NUCLEAR REACTORS

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BY

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Abstract

Nuclear reactors are devices containing fissionable material in sufficient quantity and so arranged as to be capable of maintaining a controlled, self-sustaining NUCLEAR FISSION chain reaction. They are also known as atomic piles, atomic reactors, fission reactors, and nuclear piles, although such names are deprecated. The power level at which a nuclear operates is proportional to the rate of fissions, which in turn , depends on the number of neutrons in the reactor. There fore by controlling the number of neutrons ,we can control the power level of the reactor.

Recently, there has been a resurgence in promoting nuclear reactors as a viable and necessary component of technology . The design ,construction and operation of a nuclear reactor are today part of a huge and expanding field of nuclear engineering. **[7] , [27]**

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Chapter - 1

General Introduction

1.1 Nuclear reactors

Most nuclear reactors use a chain reaction to induce a controlled rate of nuclear fission in fissile material, releasing both energy and free neutrons. A reactor consists of an assembly of nuclear fuel (a reactor core), usually surrounded by a neutron moderator such as regular water,heavy water,graphite, or zirconium hydride, and fitted with mechanisms such as control rods that control the rate of the reaction.

Nuclear reactor physics is the branch of science that deals with the study and application of chain reaction to induce controlled rate of fission for energy in reactors. **[1]**

1.2 behaviors of nuclear reactors

Criticality- In a nuclear reactor, the neutron population at any instant is a function of the rate of neutron production (due to fission processes) and the rate of neutron losses (via non-fission absorption mechanisms and leakage from the system). When a reactor's neutron population remains steady from one generation to the next (creating as many new neutrons as are lost), the fission chain reaction is self-sustaining and the reactor's condition is referred to as "critical". When the reactor's neutron production exceeds losses, characterized by increasing power level, it is considered "supercritical", and; when losses dominate, it is considered "sub critical" and exhibits decreasing power.

The "six-factor formula" is the neutron life-cycle balance equation, which includes six separate factors, the product of which is equal to the ratio of the number of neutrons in any generation to that of the previous one; this parameter is called the effective multiplication factor (k),

$$k = L_f \rho L_{th} f \eta \epsilon, \quad \ldots \quad 1.1$$

where L_f = "fast non-leakage factor"; ρ = "resonance escape probability"; L_{th} = "thermal non-leakage factor"; f = "thermal fuel utilization factor"; η = "reproduction factor"; Є = "fast-fission factor".

k = (Neutrons produced in one generation)/(Neutrons produced in the previous generation)

When the reactor is critical, k = 1. When the reactor is subcritical, k < 1. and

When the reactor is supercritical, k > 1.

" Reactivity" is an expression of the departure from criticality.

$$\delta k = (k - 1)/k \quad \ldots \quad 1.2$$

When the reactor is critical, δk = 0. When the reactor is subcritical, δk < 0. When the reactor is supercritical, δk > 0. Reactivity is also represented by the lowercase Greek letter rho (**ρ**). Reactivity is commonly expressed in decimals or percentages or pcm (per cent mille) of Δk/k. When reactivity ρ is expressed in units of delayed neutron fraction β, the unit is called the *dollar*.

If we write 'N' for the number of free neutrons in a reactor core and 'τ' for the average lifetime of each neutron (before it either escapes from the core or is absorbed by a nucleus), then the reactor will follow differential equation(the *evolution equation*)

$$dN / dt = \alpha N / \tau \quad \ldots \quad 1.3$$

where α is a constant of proportionality, and dN / dt is the rate of change of the neutron count in the core. This type of differential equation describes exponential growth or exponential decay, depending on the sign of the constant α, which is just the expected number of neutrons after one average neutron lifetime has elapsed:

$$\alpha = P_{impact} P_{fission} n_{avg} - P_{absorb} - P_{escape} \quad \ldots \quad 1.4$$

Here, p_{impact} is the probability that a particular neutron will strike a fuel nucleus, $P_{fission}$ is the probability that the neutron, having struck the fuel, will cause that nucleus to undergo fission,

P_{absorb} is the probability that it will be absorbed by something other than fuel, and P_{escape} is the probability that it will "escape" by leaving the core altogether. n_{avg} is the number of neutrons produced, on average, by a fission event it is between 2 and 3 for both ^{235}U and ^{239}Pu.

If α is positive, then the core is *supercritical* and the rate of neutron production will grow exponentially until some other effect stops the growth.

If α is negative, then the core is "sub critical" and the number of free neutrons in the core will shrink exponentially until it reaches an equilibrium at zero (or the background level from spontaneous fission). If α is exactly zero, then the reactor is *critical* and its output does not vary in time ($dN / dt = 0$, from above).Nuclear reactors are engineered to reduce P_{escape} and P_{absorb}. Small, compact structures reduce the probability of direct escape by minimizing the surface area of the core, and some materials (such as graphite) can reflect some neutrons back into the core, further reducing P_{escape}. The probability of fission, $P_{fission}$, depends on the nuclear physics of the fuel, and is often expressed as a cross section. Reactors are usually controlled by adjusting Pabsorb. Control rods made of a strongly neutron-absorbent material such as cadmium or boron can be inserted into the core: any neutron that happens to impact the control rod is lost from the chain reaction, reducing α. P_{absorb} is also controlled by the recent history of the reactor core itself **.**

Starter sources -The mere fact that an assembly is supercritical does not guarantee that it contains any free neutrons at all. At least one neutron is required to "strike" a chain reaction, and if the spontaneous fission rate is sufficiently low it may take a long time (in ^{235}U reactors, as long as many minutes) before a chance neutron encounter starts a chain reaction even if the reactor is supercritical.

Most nuclear reactors include a "starter"neutron source that ensures there are always a few free neutrons in the reactor core, so that a chain reaction will begin immediately when the core is made critical. A common type of startup neutron source is a mixture of an alpha particle emitter such as ^{241}Am (Americium -241) with a lightweight isotope such as ^{9}Be Beryllium-9).The primary sources described above have to be used with fresh reactor cores. For operational reactors, secondary sources are used; most often a combination of antimony with beryllium. Antimony becomes activated in the reactor and produces high-energy gamma photons, which produce photo neutrons from beryllium. Uranium-235 undergoes a small rate of natural spontaneous fission, so there are always some neutrons being produced even in a fully shutdown reactor. When the control rods are withdrawn and criticality is approached the number increases because the absorption of neutrons is being progressively reduced, until at criticality the chain reaction becomes self sustaining. Note that while a neutron source is provided in the reactor, this is not essential to start the chain reaction, its main purpose is to give a shutdown neutron population which is detectable by instruments and so make the approach to critical more observable. The reactor will go critical at the same control rod position whether a source is loaded or not. Once the chain reaction is begun, the primary starter source may be removed from the core to prevent damage from the high neutron flux in the operating reactor core; the secondary sources usually remains in situ to provide a background reference level for control of criticality**.**

Sub critical multiplication -Even in a sub critical assembly such as a shut-down reactor core, any stray neutron that happens to be present in the core (for example from spontaneous fission of the fuel, from radioactive decay of fission products, or from a neutron source) will trigger an exponentially decaying chain reaction. Although the chain reaction is not self-sustaining, it acts as a multiplier that increases the equilibrium number of neutrons in the core. This sub critical *multiplication* effect can be used in two ways: as a probe of how close a core is to criticality, and as a way to generate fission power without the risks associated with a critical mass. As a measurement technique, sub critical multiplication was used during the Manhattan project in early experiments to determine the minimum critical masses of ^{235}U and of ^{239}Pu. It is still used today to calibrate the controls for nuclear reactors during startup, as many effects (discussed in the following sections) can change the required control settings to achieve criticality in a reactor. As a power-generating technique, subcritical multiplication allows generation of nuclear power for fission where a critical assembly is undesirable for safety or other reasons. A subcritical assembly together with a neutron source can serve as a steady source of heat to generate power from fission. Including the effect of an external neutron source ("external" to the fission process, not physically external to the core), one can write a modified evolution equation:

$$dN / dt = \alpha N / \tau + R_{ext} \qquad \ldots\ldots\ldots\ldots\ldots\ldots \qquad 1.5$$

where R_{ext} is the rate at which the external source injects neutrons into the core. In equilibrium , the core is not changing and dN/dt is zero, so the equilibrium number of neutrons is given by:

$$N = \tau R_{ext} / (-\alpha) \qquad \ldots\ldots\ldots\ldots\ldots\ldots \qquad 1.6$$

If the core is sub critical, then α is negative so there is an equilibrium with a positive number of neutrons.

