Introduction:-

- In this unit we are going to discuss about the Principles For using nuclear Power to Produce electricity

- Energy released from Fission of atoms of the Fuel is harnessed as heat in either gas or water is used to produce steam.

- Steam is used to drive turbines which Produce electricity

- Difference b/w nuclear Power plant & conventional is how heat is produced.

- In fossil plant oil, gas, or coal is Fired in boiler, chemical energy in to heat.

- nuclear power plant energy comes from Fission reaction is utilized

Radiation:-

- nuclear radiation can extremely beneficial & dangerous depend on how use it. Problem will be environmental Pollution, mine safety, Fuel transportation are much less severe in nuclear Power Station.

- The structure of nuclear P.P in many aspects resembles to conventional thermal Power station., both cases the heat

Produced in boiler is transported by some coolant & used to generate steam

- steam then goes to blades of turbine & rotating it. The connected generator will produce electric energy.

- steam goes to condenser, where it condenses (ie) become liquid again.

- the cooled down water afterwards gets back to boiler or reactor

In this unit we are going to discuss about the basics of nuclear Engineering (ie) Atoms & elements, Radio activity, units of radio activity, biological effects, radioactive decay, Alpha decay, Beta. negative decay, Gamma decay Electron capture, Decay chains

Then about the Layout & the Subsystem of nuclear Power Plant & its Structure, & also about the working of nuclear reactors (ie)

Boiling water reactor (BWR)

Pressurized water reactor (PWR)

Canada Deuterium - uranium reactor (CANDU) & also about the Breeder Structure & its operation.

– Also we are going to discuss about the concept of reactors and its types (i.e) Gas cooled & liquid metal cooled reactors and with the same thing we are going to discuss about main components of Nuclear Reo Power plant. (ie) Fuel Rods, Control Rods, Reactor, Heat Exchanger, Pump, Steam line, Generator, Turbine, containment cooling water tower, Radio active non radioactive water loop.

Also we discuss about the Safety measures of Nuclear power plants.

(i) control of Radio activity.

(ii) Maintanance of core cooling.

(iii) Maintanance of barriers that prevent the release of radiation.

Nuclear Power Plant Challenges &

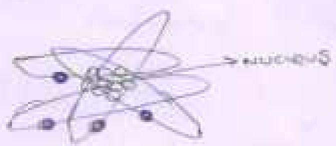
Nuclear Power Plant in india.

Basics of Nuclear Engineering:-

→ Smallest Particle of element is called atom, & atom consist of Proton, neutron & electron

→ Protons & neutrons found in nucleus

cloud of electrons moving around orbit.



→ uranium has 92 Protons & 92 electrons & naturally occur as a mixture of two isotopes (U235, U238). The nucleus of isotopes such as U235 absorp an extra neutron then split in a process known as nuclear Fision

Fission produces 2 to 3 free neutrons

Radioactivity:-

→ 1975 concept album by Kraft werk.

→ Nucleus emits α, β. electromagnetic rays during this Process

Uses of Radio activity:-

- Roentgen (R):- Defined as amount of ionizing radiation which Produces 2.08×10^{9} ion Pairs in $1cm^3$ of air.

→ RAD:- (Radiation Absorbed Dose)

A rad is a amount of radiation that puts

3

RBE :- (Relative Biological Effectiveness)

Biological Risk α, β, γ radiation differ

REM :- (Roentgen Equivalent in man)

→ Product of amount of rad to the RBE Factor

Gray (Gy) :- 100 rads

Biological Effects of Radiation :-

→ Ionizing radiation causes Physical damage to Cell & DNA

Radio Active Decay :-

Atoms are continuously undergoing decay.

$^{238}_{92}U$ ← Element

↑ charge (or) Atomic number

Five different types of radio active decay

→ Alpha decay (α) (Pu 239 → u235 + α Particle)

→ Beta (−ve) decay (β) $^{x}_{z}A \rightarrow ^{0}_{-1}e^{-1} \rightarrow ^{x}_{z+1}B$

→ Gamma decay (γ) $^{x}_{z}A \rightarrow ^{0}_{0}\gamma \rightarrow ^{x}_{z}B$

→ Positron emission (β^{+}) $^{x}_{z}A \rightarrow ^{0}_{0}e \rightarrow ^{x}_{z-1}B$

→ Electron Capture

$^{x}_{z}A \rightarrow ^{0}_{-1}e \rightarrow ^{x}_{z-1}B$

Radio active Decay Rate:-

Half life:- symbol $t_{1/2}$

→ Time taken for the activity of a given amount of a radio active substance to decay to half of its initial value

Mean life time:- symbol τ:-

The average life time of radio active particle

Decay constant:- symbol λ:-

The inverse of mean life time

Nuclear Fission:-

Atom nucleus split & tremendous amount of energy is released. Energy is both heat & light energy. Einsten said very small amount of matter contains very large amount of energy

Engineering problem which must take in to account factors:

→ control - keeping the nuclear reaction from dying out or exploding

→ safety:- If some thing goes wrong it can be contained.

