85% of the world's nuclear electricity. The main design is the pressurized water reactor (PWR) which has water at over 300°C under pressure in its primary cooling/heat transfer circuit, and generates steam in a secondary circuit. Numerous boiling water reactors (BWR) make steam in the primary circuit above the reactor core, at similar temperatures and pressure. Both types use water as both coolant and moderator, to slow neutrons. Since water normally boils at 100°C, they have robust steel pressure vessels or tubes to enable the higher operating temperature. (Another type uses heavy water, with deuterium atoms, as moderator. Hence the term ‘light water’ is used to differentiate.)

3.2 Components of a nuclear reactor core

FIGURE-4 TOP VIEW OF REACTOR CORE



There are several components common to most types of reactors:

3.2.1 Fuel

Uranium is the basic fuel. Usually pellets of uranium oxide (UO_2) are arranged in tubes to form fuel rods. The rods are arranged into fuel assemblies in the reactor core.*

* In a new reactor with new fuel a neutron source is needed to get the reaction going. Usually this is beryllium mixed with polonium, radium or other alpha-emitter. Alpha particles from the decay cause a release of neutrons from the beryllium as it turns to carbon-12. Restarting a reactor with some used fuel may not require this, as there may be enough neutrons to achieve criticality when control rods are removed.

3.2.2 Moderator

A moderator is designed to slow down fast neutrons such that they are more easily absorbed by fissile nuclei. There are two main factors in choosing a moderator:

1. The moderator must not absorb neutrons itself. This means it should have a relatively low neutron absorption cross-section.
2. The moderator should efficiently slow down the neutrons. Modelling neutron-nuclei collisions as a classical elastic collision, in much the same way as gas molecules are modelled, gives the result that the closer the nucleus' mass is to that of the neutron, the more energy will be transferred in the collision. This means that lighter elements are favoured.

The following equation shows the fractional energy lost per collision, ξ, on average for a neutron colliding with a nuclide of mass A. E_0 is the initial energy of the neutron, and E_s is the energy after scattering has occurred.

$$\xi = \left\langle \ln\left(\frac{E_0}{E_s}\right) \right\rangle = 1 - \frac{(A-1)^2}{2A} \ln\left(\frac{A+1}{A-1}\right)$$

It is beyond the scope of this TLP to derive this equation, but the basic physics is straightforward. In elastic collisions kinetic energy and momentum are conserved and the energy lost by the neutron can be calculated for any given angle of contact. In three dimensions it is necessary to integrate over all possible angles to obtain an average.

The equation is well approximated by:

$$\xi \approx \frac{6}{3A+2}$$

This is good enough for most purposes (to see the error in the approximation click here.). Since this is a classical derivation applied to a quantum situation, there is probably more error due to the original assumptions than this mathematical approximation.

Try out the interactive Flash movie below to see this effect in action. The movie obeys the same physics used to derive the above equations, except in a two-dimensional rather than three-dimensional case. The simulation is meant to show energy lost per collision, and does not give an accurate impression of how often these collisions occur: interatomic distances have been greatly reduced for illustrative purposes. In practice it is the scattering cross-section which determines the *rate* of neutron collisions. [15]

3.2.3 Control rods

These are made with neutron-absorbing material such as cadmium, hafnium or boron, and are inserted or withdrawn from the core to control the rate of reaction, or to halt it. In some PWR reactors, special control rods are used to enable the core to sustain a low level of power efficiently. (Secondary control systems involve other neutron absorbers, usually boron in the coolant – its concentration can be adjusted over time as the fuel burns up.)

* In fission, most of the neutrons are released promptly, but some are delayed. These are crucial in enabling a chain reacting system (or reactor) to be controllable and to be able to be held precisely critical.

3.2.4 Coolant

What is Nuclear Reactor Coolant?

The heat released by fission in nuclear reactors must be captured and transferred for use in electricity generation. To this end, reactors use coolants that remove heat from the core where the fuel is processed and carry it to electrical generators. Coolants also serve to maintain manageable pressures within the core.

General Parameters For a Good Coolant

In order for the coolant to work effectively, it must fulfill a number of key specifications. Most basically, it must have efficient heat transfer properties. The coolant must also be a fluid that can fill the interstices of the core and be pumped to a steam generator or turbine. Thermal and material compatibility are vital as well; the coolant should be chemically stable at high temperatures, non-corrosive and a poor neutron absorber. This last parameter is achieved by ensuring that the coolant has a low absorption cross section. As a neutron is ejected from the uranium-235 in the fuel rod (or, in rare cases, dissolved in the coolant itself), the atoms with which it collides will either scatter or absorb the neutron. The chance of each event is expressed as a nuclear cross section, or effective area presented by the nucleus, and has the units barns (1 barn = 1×10^{-28} m^2). [1] The reason a high scattering and low absorption cross section is optimal is that the coolant should not eat the neutrons before they can be taken up by the fissile material. In the cases when coolant does absorb neutrons, however, the resulting radioactivity should have a short lifetime. Lastly, cost-effectiveness is a relevant consideration for reactors.

Note also the coolant affects significant aspects of the reactor itself, such as the operating temperature and pressure, the size of the core, and methods of fuel handling.