If the core is close to criticality, then α is very small and thus the final number of neutrons can be made arbitrarily large**.**

Neutron moderators -To improve $P_{fission}$ and enable a chain reaction, uranium-fueled reactors must include a neutron moderator that interacts with newly produced fast neutrons from fission events to reduce their kinetic energy from several Mev to several eV, making them more likely to induce fission .This is because ^{235}U is much more likely to undergo fission when struck by one of these thermal neutrons than by a freshly-produced neutron from fission. Neutron moderators are materials that interact weakly with the neutrons but absorb kinetic

energy from them. Most moderators rely on either weakly bound hydrogen or a loose crystal structure of another light element such as carbon to transfer kinetic energy from the fast-moving neutrons. Hydrogen moderators include water(H_2O),heavy water (D_2O), and zirconium hydride (ZrH_2), all of which work because a hydrogen nucleus has nearly the same mass as a free neutron: neutron-H_2O or neutron-ZrH_2 impacts excite rotational modes of the molecules (spinning them around).Deuterium nuclei (in heavy water) absorb kinetic energy less well than do light hydrogen nuclei, but they are much less likely to absorb the impacting neutron.

Water or heavy water have the advantage of being transparent liquids , so that, in addition to shielding and moderating a reactor core, they permit direct viewing of the core in operation and can also serve as a working fluid for heat transfer.

Crystal structure moderators rely on a floppy crystal matrix to absorb photons from neutron-crystal impacts. Graphite is the most common example of such a moderator. It was used in Chicago pile-1, the world's first man-made critical assembly, and was commonplace in early reactor designs including the Soviet RBMK nuclear power plants, of which the Chernobyl plant was one**.**

Reactor poisons -*Nuclear poison* -Any element that strongly absorbs neutrons is called a reactor poison, because it tends to shut down (poison) an ongoing fission chain reaction. Some reactor poisons are deliberately inserted into fission reactor cores to control the reaction; boron or cadmium control rods are the best example. Many reactor poisons are produced by the fission process itself, and buildup of neutron-absorbing fission products affects both the fuel economics and the controllability of nuclear reactors**.**

Uranium enrichment- While many fissionable isotopes exist in nature, the only usefully fissible isotope found in any quantity is ^{235}U. About 0.7% of the uranium in most ores is the 235 isotope, and about 99.3% is the inert 238 isotope. For most uses as a nuclear fuel, uranium must be *enriched* - purified so that it contains a higher percentage of ^{235}U. Because ^{238}U absorbs fast neutrons, the critical mass needed to sustain a chain reaction increases as the ^{238}U content increases, reaching infinity at 94% ^{238}U (6% ^{235}U). Concentrations lower than 6% ^{235}U cannot go fast critical, though they are usable in a nuclear reactor with a neutron moderator.

A nuclear weapon primary stage using uranium uses HEU enriched to ~90% ^{235}U, though the secondary stage often uses lower enrichments. Nuclear reactors with water moderator can operate with only moderate enrichment of ~5% ^{235}U. Nuclear reactors with heavy water moderation can operate with natural uranium, eliminating altogether the need for enrichment and preventing the fuel from being useful for nuclear weapons; the CANDU power reactors used in Canadian power plants are an example of this type .Uranium enrichment is difficult because the chemical properties of ^{235}U and ^{238}U are identical, so physical processes such as gaseous diffusion,gas centrifuge or mass spectrometry must be used for isotopic separation based on small differences in mass. Because enrichment is the main technical hurdle to production of nuclear fuel and simple nuclear weapons, enrichment technology is politically sensitive**.[2]**

Natural nuclear fission reactor *-Modern* deposits of uranium contain only up to ~0.7% ^{235}U (and ~99.3% ^{238}U), which is not enough to sustain a chain reaction moderated by ordinary water. But ^{235}U has a much shorter half-life(700 million years) than ^{238}U (4.5 billion years), so in the distant past the percentage of ^{235}U was much higher. About two billion years ago, a water-saturated uranium deposit (in what is now the Oklo mine in Gabon,West Africa) underwent a naturally occurring chain reaction that was moderated by ground water and, presumably, controlled by the negative void coefficient as the water boiled from the heat of the reaction. Uranium from the Oklo mine is about 50% depleted compared to other locations: it is only about 0.3% to 0.7% ^{235}U; and the ore contains traces of stable daughters of long-decayed fission products **. [3]**

Chapter - 2

Basic Nuclear Reactor System

2.1 Introduction

A **nuclear reactor** is a device in which nuclear chain reactions are initiated, controlled, and sustained at a steady rate. The chain reaction is started by inserting some 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.

Neutrons in motion are the starting point for everything that happens in a nuclear reactor. When a neutron passes near to a heavy nucleus, for example uranium-235 (U-235), the neutron may be captured by the nucleus and this may or may not be followed by fission. Capture involves the addition of the neutron to the uranium nucleus to form a new compound nucleus. A simple example is U-238 + n ==> U-239, which represents formation of the nucleus U-239. The new nucleus may decay into a different nuclide. In this example, U-239 becomes Np-239 after emission of a beta particle (electron). But in certain cases the initial capture is rapidly followed by the fission of the new nucleus. Whether fission takes place, and indeed whether capture occurs at all, depends on the velocity of the passing neutron and on the particular heavy nucleus involved.

The most significant use of nuclear reactors is as an energy source for the generation of electrical power and for the power in some ships . This is usually accomplished by methods that involve using heat from the nuclear reaction to power steam turbines. **[4]**

2.2 How it works

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 .

2.2.1 Reactor

The reactor is used to convert nuclear (also known as 'atomic') energy into heat. While a reactor could be one in which heat is produced by fusion or radioactive decay, this description focuses on the basic principles of the fission reactor**.**

2.2.1(a) Fission- the process

When a relatively large fissible atomic nucleus (usually uranium-235, plutonium-239 or plutonium -241) absorbs a neutrons it is likely to under go nuclear fission .

The original heavy nucleus splits into two or more lighter nuclei, releasing kinetic energy,gamma radiation and free neutrons ; collectively known as fission products. A portion of these neutrons may later be absorbed by other fissile atoms and trigger further fission events, which release more neutrons, and so on, i.e for example a neutron is absorbed by the nucleus of a uranium-235 atom, which in turn splits into fast-moving lighter elements (fission products) and free neutrons.

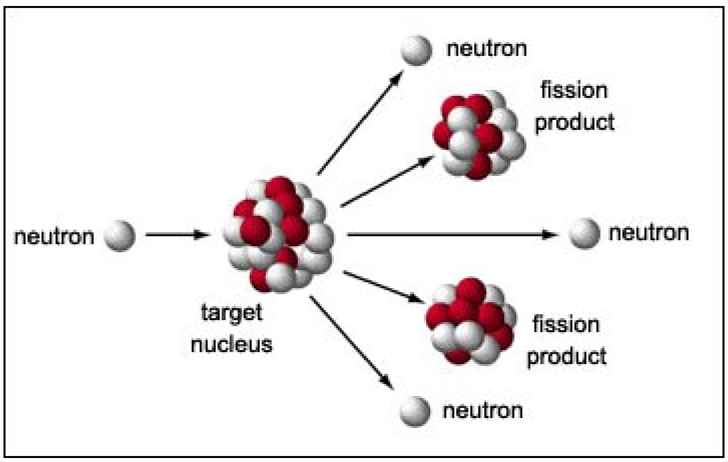


Fig 2.1 Nuclear fission

The number of neutrons and the specific fission products from any fission event are governed by statistical probability, in that the precise break up of a single nucleus cannot be predicted. However, conservation laws require the total number of nucleons and the total energy to be conserved.