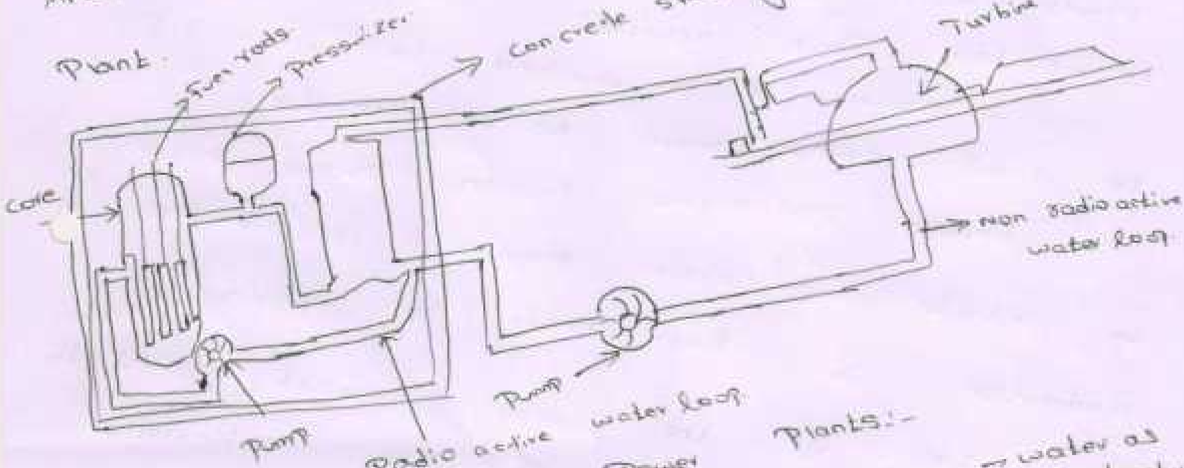
→ Re fueling - Adding more nuclear fuel

→ waste production

→ Efficiency.

Layout * Subsystem of nuclear power plant.

- nuclear fuel cycle begins when uranium is mined, enriched, & manufactured in to nuclear fuel which is deliver in to nuclear plant. After usage in plant spent fuel is deliver to - reprocessing plant.



Components of nuclear power plants:-

→ Fuel rods → control Rods - moderator → water as moderator

→ coolant → containment. → cooling water tower.

→ radioactive non radio active water loop

Fuel:-
→ Enriched uranium is typically formed in to inch long (2.5 cm long) pellets. each with approximatey same diameter as a dime.
usually pellets of uranium oxide (UO_2)
arrange in tubes to form fuel rods. Rods are arranged in to fuel assemblies in reactor core

Moderator:-

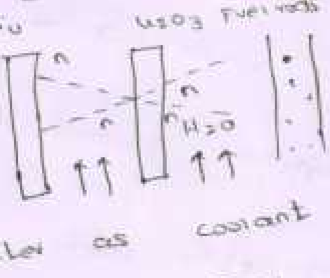
- Slows down the neutrons released from fission, so they cause more fission. It is usually water but may be heavy water.

Water as moderator:-

- Neutrons from fission have very high speeds must be slowed greatly by water to maintain chain reaction.
- Uranium - 235 is enriched to 2.5 - 3.5 % to allow ordinary water to be moderator.

Enough spontaneous fission events occur to initiate a chain reaction if proper fuel density is provided moderation → coolant kills the

Loss of the water fuel configuration chain reaction since the water moderation is not critical with out water moderation



→ moderator for water as coolant flow b/w fuel rods

Loss of water Even with moderator fuel is not critical with out inclusion of delayed neutrons which may be emitted several minutes after fission

The rods can also be lowered completely in to uranium bundle to shut the reactor down in case of an accident or to charge fuel

The uranium bundle act as an extremely high energy source of heat. It heats the water & turns it to steam. The steam drives a turbine which spins a generator to produce power.

These are made with neutron absorbing material such as cadmium, hafnium boron & are inserted or with drawn from core to control rate of reaction.

Coolant:- A liquid or gas circulate through core so as to transfer heat from it. In light water reactor water moderator function also as primary coolant Except in BWR's there is secondary coolant is what makes steam control rods:-

→ The Fuel rods are surrounded submerged inside water a Pressure level The water act as coolant.

→ For the reactor to work, the submerged bundles must be slightly super critical. The uranium would eventually over heat & melt.

→ To prevent over heating control rods made of a material that absorb neutron are inserted in to uranium bundle using a mechanism that can raise or lower the control rods.

→ Raising & lowering the control rods allow operators to control the rate of nuclear reaction.

When an operator wants the uranium core to produce more heat, the control rods are raised out of uranium bundle. To create less heat, they are lowered in to uranium bundle.

Nuclear Reactor:-

→ Reactor can be homogenous or heterogenous.

→ heterogenous has large number of Fuel Rods with coolant circulate around them & carrying away the heat released by fission.