Specific Coolants

Since no coolant qualifies as perfect for all, various substances are used in industry. Below I will cover two common coolants: water and liquid sodium.

Water

The two major types of water-cooled reactors are light water reactors (PWR) and boiling water reactors (BWR). Both use light (normal) water, but with slightly differing cooling mechanisms. In a BWR, the water turns into steam in the reactor core and is then pumped directly to the turbines that power electrical generators. In a PWR, the primary loop of coolant flowing through the core is at very high pressure (2250 psi) so it will remain a liquid. [2] It then transfers heat to a secondary loop of water that vaporizes and turns the turbines. This latter method ensures that any radioactivity activated in the coolant remains within the reactor. Because the heat of vaporization that is required for the phase change from liquid to steam limits thermal efficiency, there is currently research being done on a Generation IV supercritical reactor. [3] Light water is a good coolant for thermal reactors but not for fast breeders; pressurized water also moderates (slows down) the neutrons because hydrogen-1 (H-1), which comprises much of water, has a scattering cross section of $\sigma = 82.03$ barns, far larger than any other atom. [4] PWRs have an intrinsic failsafe should the reactor overheat to the point where the water in the primary loop boils; neutrons interact less with steam and do not get thermalized, so the abundance of fast neutrons causes the rate of fission to drop. After a few minutes, the reactor achieves passive shut-down.

An even more effective coolant and moderator is heavy water, or deuterium (liquid D_2O), because its absorption cross section is three orders of magnitude smaller than that of hydrogen. However, it is also prohibitively expensive: approximately $2400/L. [5]

3.2.5 Pressure vessel or pressure tubes

Usually a robust steel vessel containing the reactor core and moderator/coolant, but it may be a series of tubes holding the fuel and conveying the coolant through the surrounding moderator.

3.2.6 Steam generator

(not in BWR) Part of the cooling system where the high-pressure primary coolant bringing heat from the reactor is used to make steam for the turbine, in a secondary circuit. Essentially a heat exchanger like a motor car radiator*. Reactors may have up to four 'loops', each with a steam generator.

These are large heat exchangers for transferring heat from one fluid to another – here from high-pressure primary circuit in PWR to secondary circuit where water turns to steam. Each structure weighs up to 800 tonnes and contains from 300 to 16,000 tubes about 2 cm diameters for the primary coolant, which is radioactive due to nitrogen-16 (N-16, formed by neutron bombardment of oxygen, with half-life of 7 seconds). The secondary water must flow through the support structures for the tubes. The whole thing needs to be designed so that the tubes don't vibrate and fret, operated so that deposits do not build up to impede the flow, and maintained chemically to avoid corrosion. Tubes which fail and leak are plugged, and surplus capacity is designed to allow for this. Leaks can be detected by monitoring N-16 levels in the steam as it leaves the steam generator.

3.2.7 Containment

A containment building, in its most common usage, is a reinforced steel or lead structure enclosing a nuclear_reactor. It is designed, in any emergency, to contain the escape of radiation to a maximum pressure in the range of 40 to 80 psi (410 to 1400 kPa). The containment is the fourth and final barrier to radioactive_release (part of a nuclear reactor's defence_in_depth strategy), the first being the fuel ceramic itself, the second being the metal fuel cladding tubes, the third being the reactor_vessel and coolant system.

Each nuclear plant in the US is designed to withstand certain conditions which are spelled out as "Design Basis Accidents" in the Final Safety Analysis Report (FSAR). The FSAR is available for public viewing, usually at a public library near the nuclear plant.

The containment building itself is typically an airtight steel structure enclosing the reactor normally sealed off from the outside atmosphere. The steel is either free-standing or attached to the concrete missile shield. In the United_States, the design and thickness of the containment and the missile shield are governed by federal regulations (10 CFR 50.55a), and must be strong enough to withstand the impact of a fully loaded passenger airliner without rupture.

While the containment plays a critical role in the most severe nuclear reactor accidents, it is only designed to contain or condense steam in the short term (for large break accidents) and long term heat removal still must be provided by other systems. In the Three Mile Island accident the containment pressure boundary was maintained, but due to insufficient cooling, sometime after the accident, radioactive gas was intentionally let from containment by operators to prevent over pressurization. This, combined with further failures, caused the release of up to 13 million curies of radioactive gas to atmosphere during the accident. While the Fukushima Dai-Ichi plant had operated safely since 1971, an earthquake and tsunami well beyond the design basis resulted in failure of AC power, backup generators and batteries which defeated all safety systems. These systems were necessary to keep the fuel cool after the reactor had been shut down. This resulted in partial or complete meltdown of fuel rods, damage to fuel storage pools and buildings, release of radioactive debris to surrounding area, air and sea, and resorting to the expedient use of fire engines and concrete pumps to deliver cooling water to spent fuel pools and containment. The containment was breached from a hydrogen gas explosion. The fuel cladding around the rods heated up, releasing hydrogen gas which built up inside the reactor, without being vented

3.2.8 Enrichment

Enriched uranium is a type of uranium in which the percent composition of uranium-235 has been increased through the process of isotope_separation. Natural_uranium is 99.284% ^{238}U isotope, with ^{235}U only constituting about 0.711% of its weight. ^{235}U is the only nuclide_existing_in_nature (in any appreciable amount) that is fissile with thermal_neutrons

Enriched uranium is a critical component for both civil nuclear_power_generation and military nuclear_weapons. The International_Atomic_Energy_Agency attempts to monitor and control enriched uranium supplies and processes in its efforts to ensure nuclear power generation safety and curb nuclear_weapons_proliferation.