The fission reaction in U-235 produces fission products such as Ba, Kr, Sr, Cs, I and Xe with atomic masses distributed around 95 and 135. Examples may be given of typical reaction products, such as:

U-235 + n ===> Ba-144 + Kr-90 + 2n + energy

U-235 + n ===> Ba-141 + Kr-92 + 3n + 170 Me V …..................2.1

U-235 + n ===> Zr-94 + Te-139 + 3n + 197 Me V

In such an equation, the number of nucleons (protons + neutrons) is conserved, e.g. 235 + 1 = 141 + 92 + 3, but a small loss in atomic mass may be shown to be equivalent to the energy released. Both the barium and krypton isotopes subsequently decay and form more stable isotopes of neodymium and yttrium, with the emission of several electrons from the nucleus (beta decays). It is the beta decays, with some associated gamma rays, which make the fission products highly radioactive. This radioactivity (by definition!) decreases with time.

The total energy released in fission of an atomic nucleus varies with the precise break up, but averages about 200 MeV for U-235 or 3.2×10^{-11} joule. That from Pu-239 is about 210 MeV per fission. (This contrasts with 4 eV or 6.5×10^{-19} J per atom of carbon burned in fossil fuels.)

These are total available energy release figures, consisting of kinetic energy values (Ek) of the fission fragments plus neutron, gamma and delayed energy releases which add about 30 Me V.

About 6% of the heat generated in the the reactor core originates from radioactive decay of fission products and transuranic elements formed by neutron capture , mostly the former . This must be allowed for when the reactor is shut down , since heat generation continues after fission stops. It is decay which makes spent fuel initially generate heat and hence need cooling. Even after one year,typical spent fuel generates about 10kW of decay heat per tonne, decreasing to about 1kW/t after ten years.

The nuclear chain reaction can be controlled by using neutron poisons and neutron moderator to change the fraction of neutrons that will go on to cause more fissions. In nuclear engineering, a neutron moderator is a medium which reduces the velocity of fast neutrons, thereby turning them into thermal neutrons capable of sustaining a nuclear chain reaction involving uranium-235.

Commonly used moderators include regular (light) water (75% of the world's reactors) solid graphite (20% of reactors) and heavy water (5% of reactors).

Beryllium has also been used in some experimental types, hydrocarbon have been suggested as another possibility. Increasing or decreasing the rate of fission will also increase or decrease the energy output of the reactor**.**

- ***Neutron Capture: Transuranic elements & activation products***

Neutrons may be captured by non-fissile nuclei, and some energy is produced by this mechanism in the form of gamma rays as the compound nucleus de-excites. The resultant new nucleus may become more stable by emitting alpha or beta particles. Neutron capture by one of the uranium isotopes will form what are called transuranic elements, actinides beyond uranium in the periodic table.

Since U-238 is the major proportion of the fuel element material in a thermal reactor, capture of neutrons by U-238 and the creation of U-239 is an important process.

- U-239 quickly emits a beta particle to become neptunium-239,
- Np-239 in turn emits a beta particle to become plutonium-239, which is relatively stable,
- Some Pu-239 nuclei may capture a neutron to become Pu-240, which is less stable,
- by further neutron capture, some Pu-240 nuclei may in turn form Pu-241
- Pu-241 also undergoes beta decay to americium-241 (the heart of household smoke detectors).

As already noted, Pu-239 is fissile in the same way as U-235, i.e. with thermal neutrons. It is the other main source of energy in any nuclear reactor. If fuel is left in the reactor for a typical three years, about two thirds of the Pu-239 is fissioned with the U-235, and it typically contributes about one third of the energy output. The masses of its fission products are distributed around 100 and 135 atomic mass units.

The main transuranic constituents of spent fuel are isotopes of plutonium, neptunium and americium. These are alpha-emitters and have long half-lives, decaying on a similar time scale to the uranium isotopes. They are the reason that spent fuel needs secure disposal beyond the few thousand years or so which might be necessary for the decay of fission products alone. **[5]**

2.2.1(b) 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).

2.2.1(c) Cooling

- A nuclear reactor coolant - usually water but sometime 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 cores, for example the boiling water reactor.

2.2.1(d) Reactivity control

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

In other reactors the coolant acts as a poison by absorbing neutrons in the same way that the control rods do. In these reactors power output can be increased by heating the coolant, which makes it a less dense poison. Nuclear reactors generally have automatic and manual systems to insert large amounts of poison (often boron in the form of boric acid) into the reactor to shut the fission reaction down if unsafe conditions are detected or anticipated.

Let us state the above paragraph by considering fission of U-235 nuclei.

Fission of U-235 nuclei typically releases 2 or 3 neutrons, with an average of about 2.5. One of these neutrons is needed to sustain the chain reaction at a steady level of controlled criticality; on average, the other 1.5 leak from the core region or are absorbed in non-fission reactions. Neutron-absorbing control rods are used to adjust the power output of a reactor. These typically use boron and/or cadmium (both are strong neutron absorbers) and are inserted among the fuel assemblies. When they are slightly withdrawn from their position at criticality, the number of neutrons available for ongoing fission exceeds unity (ie criticality is exceeded) and the power level increases. When the power reaches the desired level, the control rods are returned to the critical position and the power stabilizes. The ability to control the chain reaction is entirely due to the presence of the small proportion of delayed neutrons arising from fission. Without these, any change in the critical balance of the chain reaction would lead to a virtually instantaneous and uncontrollable rise or fall in the neutron population. It is also relevant to note that safe design and operation of a reactor sets very strict limits on the extent to which departures from criticality are permitted. These limits are built in to the overall design.**[6]**

2.2.2 Electrical power generation

The energy released in the fission process generates heat, some of which can be converted into usable energy. A common method of harnessing this thermal energy is to use it to boil water to produce pressurized steam which will then drive a steam turbine that generates electricity.**[8]**

Chapter - 3

Reactor Types

3.1 Introduction

As it has been already discussed in chapter 2, 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).

There are several components common to most types of reactors:

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

Moderator. This is material in the core which slows down the neutrons released from fission so that they cause more fission. It is usually water, but may be heavy water or graphite.

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 reactors, special control rods are used to enable the core to sustain a low level of power efficiently. (Secondary shutdown systems involve adding other neutron absorbers, usually as a fluid, to the system.

Coolant. A liquid or gas circulating through the core so as to transfer the heat from it. In light water reactors the water moderator functions also as primary coolant. Except in BWRs, there is secondary coolant circuit where the steam is made.

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 moderator.

***Steam generator*.** (not in BWR) Part of the cooling system where the primary coolant bringing heat from the reactor is used to make steam for the turbine.

***Containment*.** The structure around the reactor core which is designed to protect it from outside intrusion and to protect those outside from the effects of radiation in case of any malfunction inside. It is typically a metre-thick concrete and steel structure.**[9]**

Most reactors need to be shut down for refueling, so that the pressure vessel can be opened up. In this case refuel ling is at intervals of 1-2 years, when a quarter to a third of the fuel assemblies are replaced with fresh ones. The CANDU and RBMK types have pressure tubes (rather than a pressure vessel enclosing the reactor core) and can be refelled 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. Practically all fuel is ceramic uranium oxide (UO_2 with a melting point of 2800°C) and most is enriched. The fuel pellets (usually about 1cm 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 metres long. 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 refuelling.

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 refuel lings**.[10]**

In general nuclear reactors are classified by several methods; a brief out line of these classification schemes is provided as: classification by type of nuclear reaction, classification by moderator material, classification by coolant, classification by generation ,classification by phase of fuel, classification by use,etc**.[11]**

3.2 New Types

New reactor designs are being proposed that claim to offer considerable improvement over existing reactors with little supporting evidence. All nuclear reactor types – conventional uranium, plutonium of 'fast neutron' reactors, fusion and thorium – pose serious risks of contributing to the proliferation of nuclear weapons.

New nuclear reactor types are being promoted with claims that they will produce less nuclear waste than conventional reactors, reduce weapons proliferation risks, and reduce the risk of serious accidents.

While there is certainly scope for considerable improvement on all three fronts, the claims should be treated with some scepticism. It is uncertain whether new reactor types will be developed, with the very large R&D costs being one of the major obstacles. Reactor types with the greatest likelihood of deployment are those which are relatively minor modifications of existing reactor types; as such, any advantages over existing reactors will be marginal.

If new reactor types are developed, they are unlikely to be commercially deployed for some decades (other than those which are minor modifications of existing reactor types). While new reactor types are being promoted as advantageous in relation to waste, weapons and safety, closer inspection of R&D programs suggests that the primary aim is to lower the cost of nuclear power. Indicative of this emphasis on improving economic competitiveness is the list of objectives of 'advanced' reactor types provided by the Uranium Information Centre and the World Nuclear Association:

• a standardised design for each type to expedite licensing, reduce capital cost and reduce construction time,

• simpler and more rugged design, easier to operate and less vulnerable to operational upsets,

•higher availability and longer operating life,

• economically competitive in a range of sizes,

• further reduce the possibility of core melt accidents, and

• higher burn-up to reduce fuel use and the amount of waste.

To the extent that the nuclear power industry is able to improve its cost competitiveness by means other than technological innovation, this will reduce the incentive to develop new reactor types. Methods of improving cost competitiveness in the absence of technological development are:

• reducing regulatory requirements and the attendant costs;

• the imposition of carbon taxes or other disincentives to the use of fossil fuels; and

•further subsidisation of nuclear power e.g. with R&D funding and favourable insurance arrangements such as the US Price Anderson Act.

Improving the economics of nuclear power may come into conflict with the other stated objectives in relation to weapons, waste and safety. Most importantly, there is little reason to believe that minimising proliferation risks will be a priority in the development of new reactor types. A number of the 'advanced' reactor concepts being studied involve a 'closed' fuel cycle that involves reprocessing and thus the actual or potential separation of weapons-useable plutonium (or weapons-useable Uranium-233) from irradiated fuel or targets. Passive or 'inherent' safety systems can improve overall plant safety, such as the use of gravity rather than (failure-prone) pumps to feed coolant into the plant as required. However, overblown and unsubstantiated claims about future reactor designs with (some) passive safety systems has attracted scepticism and cynicism even from within the nuclear industry, with one industry representative quipping that "the paper-moderated, inkcooled reactor is the safest of all" and noting that "all kinds of unexpected problems may occur after a project has been launched".

Importantly, safety depends on social as well as technological factors.

The Massachusetts Institute of Technology (MIT) Interdisciplinary Study states: "We do not believe there is a nuclear plant design that is totally risk free. In part, this is due to technical possibilities; in part due to workforce issues. Safe operation requires effective regulation, a management committed to safety, and a skilled work force." Serious, unresolved problems remain on all three fronts – regulation, management, and workforce skills. The safety culture varies considerably within and between nations operating nuclear power plants.

As the MIT study notes: "It is still an open question whether the average performers in the industry have yet incorporated an effective safety culture into their conduct of business." **[12]**

3.2.1 Generations I-II

Among commercial nuclear power plant types, four generations of reactors are commonly distinguished. Generation I were prototype commercial reactors developed in the 1950s and 1960s. They mostly used natural uranium fuel and used graphite as moderator. Most, but not all of them have already been decommissioned although some Magnox reactors are still operating. The vast majority of the 441 power reactors in commercial operation worldwide today belong to Generation II. They include the following (with parentheses indicating the number in operation, fuel, coolant and moderator)

• Pressurized Water Reactors (268 in operation - enriched uranium dioxide fuel - water coolant - water moderator)

• Boiling Water Reactors (94 - enriched uranium dioxide - water - water)

• Gas-cooled reactors (Magnox and AGR) (23 - natural or enriched uranium - carbon dioxide coolant - graphite moderator)

• Graphite Moderated Boiling Water Reactors (12 - enriched uranium dioxide - water - graphite)

•Pressurized Heavy Water Reactors (40 - natural uranium dioxide - heavy water - heavy water)

• Fast Neutron Reactors (4 - plutonium and uranium dioxide - liquid sodium - no moderator). **[13]**

3.2.1(a) Pressurized Water Reactor (PWR)

In the pressurized water reactor, the water which flows through the reactor core is isolated from the turbine. In this reactor, (PWR), the water which passes over the reactor core to act as moderator and coolant does not flow to the turbine, but is contained in a pressurized primary loop. The primary loop water produces steam in the secondary loop which drives the turbine. The obvious advantage to this is that a fuel leak in the core would not pass any radioactive contaminants to the turbine and condenser.

Another advantage is that the PWR can operate at higher pressure and temperature, about 160 atmospheres and about 315 C. This provides a higher carnot efficiency than theBWR, but the reactor is more complicated and more costly to construct. Most of the U.S. reactors are pressurized water reactors.

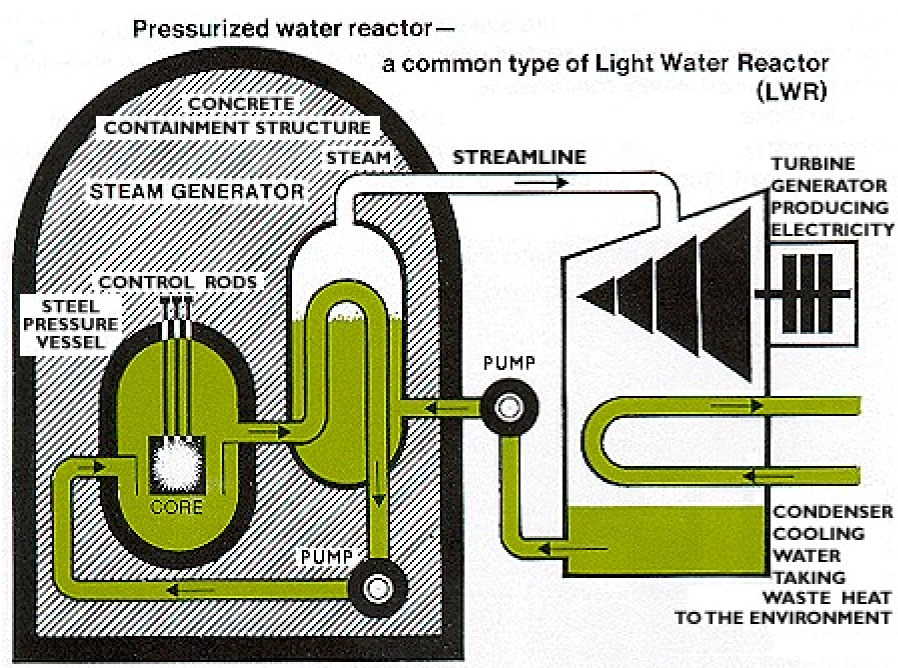


Fig.3.2.1(a) pressurized water reactor (PWR)

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. 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 tonnes 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.**[14]**

3.2.1(b) Boiling Water Reactor (BWR)

In the boiling water reactor the same water loop serves as moderator, coolant for the core, and steam source for the turbine.

In the boiling water reactor (BWR), the water which passes over the reactor core to act as moderator and coolant is also the steam source for the turbine. The disadvantage of this is that any fuel leak might make the water radioactive and that radioactivity would reach the turbine and the rest of the loop.

A typical operating pressure for such reactors is about 70 atmospheres at which pressure the water boils at about 285�C.

This operating temperature gives a carnot efficiency only 42% with a practical operating efficiency of around 32%, somewhat less than the PWR.