During the Manhattan_Project enriched uranium was given the codename oralloy, a shortened version of Oak_Ridge alloy, after the location of the plants where the uranium was enriched. The term oralloy is still occasionally used to refer to enriched

uranium. There are about 2,000 tonnes (t, Mg) of highly enriched uranium in the world,[2] produced mostly for nuclear_weapons, naval_propulsion, and smaller quantities for research reactors.
The ^{238}U remaining after enrichment is known as depleted_uranium (DU), and is considerably less radioactive than even natural uranium, though still very dense and extremely hazardous in granulated form – such granules are a natural by-product of the shearing action that makes it useful for armor-penetrating_weapons and radiation shielding. At present, 95% of the world's stocks of depleted uranium remain in secure storage.

3.3 Fuelling a nuclear power reactor

Most reactors need to be shut down for refueling, so that the pressure vessel can be opened up. In this case refueling is at intervals of 1-2 years, when a quarter to a third of the fuel assemblies is replaced with fresh ones. The CANDU and RBMK types have pressure tubes (rather than a pressure vessel enclosing the reactor core) and can be refueled under load by disconnecting individual pressure tubes.
If graphite or heavy water is used as moderator, it is possible to run a power reactor on natural instead of enriched uranium. Natural uranium has the same elemental composition as when it was mined (0.7% U-235, over 99.2% U-238), enriched uranium has had the proportion of the fissile isotope (U-235) increased by a process called enrichment, commonly to 3.5 - 5.0%. In this case the moderator can be ordinary water, and such reactors are collectively called light water reactors. Because the light water absorbs neutrons as well as slowing them, it is less efficient as a moderator than heavy water or graphite.
During operation, some of the U-238 is changed to plutonium, and Pu-239 ends up providing about one third of the energy from the fuel.
In most reactors the fuel is ceramic uranium oxide (UO_2 with a melting point of 2800°C) and most is enriched. The fuel pellets (usually about 1 cm diameter and 1.5 cm long) are typically arranged in a long zirconium alloy (zircaloy) tube to form a fuel rod, the zirconium being hard, corrosion-resistant and permeable to neutrons.* Numerous rods form a fuel assembly, which is an open lattice and can be lifted into and out of the reactor core. In the most common reactors these are about 3.5 to 4 meters long.
*Zirconium is an important mineral for nuclear power, where it finds its main use. It is therefore subject to controls on trading. It is normally contaminated with hafnium, a neutron absorber, so very pure 'nuclear grade' Zr is used to make the zircaloy, which is about 98% Zr plus tin, iron, chromium and sometimes nickel to enhance its strength.
Burnable poisons are often used (especially in BWR) in fuel or coolant to even out the performance of the reactor over time from fresh fuel being loaded to refueling. These are neutron absorbers which decay under neutron exposure, compensating for the progressive build up of neutron absorbers in the fuel as it is burned. The best known is gadolinium, which is a vital ingredient of fuel in naval reactors where installing fresh fuel is very inconvenient, so reactors are designed to run more than a decade between refueling.

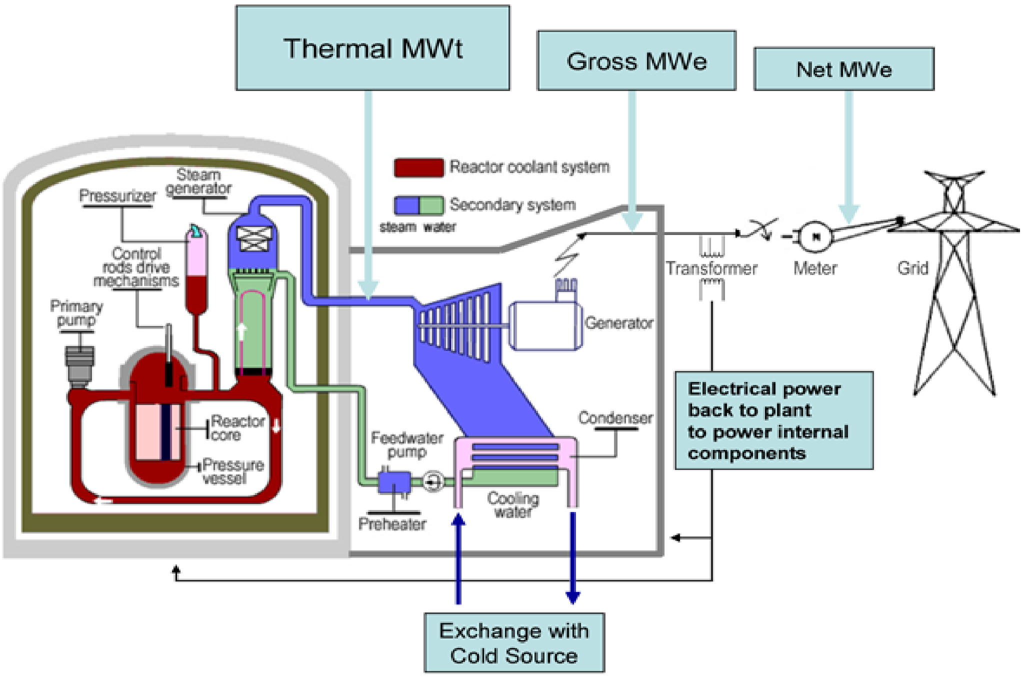
3.4 The power rating of a nuclear power reactor