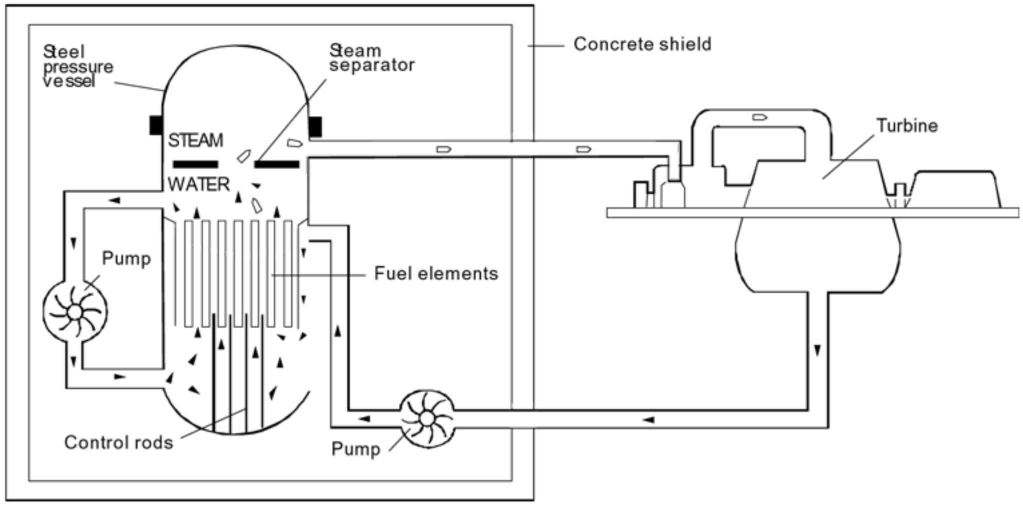


Fig.3.2.1(b)Boiling water reactor(BWR)

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. 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. 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**.[15]**

3.2.1(c) Pressurized Heavy Water Reactor (PHWR orCANDU)

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 (ie 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 refuelled progressively without shutting down, by isolating individual pressure tubes from the cooling circuit.

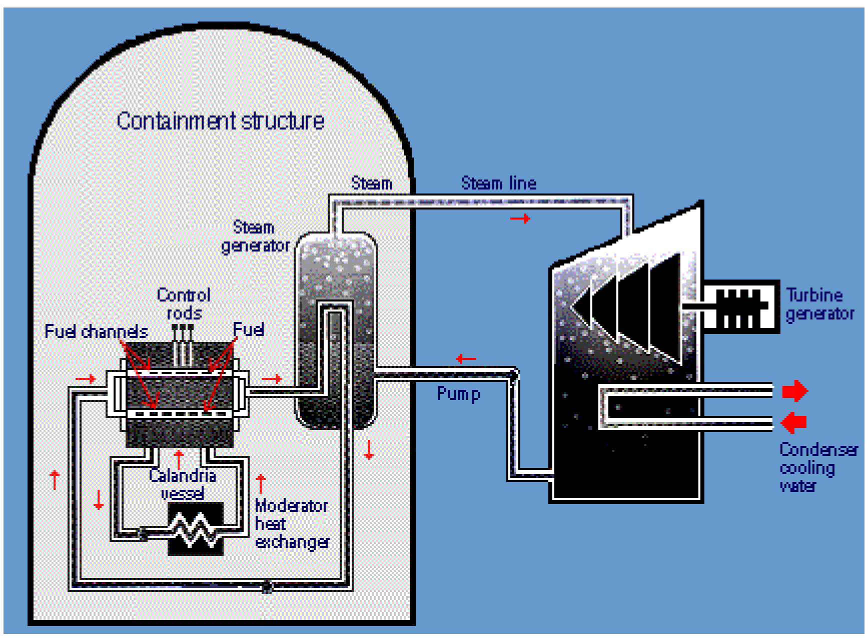


Fig.3.2.1(c) Pressurized Heavy Water Reactor(PHWR OR CANDU)

A CANDU fuel assembly consists of a bundle of 37 half metre 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 Candu Reactor (ACR) have light water cooling and slightly-enriched fuel.**[16]**

3.2.1(d)Advanced Gas-cooled Reactor (AGR)

These are the second generation of 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.3.2.4)

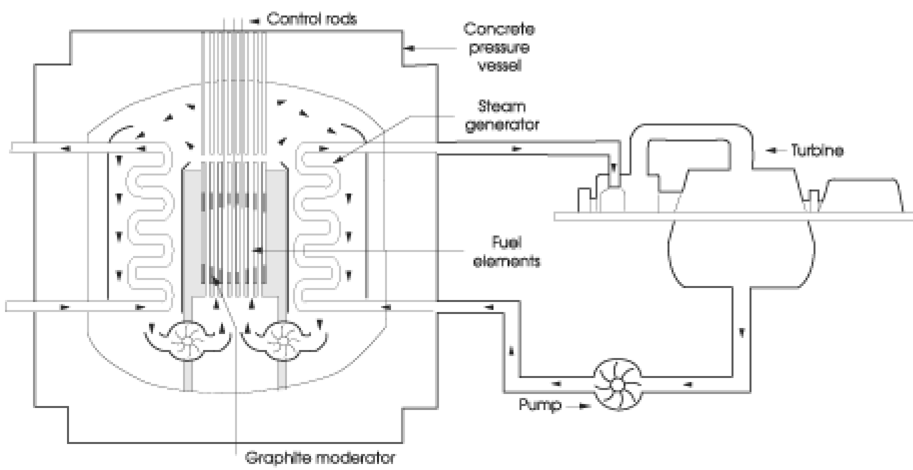


Fig.3.2.1(d) Advanced Gas Cooled Reactor(AGCR)

The AGR was developed from the Magnox reactor, also graphite moderated and CO_2 cooled. They use natural uranium fuel in metal form. **[17]**

3.2.1(e) Light water graphite-moderated reactor (LWGMR)

This design is developed from plutonium production reactors. It employs long (7 metre) 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 metres 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.**[18]**

3.2.2 Generation III

Throughout the world there are around 20 different concepts for the next generation of reactor design, known as Generation III. Most of them are "evolutionary" designs that have been developed from Generation II reactor types with some modifications. A smaller number of proposed Generation III reactor types are more innovative. Only in Japan are there any commercial scale reactors of Generation III in operation - the Advanced Boiling Water Reactors, which are modifications of existing reactor types. The next most advanced design is the European Pressurised Water Reactor, which is being built in Finland and may be also sited in France. According to Hirsch et al. this design is a slightly modified version of current reactor designs operating in France and Germany, with some improvements, but also with reduction of safety margins and fewer redundancies for some safety systems.

Other examples of Generation III reactor types are: various pressurised water reactor types, the pebble bed modular reactor, boiling water reactors, heavy water reactors, gas cooled reactors, and fast breeder reactors. Hirsch et al. conclude that: "All in all, "Generation III" appears as a heterogeneous collection of different reactor concepts. Some are barely evolved from the current Generation II, with modifications aiming primarily at better economics, yet bearing the label of being safer than current reactors in the hope of improving public acceptance. Others are mostly theoretical concepts so far, with a mixture of innovative and conventional features, which are being used to underpin the promise of a safe and bright nuclear future – while also not forgetting about simplification and cost-cutting." **[19]**

3.2.3 Generation IV

Generation iv reactors are a set of theoretical nuclear reactor designs currently being researched . These designs are generally not expected to be available for commercial construction before 2030.

Current reactors in operation around the world are generally considered second or third -generation systems,with the first generation systems having been retired some time a go. Under the leadership of the US, the “Generation IV International Forum” (GIF) was established in 2000. The GIF also includes Argentina, Brazil, China, Canada, France, Japan, Russia, South Africa, South Korea, Switzerland, the UK, and EURATOM.

A parallel initiative is the IAEA-led International Projects on Innovative Nuclear Reactors and Fue Cycles (INPRO), established in 2000. Generation IV reactor types generally represent considerable departures from conventional reactor technology. Development to the point of commercial deployment will necessarily involve major financial investments over a period of some decades.

While electricity generation is the primary focus, there is also some interest in the development of reactor types suitable for hydrogen production and nuclear waste treatment.

Currently, there are six reactor designs being considered, including:

- Gas-Cooled Fast Reactor System
- Lead-Cooled Fast Reactor System
- Molten Salt Reactor System
- Supercritical-Water-Cooled Reactor System
- Sodium-Cooled Fast Reactor System
- Very-High-Temperature Reactor System

Hirsch et al. summarise the gap between rhetoric and reality in relation to Generation IV designs: “A closer look at the technical concepts shows that many safety problems are still completely unresolved. Safety improvements in one respect sometimes create new safety problems. And even the Generation IV strategists themselves do not expect significant improvements regarding proliferation resistance. But even real technical improvements that might be feasible in principle are only implemented if their costs are not too high. There is an enormous discrepancy between the catch-words used to describe Generation IV for the media, politicians and the public, and the actual basic driving force behind the initiative, which is economic competitiveness.”**[20]**

3.2.4 Generation III- IV Reactor types

It is beyond the scope of this paper to describe and analyse all of the Generation III and IV reactor types but some of the best-known types are discussed below - the Pebble Bed Modular Reactor, plutonium breeder reactors, fusion power, and thorium-powered systems.