Nuclear power plant reactor power outputs are quoted in three ways:

- Thermal MWt, which depends on the design of the actual nuclear reactor itself, and relates to the quantity and quality of the steam it produces.

- Gross electrical MWe indicates the power produced by the attached steam turbine and generator, and also takes into account the ambient temperature for the condenser circuit (cooler means more electric power, warmer means less).

Fig 3.1: power rating of a nuclear power reactor.



- Rated gross power assumes certain conditions with both.
- Net electrical MWe, which is the power available to be sent out from the plant to the grid, after deducting the electrical power needed to run the reactor (cooling and feed-water pumps, etc.) and the rest of the plant.*

  * Net electrical MWe and gross MWe vary slightly from summer to winter, so normally the lower summer figure, or an average figure, is used. If the summer figure is quoted plants may show a capacity factor greater than 100% in cooler times. Some design options, such as powering the main large feed-water pumps with electric motors (as in EPR) rather than steam turbines (taking steam before it gets to the main turbine-generator), explains some gross to net differences between different reactor types. The EPR has a relatively large drop from gross to net MWe for this reason

3.5 Different Types of Reactor

There are different types of reactor indicated as follows:

3.5.1 Pressurized Water Reactor (PWR)

This is the most common type, with over 230 in use for power generation and several hundred more employed for naval propulsion. The design of PWRs originated as a submarine power plant. PWRs use ordinary water as both coolant and moderator. The design is distinguished by having a primary cooling circuit which flows through the core of the reactor under very high pressure, and a secondary circuit in which steam is generated to drive the turbine. In Russia these are known as VVER types - water-moderated and -cooled

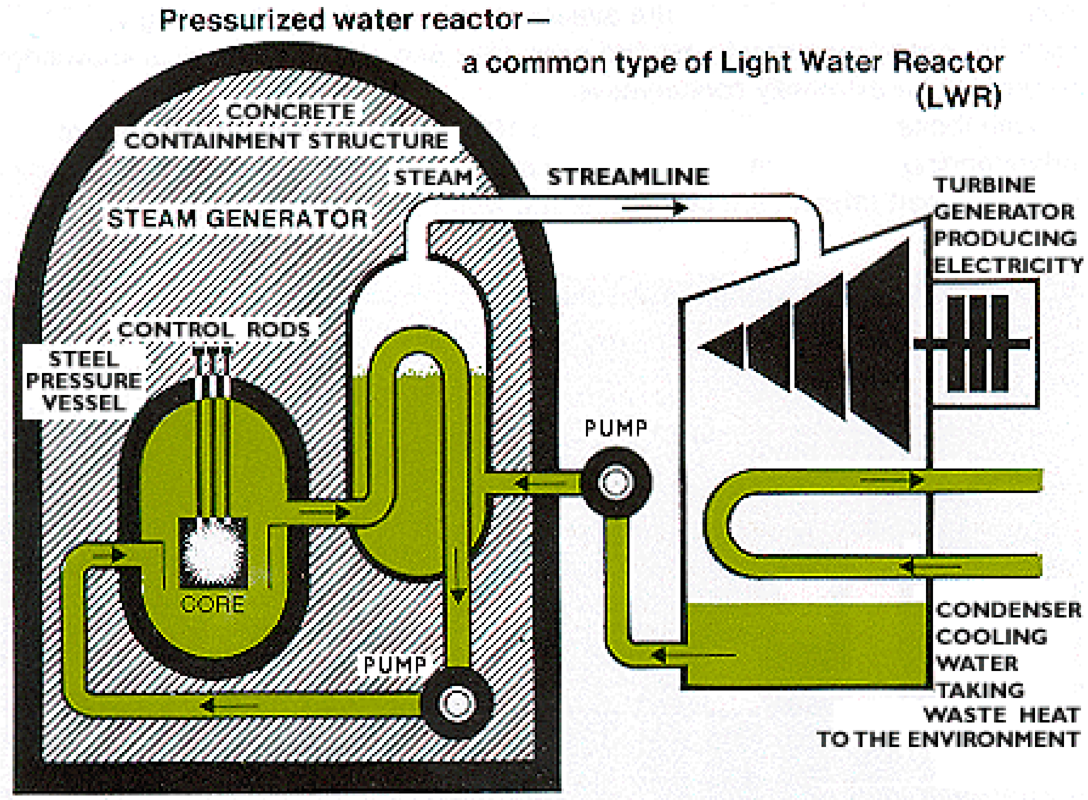


Fig 3.2: Schematic Diagram of Pressurized Water Reactor (PWR)

A PWR has fuel assemblies of 200-300 rods each, arranged vertically in the core, and a large reactor would have about 150-250 fuel assemblies with 80-100 tons of uranium.

Water in the reactor core reaches about 325°C, hence it must be kept under about 150 times atmospheric pressure to prevent it boiling. Pressure is maintained by steam in a pressurizer (see diagram). In the primary cooling circuit the water is also the moderator, and if any of it turned to steam the fission reaction would slow down. This negative feedback effect is one of the safety features of the type. The secondary shutdown system involves adding boron to the primary circuit.

The secondary circuit is under less pressure and the water here boils in the heat exchangers which are thus steam generators. The steam drives the turbine to produce electricity, and is then condensed and returned to the heat exchangers in contact with the primary circuit.

3.5.2 Boiling Water Reactor (BWR)

This design has many similarities to the PWR, except that there is only a single circuit in which the water is at lower pressure (about 75 times atmospheric pressure) so that it boils in the core at about 285°C. The reactor is designed to operate with 12-15% of the water in the top part of the core as steam, and hence with less moderating effect and thus efficiency there. BWR units can operate in load-following mode more readily then PWRs.

The steam passes through drier plates (steam separators) above the core and then directly to the turbines, which are thus part of the reactor circuit. Since the water around the core of a reactor is always contaminated with traces of radionuclides, it means that the turbine must be shielded and radiological protection provided during maintenance. The cost of this tends to balance the savings due to the simpler design.

Most of the radioactivity in the water is very short-lived*, so the turbine hall can be entered soon after the reactor is shut down.
* Mostly N-16, with a 7 second half-life
A BWR fuel assembly comprises 90-100 fuel rods, and there are up to 750 assemblies in a reactor core, holding up to 140 tonnes of uranium. The secondary control system involves restricting water flow through the core so that more steam in the top part reduces moderation.

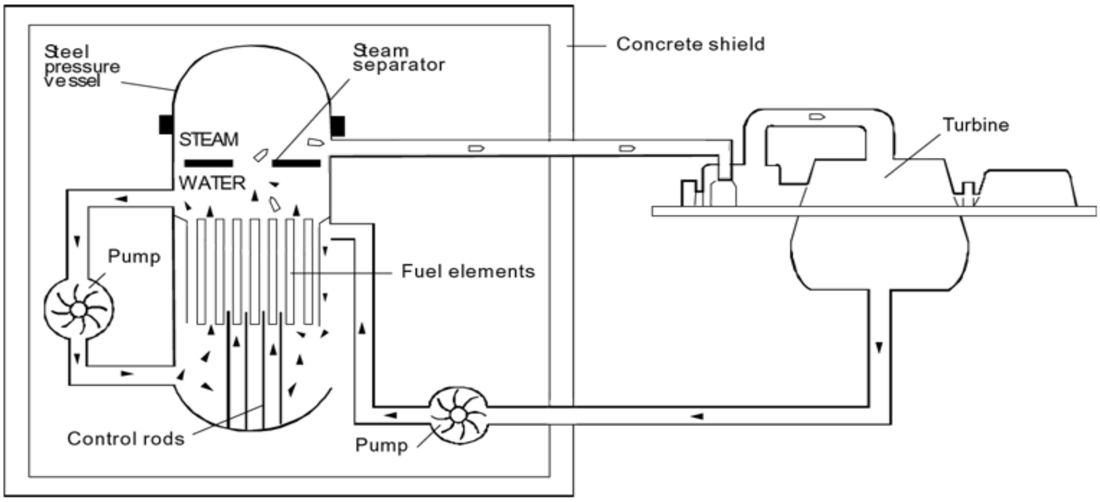


Fig 3.3: Schematic Diagram of Boiling Water Reactor (BWR)

3.5.3 Pressurized Heavy Water Reactor (PHWR or CANDU)

The PHWR reactor design has been developed since the 1950s in Canada as the CANDU, and more recently also in India. It uses natural uranium (0.7% U-235) oxide as fuel, hence needs a more efficient moderator, in this case heavy water (D_2O).**
** With the CANDU system, the moderator is enriched (i.e water) rather than the fuel, - a cost trade-off.
The moderator is in a large tank called a calandria, penetrated by several hundred horizontal pressure tubes which form channels for the fuel, cooled by a flow of heavy water under high pressure in the primary cooling circuit, reaching 290°C. As in the PWR, the primary coolant generates steam in a secondary circuit to drive the turbines. The pressure tube design means that the reactor can be refueled progressively without shutting down, by isolating individual pressure tubes from the cooling circuit.