3.2.4 (a) Pebble Bed Modular Reactors (PBMR)

Of the more innovative Generation III reactor types, the best known is the Pebble Bed Modular Reactor (PBMR). PBMRs are helium cooled and graphite moderated and intended to be built in small modules. Pressurized helium heated in the reactor core drives turbines that attach to an electrical generator. While the PBMR is in some respects innovative, it also shares features with high temperature gas cooled reactors (HGTR). The HTGR line has been pursued until the late 80s in several countries; however, only prototype plants were ever operated (in the USA, UK and Germany), all of which were decommissioned after about 12 years of operation at most. China operates an experimental PBMR with a larger (200 MWe) ‘demonstration’ reactor planned. A pilot PBMR is planned in South Africa.

Internal documents from South African utility giant Eskom, leaked in 2005, point to considerable financial risks in the development of PBMR technology. The US-based company Exelon withdrew its involvement in the development of PBMR technology in 2002. PBMR proponents claim major safety advantages resulting from the heat-resistant quality and integrity of the small fuel pebbles, many thousands of which are continuously fed from a silo. Each spherical fuel element has a graphite core embedded with thousands of small fuel particles of enriched uranium (up to 10% uranium-235), encapsulated in layers of carbon. The safety advantages of PBMR technology include a greater ability to retain fissile products in the event of a loss- of-coolant accident. While this configuration is potentially advantageous compared to conventional reactors, it does not altogether avoid the risk of serious accidents; in other words, claims that the system is ‘walk-away safe’ are overblown. Familiar commercial pressures can undermine the safety advantages; for example there are plans to develop PBMR reactors with no containment building.

In relation to weapons proliferation (Harding, 2004)

•The nature of the fuel pebbles may make it somewhat more difficult to separate plutonium from irradiated fuel, but plutonium separation is certainly not impossible.

• Uranium (or depleted uranium) targets could be inserted to produce weapon-grade plutonium for weapons, or thorium targets could be inserted to produce uranium-233.

• The enriched uranium fuel could be further enriched for weapons.

•The reliance on enriched uranium will encourage the use and perhaps proliferation of enrichment plants, which can be used to produce highly enriched uranium for weapons.

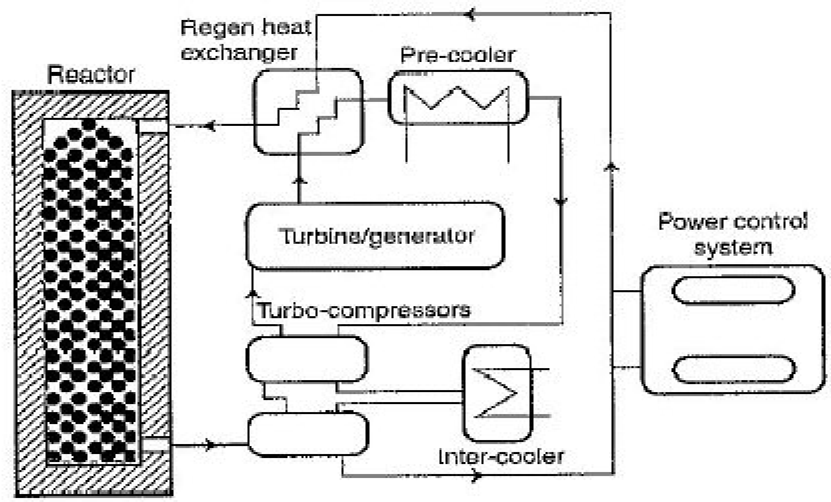


Figure:3.2.4(a) Circuit of pebble Bed Modular Reactors

3.2.4(b)Plutonium Breeder Reactors

Fast neutron reactors use plutonium as the primary fuel. They do not require a moderator as the fuel fissions sufficiently with fast neutrons to maintain a chain reaction. The various possible configurations include ‘breeders’ which produce more plutonium than they consume, ‘burners’ which do the reverse, and configurations that both breed and burn plutonium.

There are various possible configurations of breeder systems. Most rely on irradiation of a natural or depleted uranium blanket that produces plutonium which can be separated and used as fuel.

According to the World Nuclear Association (2004), worldwide experience with fast neutron reactors amounts to just 200 reactor-years and only “some” of that experience involves reactors in breeder mode. According to an IAEA scientist, the introduction of breeder reactors into the competitive electricity market is not expected before 2030, at which time breeders are expected to provide 1-2% of nuclear energy output, and this prediction may be “optimistic”.

Small breeder R&D programs are ongoing in a few countries (e.g. India, Russia, France) but in other countries the technology has been stalled or abandoned (e.g. the UK, the US, and Germany) or never developed in the first place. Japan’s plans for breeder reactors have been limited and delayed by accidents including the sodium leak and fire at the experimental Monju reactor in 1995.

One reason for the limited interest in plutonium breeder power sources has been the cheap, plentiful supply of uranium. That situation may change, but while breeder technology certainly holds out the promise of successfully addressing the problem of limited conventional uranium reserves, it is doubtful whether the wider range of technical, economic, safety and proliferation issues can be successfully addressed.

Breeder technology is highly problematic in relation to proliferation because it involves the large-scale production and separation of plutonium (although separation is not required in some proposed configurations). The proliferation of reprocessing capabilities is a likely outcome. Interest in breeder and reprocessing technology in South Korea and China is arguably driven in part by concerns over Japan’s plutonium policies (which involve the large-scale separation and stockpiling of plutonium).

3.2.4(c) Fusion Power

Fusion fuel - using different isotopes of hydrogen - must be heated to extreme temperatures of some 100 million degrees Celsius, and must be kept dense enough, and confined for long enough to enable fusion to become self- sustaining.

A major fusion R&D program is underway called the International Thermonuclear Experimental Reactor. It involves the European Union, Japan, China, India, South

Korea, Russia, and the USA. An experimental plant is to be built at Cadarache in the South of France.

Australian interest in fusion is concentrated in a coalition called the Australian ITER Forum.

Fusion power remains a distant dream. According to the World Nuclear Association (2005C), fusion “presents so far insurmountable scientific and engineering challenges”.

Australian proponents of fusion claim it is “intrinsically clean” and “inherently safe”. However, in relation to radioactive waste issues, the World Nuclear Association states: “Although fusion generates no radioactive fission products or transuranic elements and the unburned gases can be treated on site, there would be a short-term radioactive waste problem due to activation products.

Some component materials will become radioactive during the lifetime of a reactor, due to bombardment with high-energy neutrons, and will eventually become radioactive waste.

The volume of such waste would be similar to that due to activation products from a fission reactor. The radiotoxicity of these wastes would be relatively short-lived compared with the actinides (long-lived alpha-emitting transuranic isotopes) from a fission reactor.”

In relation to safety issues, the World Nuclear Association points to potential problems identified by the American Association for the Advancement of Science (AAAS): These include the hazard arising from an accident to the magnetic system.

The total energy stored in the magnetic field would be similar to that of an average lightning bolt (100 billion joules, equivalent to about 45 tonnes of TNT). Attention was also drawn to the possibility of a lithium fire. In contact with air or water lithium burns spontaneously and could release many times that amount of energy. Safety of nuclear fusion is a major issue. But the AAAS was most concerned about the release of tritium into the environment.

It is radioactive and very difficult to contain since it can penetrate concrete, rubber and some grades of steel. As an isotope of hydrogen it is easily incorporated into water, making the water itself weakly radioactive. With a half-life of 12.4 years, tritium remains a threat to health for over one hundred years after it is created, as a gas or in water. It can be inhaled, absorbed through the skin or ingested.