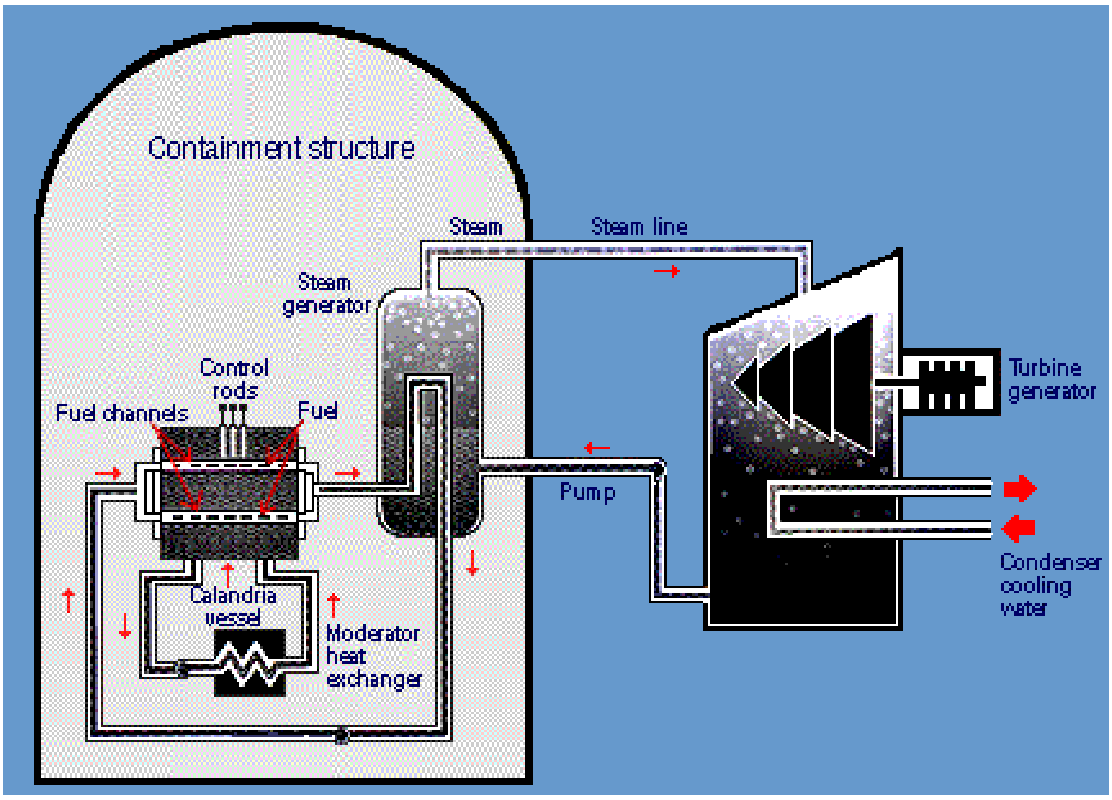


Fig3.4: Schematic Diagram of Pressurized Heavy Water Reactors.

A CANDU fuel assembly consists of a bundle of 37 half meter long fuel rods (ceramic fuel pellets in zircaloy tubes) plus a support structure, with 12 bundles lying end to end in a fuel channel. Control rods penetrate the calandria vertically, and a secondary shutdown system involves adding gadolinium to the moderator. The heavy water moderator circulating through the body of the calandria vessel also yields some heat (though this circuit is not shown on the diagram above).
Newer PHWR designs such as the Advanced Cando Reactor (ACR) have light water cooling and slightly-enriched fuel.
CANDU reactors can readily be run on recycled uranium from reprocessing LWR used fuel, or a blend of this and depleted uranium left over from enrichment plants. About 4000 MWe of PWR can then fuel 1000 MWe of CANDU capacity, with addition of depleted uranium. [16]

3.5.3.1 Importance of Heavy Water

The nuclear power plants of Kota in Rajasthan, Kalpakkam in Tamil Nadu and Narora in U.P. use heavy water as coolant and moderator. All these projects have CANDU reactors using natural uranium as fuel and heavy water as moderator. After this enriched uranium natural water reactor at Tarapur, the CANDU reactors are the second generation of reactors in India's nuclear power programmed. The CANDU reactor will produce plutonium which will be the core fuel for fast breeder reactor. In fact in breeder reactor heavy water is used as moderator.
A CANDU reactor of 200 MW capacity requires about 220 tonnes of heavy water in the initial stages and about 18 to 24 tonnes each year subsequently. Therefore, about one thousand tonnes of heavy water will be required to start the different nuclear power stations using heavy water. The total capacity of different heavy water plants will be about 300 tonnes per year if all the heavy water plant under construction start production. It is expected that heavy water from domestic production will be available

from Madras and Narora atomic power plants. The management of the heavy water system is a highly complicated affair and requires utmost caution. Heavy water is present in ordinary water in the ratio 1: 6000. One of the methods of obtaining heavy water is electrolysis of ordinary water.

3.5.4 Advanced Gas-cooled Reactor (AGR)

These are the second generation of British gas-cooled reactors, using graphite moderator and carbon dioxide as coolant. The fuel is uranium oxide pellets, enriched to 2.5-3.5%, in stainless steel tubes. The carbon dioxide circulates through the core, reaching 650°C and then past steam generator tubes outside it, but still inside the concrete and steel pressure vessel. Control rods penetrate the moderator and a secondary shutdown system involves injecting nitrogen to the coolant.

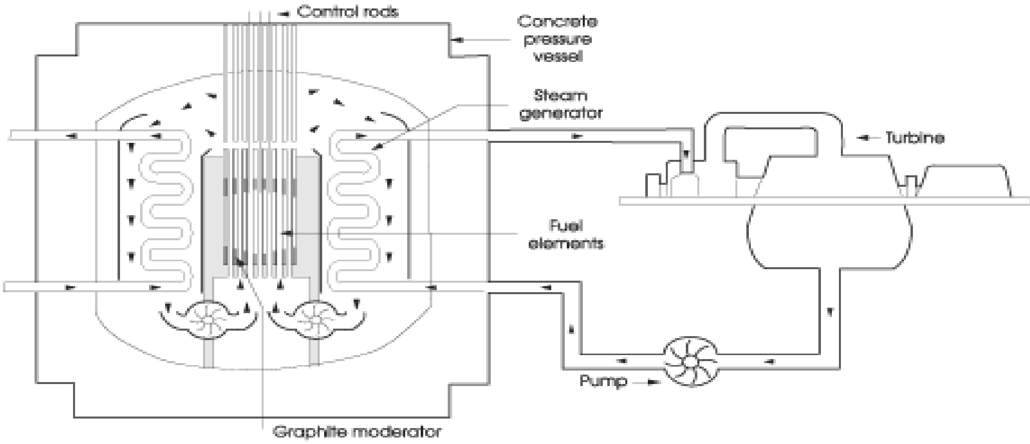


Fig 3.5: Schematic Diagram of Advanced Gas-cooled Reactor (AGR)

The AGR was developed from the Magnox reactor, also graphite moderated and CO_2 cooled, and two of these are still operating in UK. They use natural uranium fuel in metal form. Secondary coolant is water. [17]

3.5.5 Light water graphite-moderated reactor (RBMK)

This is a Soviet design, developed from plutonium production reactors. It employs long (7 meter) vertical pressure tubes running through graphite moderator, and is cooled by water, which is allowed to boil in the core at 290°C, much as in a BWR. Fuel is low-enriched uranium oxide made up into fuel assemblies 3.5 meters long. With moderation largely due to the fixed graphite, excess boiling simply reduces the cooling and neutron absorption without inhibiting the fission reaction, and a positive feedback problem can arise, which is why they have never been built outside the Soviet Union. See appendix on RBMK Reactors for more detail.

Also there are two types of Nuclear reactors depending upon the energy of the neutrons at the time they are captured by the fuel to induce fissions, the reactors can be named as follows:

3.5.6 Fast reactors

In such reactors fission is brought about by fast (none moderated) neutrons. Some reactors (only one in commercial service) do not have a moderator and utilize fast neutrons, generating power from plutonium while making more of it from the U-238 isotope in or around the fuel. While they get more than 60 times as much energy from the original uranium compared with the normal reactors, they are expensive to build. Further development of them is likely in the next decade, and the main designs expected to be built in two decades are FNRs. If they are configured to produce more fissile material (plutonium) than they consume they are called Fast Breeder Reactors (FBR). [18]

3.5.7 Thermal Reactors or Slow Neutron Reactors

In these reactors the fast moving neutrons are slowed down by passing them through the moderator. These slow moving neutrons are then cap absorbed by the fuel material to bring about the fission.

3.6 Advanced reactors

Several generations of reactors are commonly distinguished. Generation I reactors were developed in 1950-60s and only one is still running today. They mostly used natural uranium fuel and used graphite as moderator. Generation II reactors are typified by the present US fleet and most in operation elsewhere. They typically use enriched uranium fuel and are mostly cooled and moderated by water. Generation III are the Advanced Reactors evolved from these, the first few of which are in operation in Japan and others are under construction and ready to be ordered. They are developments of the second generation with enhanced safety. There is no clear distinction Gen II to Gen III.

Generation IV designs are still on the drawing board and will not be operational before 2020 at the earliest, probably later. They will tend to have closed fuel cycles and burn the long-lived actinides now forming part of spent fuel, so that fission products are the only high-level waste. Of seven designs under development, 4 or 5 will be fast neutron reactors. Four will use fluoride or liquid metal coolants, hence operate at low pressure. Two will be gas-cooled. Most will run at much higher temperatures than today's water-cooled reactors. See Generation IV Reactors paper.

More than a dozen (Generation III) advanced reactor designs are in various stages of development. Some are evolutionary from the PWR, BWR and CANDU designs above, some are more radical departures. The former include the Advanced Boiling Water Reactor, a few of which are now operating with others under construction. The best-known radical new design has the fuel as large 'pebbles' and uses helium as coolant, at very high temperature, possibly to drive a turbine directly.

Considering the closed fuel cycle, Generation 1-3 reactors recycle plutonium (and possibly uranium), while Generation IV are expected to have full actinide recycle.

3.7 Lifetime of nuclear reactors

Most of today's nuclear plants which were originally designed for 30 or 40-year operating lives. However, with major investments in systems, structures and components lives can be extended, and in several countries there are active programs to extend operating lives. In the USA most of the more than one hundred reactors are expected to be granted license extensions from 40 to 60 years. This justifies significant capital expenditure in upgrading systems and components, including building in extra performance margins.