Inhaled tritium spreads throughout the soft tissues and tritiated water mixes quickly with all the water in the body. The AAAS estimated that each fusion reactor could release up to 2x1012 Bequerels of tritium a day during operation through routine leaks, assuming the best containment systems, much more in a year than the Three Mile Island accident released altogether. An accident would release even more. This is one reason why long-term hopes are for the deuterium-deuterium fusion process, dispensing with tritium." Some proponents of fusion falsely claim that fusion power systems pose no risk of contributing to the proliferation of nuclear weapons. In fact, there are several risks:

•The production or supply of tritium which can be diverted for use in boosted nuclear weapons.

•Using the fusion reactor's neutron radiation to bombard a uranium blanket (leading to the production of fissile plutonium) or a thorium blanket (leading to the production of fissile uranium-233).

• Research in support of a (thermonuclear) weapon program.

Fusion power R&D has already contributed to proliferation problems. According to Khidhir Hamza, a senior nuclear scientist involved in Iraq's weapons program: "Iraq took full advantage of the IAEA's recommendation in the mid 1980s to start a plasma physics program for "peaceful" fusion research. We thought that buying a plasma focus device ... would provide an excellent cover for buying and learning about fast electronics technology, which could be used to trigger atomic bombs."

3.2.4(d) Thorium Based reactors

The use of Thorium-232 as a reactor fuel is sometimes suggested as a long-term energy source, partly because of its relative abundance compared to uranium. Some experience has been gained with the use of thorium in power and research reactors – but far less experience than has been gained with conventional uranium reactors.

The Uranium Information Centre states that: "Much development work is still required before the thorium fuel cycle can be commercialised, and the effort required seems unlikely while (or where) abundant uranium is available.”

According to the World Nuclear Association: “Problems include the high cost of fuel fabrication due partly to the high radioactivity of U-233 which is always contaminated with traces of U-232, similar problems in recycling thorium due to highly radioactive Th-228, some weapons proliferation risk of U-233; and the technical problems (not yet satisfactorily solved) in reprocessing. Much development work is still required before the thorium fuel cycle can be commercialised, and the effort required seems unlikely while (or where) abundant uranium is available.”

Thorium fuel cycles are promoted on the grounds that they pose less of a proliferation risk compared to conventional reactors. However, whether there is any significant non-proliferation advantage depends on the design of the various thorium-based systems.

No thorium system would negate proliferation risks altogether.

Neutron bombardment of thorium (indirectly) produces uranium-233, a fissile material that can be used in nuclear weapons (1 Significant Quantity of U-233 = 8kg).

The USA has successfully tested weapons using Uranium-233 cores, and India may have investigated the military use of Thorium/Uranium-233 in addition to its civil applications.

The proliferation risk is exacerbated with existing and proposed configurations involving uranium-233 separation from irradiated fuel. As the World Nuclear Association notes: “Given a start with some other fissile material (U-235 or Pu-239), a breeding cycle similar to but more efficient than that with U-238 and plutonium (in slow-neutron reactors) can be set up.

The Th-232 absorbs a neutron to become Th-233 which normally decays to protactinium-233 and then U- 233. The irradiated fuel can then be unloaded from the reactor, the U-233 separated from the thorium, and fed back into another reactor as part of a closed fuel cycle.” (A research reactor in India operates on U-233 fuel extracted from thorium that has been irradiated and bred in another reactor.)

The possible use of highly enriched uranium (HEU) or plutonium to initiate a Thorium-232/Uranium-233 reaction, or proposed systems using thorium in conjunction with HEU or plutonium as fuel present the risk of diversion of HEU or plutonium for weapons production. Kang and von Hippel conclude that “the proliferation resistance of thorium fuel cycles depends very much upon how they are implemented”. For example, the co-production of Uranium-232 complicates weapons production but, as Kang and von Hippel note, “just as it is possible to produce weapon-grade plutonium in low-burnup fuel, it is also practical to use heavy-water reactors to produce U-233 containing only a few ppm of U-232 if the thorium is segregated in “target” channels and discharged a few times more frequently than the natural-uranium “driver” fuel.” One proposed system is an Accelerator Driven Systems (ADS) in which an accelerator produces a proton beam which is targeted at target nuclei (e.g. lead, bismuth) to produce neutrons.
The neutrons can be directed to a subcritical reactor containing thorium. ADS systems could reduce but not negate the proliferation risks. **[21]**

3.3 Future Reactors

3.3.1 Generation v+ Reactors

Designs which are theoretically possible, but which are not being actively considered or researched at present. Though such reactors could be built with current or near term technology ,they trigger little interest for reasons of economics , practicality, or safety.**[22]**

Chapter- 4 - Applications

4.1 Introduction

Nuclear technology uses the energy released by splitting the atoms of certain elements. It was first developed in the 1940s, and during the Second World War research initially focused on producing bombs by splitting the atoms of either uranium or plutonium.

In the 1950s attention turned to the peaceful purposes of nuclear fission, notably for power generation. Today, the world produces as much electricity from nuclear energy as it did from all sources combined in 1960. Civil nuclear power can now boast over 13,000 reactor years of experience and supplies almost 16% of global electricity needs, in 30 countries.

Many countries have also built research reactors to provide a source of neutron beams for scientific research and the production of medical and industrial isotopes.

Today, only eight countries are known to have a nuclear weapons capability. By contrast, 56 operate civil research reactors, and 30 have some 440 commercial nuclear power reactors with a total installed capacity of over 370 000 MWe . This is more than three times the total generating capacity of France or Germany from all sources. Some 30 further nuclear power reactors are under construction, equivalent to 8% of existing capacity, while over 90 are firmly planned, equivalent to 27% of present capacity.

In general nuclear reactors now account for a significant portion of the electrical power generated worldwide. At the same time, the past few decades have seen an ever-increasing number of industrial, medical, military, and research applications for nuclear reactors. **[23]**

4.2 Basic Applications

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.

There are two fundamentally different means of harnessing nuclear energy to produce electricity. The first and best known is the fission reactor. Reactors split the atoms of highly enriched uranium or plutonium fuel in a controlled reaction to release energy, including heat. The heat is used to boil water into steam, which is converted into mechanical energy by a turbine. That mechanical energy is then used to run a generator and produce electricity as it has been also out lined so far. Another form of nuclear power is the radioactive decay battery (sometimes called an atomic battery), which uses the radiation released by the decay of certain radioactive substances as a source of heat to generate electricity. There are a variety of designs for both fission reactors and atomic batteries, and some are especially well-suited to particular functions.

4.2.1 Utility Reactor

The most common use for a nuclear power plant is to generate electricity for civilian consumption. In 2009, 15 percent of the world's total electrical output was met through these utility-scale nuclear power plants, with 436 such facilities in service in 30 different countries and in 2006 ,about 14.7 percent of the world's total electrical output was also met through these utility- scale nuclear power plants .

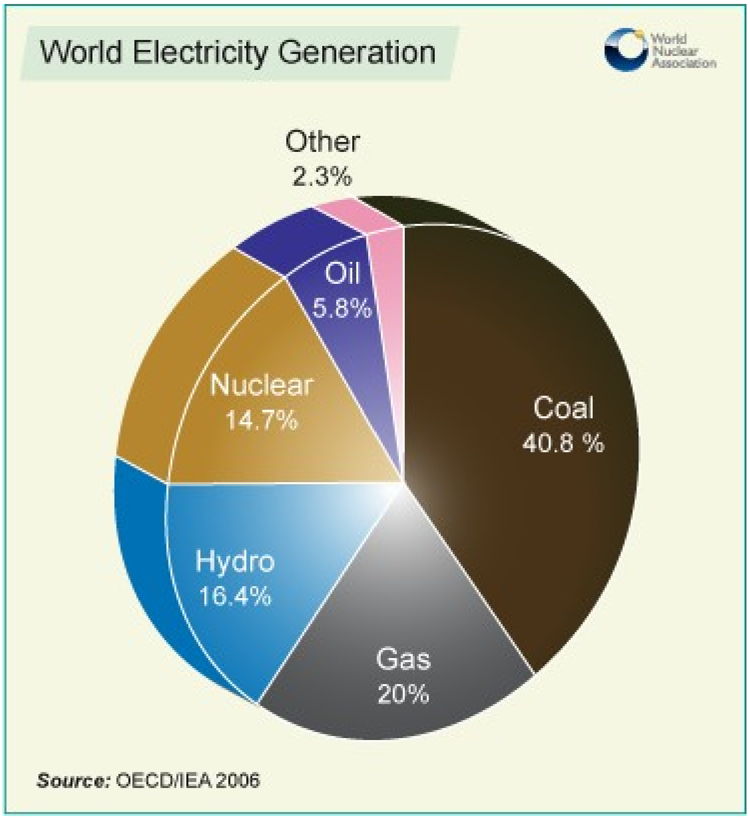


Figure:4.2

Diagram showing percentages of nuclear,and etc for world electricity generation.