Some components simply wear out, corrode or degrade to a low level of efficiency. These need to be replaced. Steam generators are the most prominent and expensive of these, and many have been replaced after about 30 years where the reactor otherwise has the prospect of running for 60 years. This is essentially an economic decision. Lesser components are more straightforward to replace as they age. In Cando reactors, pressure tube replacement has been undertaken on some plants after about 30 year's operation.

A second issue is that of obsolescence. For instance, older reactors have analogue instrument and control systems. Thirdly, the properties of materials may degrade with age, particularly with heat and neutron irradiation. In respect to all these aspects, investment is needed to maintain reliability and safety. Also, periodic safety reviews are undertaken on older plants in line with international safety conventions and principles to ensure that safety margins are maintained. [19]

Another important issue is knowledge management (KM) over the full lifecycle from design, through construction and operation to decommissioning for reactors and other facilities. This may span a century and involve several countries, and involve a succession of companies. The plant lifespan will cover several generations of engineers. Data needs to be transferable across several generations of software and IT hardware, as well as being shared with other operators of similar plants.

* Significant modifications may be made to the design over the life of the plant, so original documentation is not sufficient, and loss of design base knowledge can have huge implications (e.g. Pickering A and Bruce A in Ontario). Knowledge management is often a shared responsibility and is essential for effective decision-making and the achievement of plant safety and economics. [20]

3.8 Nuclear reactors for process heat

Producing steam to drive a turbine and generator is relatively easy, and a light water reactor running at 350°C does this readily. As the above section and Figure show, other types of reactor are required for higher temperatures. A 2010 US Department of Energy document quotes 500°C for a liquid metal cooled reactor (FNR), 860°C for a molten salt reactor (MSR), and 950°C for a high temperature gas-cooled reactor (HTR). Lower-temperature reactors can be used with supplemental gas heating to reach higher temperatures, though employing an LWR would not be practical or economic. The DOE said that high reactor outlet temperatures in the range 750 to 950°C were required to satisfy all end user requirements evaluated to date for the Next Generation Nuclear Plant. [21]

3.9 Comparison of different nuclear reactors

Reactor Type	Coolant	Moderator	Fuel	Comment
Pressurised water reactors (PWR, VVER)	Light water	Light water	Enriched uranium	Steam gener-ated in secondary loop
Boiling water reactors (BWR)	Light water	Light water	Enriched uranium	Steam from boiling water fed to turbine
Pressurised heavy water reactor (PHWR)	Heavy water	Heavy water	Natural uranium	
Advanced Gas-cooled reactors (AGR)	CO_2	Graphite	Natural or enriched uranium	

3.10 DISCUSSION

A nuclear power plant is a big and complex structure, with two main parts: nuclear reactor to produce heat from chosen material by nuclear fission and cyclic process to produce electricity from heat. Due to this complexity, it is expensive and harder to manage than coal-fired power plant or hydroelectric dam. It is not the cleanest energy source, having problems with waste management. It is not the dirties one either, having an advantage in zero carbon dioxide emissions and possibility of producing huge amounts of electricity, leaving relative small amounts of waste to future generations. Nuclear technology sector is on the new rise due tothe fight against emissions of greenhouse gases. Currently limited research and development budgets willhopefully grow, providing new technologies, with reduction in waste, increase in safety and proliferation resistance, and higher electricity yield. In this paper, technologies used in the world today were in the spotlight, mostly because sustainability for the next 100 years is attached to technologies used and built today. projections show, that energy need in the future is larger than it is today and will likely grow by 100%-400% until 2050. Energy intensities of societies are declining, while more energy efficient machinery and appliances are invented. However, there is more machinery and appliances used per capita than before. No reason can be found to expect change in this trend. Another big issue is the growth of population, which creates demand for electricity. In economics chapter, these issues were discussed and it was shown that demand for base-load capacity will grow. Problems related to renewable fuel sources were reviewed followed by conclusion that it is not possible in near future to provide the world with sufficient amount of solar or wind energy. At the same time fossil fuel sources have their own problems with CO_2emissions. One solution would be to use nuclear power plants to provide electricity. Nuclear power plants are CO_2-neutral and they are competitive in price of electricity, for large cluster plants. Technologies which provide sustainability in absolute terms were reviewed, while relative sustainability of current technologies was also shown. Minimal effects to global scale were deemed as number one sustainability goal. Goal number two was to leave as little as possible local waste behind. Third goal was not to deplete the resources of the world. While it is obvious that nuclear power plant is not sustainable in absolute terms, it was competitive against other base-load capacity providing power plants.The main reason for this assessment of better sustainability was due to the high emissions from competitors, which was infringement of the first goal or, if CCS were used, goal number two. Nuclear power is not perfect solution, as seen in amounts of waste left behind. In one year, approximately 8641.1 tons of radioactive waste is produced. With reprocessing, this amount can be reduced. In energy mix planning nuclear energy can provide about 20% of world’s total energy need. [22]

CONCLUSION

Nuclear technology is very expensive and deadly .It is very risky for densly populated country like Bangladesh. Accident in 3mile island USA (1977), Chernobi USSR in 1986 and Fukushima Japan 2009 are examples of large scale hazard and long term pollution and contamination of environment. [23]

RECOMMENDATION
Bangladesh should go for combined cycle gas lived & coal lived power station.

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