- **Improved performance from existing nuclear reactors**

Although fewer nuclear power plants are being built now than during the 1970s and 1980s, those now operating are producing more electricity. In 2007, production was 2608 billion kWh. The increase over the six years to 2006 (210 TWh) was equal to the output from 30 large new nuclear power plants. Yet between 2000 and 2006 there was no net increase in reactor numbers (and only 15 GWe in capacity).

The rest of the improvement is due to better performance from existing units. In 2007 performance dropped back by 50 TWh due to plant closures in Germany, UK and Japan.

In a longer perspective, from 1990 to 2006, world capacity rose by 44 GWe (13.5%, due both to net addition of new plants and uprating some established ones) and electricity production rose 757 billion kWh (40%). The relative contributions to this increase were: new construction 36%, uprating 7% and availability increase 57%. One quarter of the world's reactors have load factors of more than 90%, and nearly two thirds do better than 75%, compared with about a quarter of them in 1990. For 15 years Finnish plants topped the performance tables, but the USA now dominates the top 25 positions, followed by South Korea.

US nuclear power plant performance has shown a steady improvement over the past twenty years, and the average load factor now stands at around 90%, up from 66% in 1990 and 56% in 1980. This places the USA as the performance leader with 12 of the top 25 reactors, the 25th achieving more than 97.5%. The USA accounts for nearly one third of the world's nuclear electricity.

In 2007 and 2008 ten countries averaged better than 80% load factor, while French reactors averaged 76-77%, despite many being run in load-following mode, rather than purely for base-load power.

Some of these figures suggest near-maximum utilization, given that most reactors have to shut down every 18-24 months for fuel change and routine maintenance. In the USA this used to take over 100 days on average but in the last decade it has averaged about 40 days. Another measure is unplanned capability loss, which in the USA has for the last few years been below 2%.

4.2.2 Other nuclear reactors

Naval propulsion- Nuclear reactors are also used on sea-going vessels, where they provide both electricity and mechanical power for propulsion. The reactor design used for these vessels is almost always the pressurized water type. This type is widely used in civilian reactors designs, but is prized for use in ships due to its ability to function well in an unstable platform (like a ship pitching and heaving at sea) Instead of piping steam to a turbine, it transfers heat energy through super-heated water kept under very high pressure. Examples in use are found among aircraft carriers, submarines, missile cruisers, and icebreakers.

Satellites- The major application of the atomic battery power plant is on space satellites that have a substantial, long-term demand for electricity that cannot be met through other means, such as solar panels. A good example of an atomic battery in operation is the radioisotope thermoelectric generator, which uses heat from radioactive decay to operate thermocouples and produce electricity. The Cassini space probe, for example, used a radioisotope thermoelectric power source.

Byproducts- The process of creating fuel for and running nuclear power plants produces a number of useful byproducts, or can be tailored to do so. Enriching uranium for fission reactors, for example, creates an isotope commonly known as depleted uranium, which the American military uses in the manufacture of both armor and ammunition due to its extremely high density. Then there are breeder reactors, which produce new fissile material (usually plutonium) at a rate greater than that at which the reactor consumes them, thereby creating a second generation of fuel. This reactor design is useful for its high fuel economy. **[24]**

Chapter - 5

Conclusion and summary

Recently, the cost of oil is getting higher and higher. The governments have also instructed to all of nation apparatus and people to use oil wisely. The crude oil was almost very high USD per barrel when compared with other. That problem surely forces us to try to find alternative energy to make this condition better. Many scientists have tried to give some solutions to solve energy crisis in the world. Actually, there are many kinds of alternative energy like using renewable resources, winds, solar cells, geothermal, and nuclear. However, choosing the best is not easy. Each of them has its own pluses and minuses. One of good energy alternative is nuclear energy. **[25]**

Nuclear energy is beneficial because it is cheap, safe and environmentally friendly.

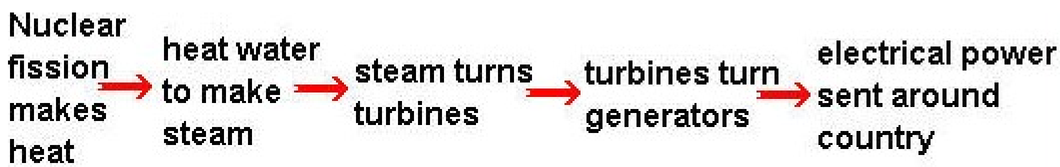
Firstly, the nuclear energy is cheap. We can know from the news of television that the cost of crude oil always increases every year. If we compare the cost of oil with the cost of nuclear energy, we will know that the cost of nuclear energy is cheaper. Even, when the cost crude oil is low, the nuclear energy is still cheaper. The nuclear energy usually uses enriched uranium as fuel of reactor. It takes just a little uranium to operate a commercial reactor. As a comparison, one gram of uranium as nuclear fuel equals to one ton energy of coal. It is very economical. Besides that, the price of nuclear energy is stable because the uranium reserve can store the uranium for several years when the price is low. The storage of uranium is simple. It only requires small space. It means that the uranium can be easily stored until it is needed. Most countries can not store its oil reserve for years. They do not have enough space to store more than 3 or 6 months supply of fossil fuel. It needs a large space. Alternative energy like nuclear energy is one of good solution get small storage and efficient space for national energy.

Secondly, the nuclear energy is safe. The use of nuclear for power plant needs a good coordination between technology, human resources, and regulation. The Integration of the three factors will create safety for people, workers and environment. The Knowledge about safety for using nuclear has advanced from publications of researchers in the world. There is a safety testing known as Probability Safety Assessment (PSA) in nuclear. That assessment can reduce the accident until one millionth. It means in one million action or operation in reactor only one probability of accident. It can be concluded that the operation nuclear reactor is very safe. Besides that, The nuclear power plant is equipped with a fine system known as Defense In Depth. When you are using nuclear as power plant many factors has to be calculated and estimated for make sure that the system will operate safely and running well. All procedures have been regulated with international standard from International Atomic Energy Agency – United Nation (IAEA-UN).

When one country plans to build a nuclear reactor, it must be chosen from the one which has been to work well in other countries. That technology must have been operated for several years without accidents.

Thirdly, the nuclear energy is environmentally friendly. The power plant which uses fossil fuel will produce many dangerous gases like carbon monoxide (CO), carbon dioxide (CO_2), sulfur dioxide, nitrogen dioxide, etc. The side effect from fossil fuel power plant is not only poisonous gases but also the increase of greenhouse effect and global warming in the world. Those things may trigger the melting of glaciers and the ice in the north or south pole. That condition can drown every port city and seacoast in the world. Besides that, sulfur dioxide will cause acid rain. It is also very dangerous. That's very different when we use uranium as fuel. When enriched uranium is burnt to operate nuclear power plant, it will not produce dangerous gases. The nuclear reactor will operate environmentally friendly without emission.

The nuclear fuel is pure and has no sulfur. It is not in contact with the air only confined in fuel element or reactor vessel. That means no nitrogen and no smoke produced to the environment. Finally, nuclear energy has been tested to be most beneficial to society of the world. Nuclear energy has also known to be a protector of the environment because of the decrease of CO2, greenhouse gases, and other gases which emitted into the atmosphere. Dependence of oil must be reduced by using alternative energy. So, the governments should alter their perspective that nuclear energy will give a low price energy to people.**[26]**



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DECLARATION

I the under signed declare that the project is my original work , has not been presented for a degree in any other university and that all sources of material used for the thesis have been duly acknowledged.

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