→ In homogenous reactor the fuel and moderator are mixed (eg) fissionable salt of uranium

→ The solution is critical in core

→ Due to difficulties in component maintenance induced radioactivity erosion & corrosion homogenous reactors are not common

Reactors are further subdivided as

1. Pressurized water reactor (PWR)
2. Boiling water reactor

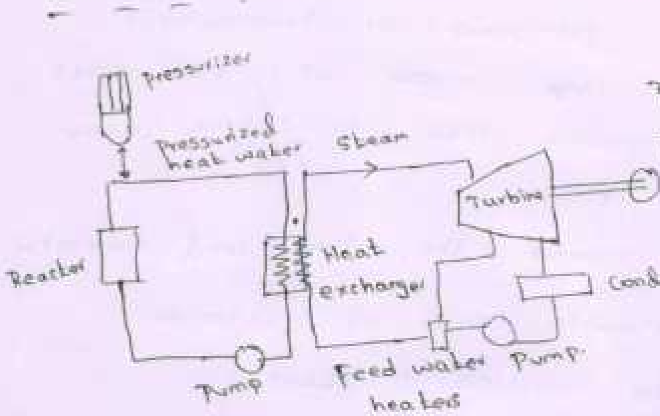
Pressurized Water Reactor (PWR)

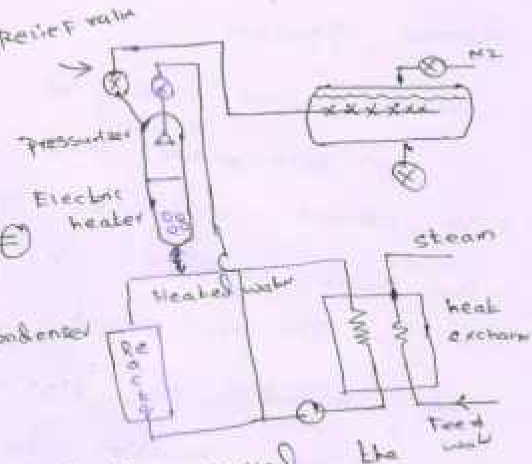
→ Excellent properties of water as moderator & coolant make it a natural choice for power reactor & it developed in USA.

→ Limitation on PWR is critical temperature of water 374°c (max. possible temp.)

→ Pressure is maintained at about 155 bar so as to prevent bulk boiling.

Schematic of PWR





- Two loops in series coolant loop called the primary loop & water steam – working fluid loop
- coolant pick heat in reactor & transfer to working fluid in steam generator, The steam then used in rankine cycle to produce electricity
- Fuel in PWR is uranium (thin rods)
- cladding is stainless steel or zircaloy
- Becz of very high coolant pressure, the steel pressure vessel containing the core must about 20 - 25 cm thick
- A typical PWR contain 200 fuel assemblies each being array of rods

Grid spacers maintain separation b/w fuel rods to prevent excessive vibration & allow some axial thermal expansion

→ coolant leaving reactor enter the steam generator which can either shell & tube type In u tube steam generator. the hot coolant enters an inlet channel head at bottom flow through u tube reverse direction to an outlet at bottom. to produce saturate steam.

→ In the primary once through design, the primary coolant enters top, flow downward through tube & exist at bottom to main pump. A low degree of super heat steam is possible

→ First land based PWR for power generation built at shipping port USA in 1957 It thermal o/p is 231 mW, pressure in the primary circuit is 141 bar water temperature at outlet from reactor is 282°C. Dry saturated steam is generated in heat exchanger at 41 bar 252°c. For a gross electrical o/p of 68 mW, thermal η% is 29.4%

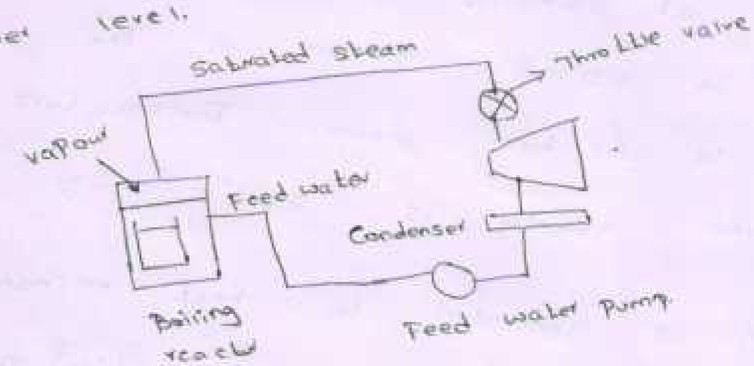
Boiling water Reactor (BWR)

→ BWR differ from PWR in steam flowing through turbine is produced directly in reactor core.

→ Steam seperated dried by mechanical devices in upper part & then directly sent to high pressure turbine thus eliminating the need for steam generator

→ coolant serve triple function coolant, moderator & working fluid.

- Increase in boiling rate displaces moderat water in core & reduces ability of to thermalize neutrons & hence reduce reactor power level.



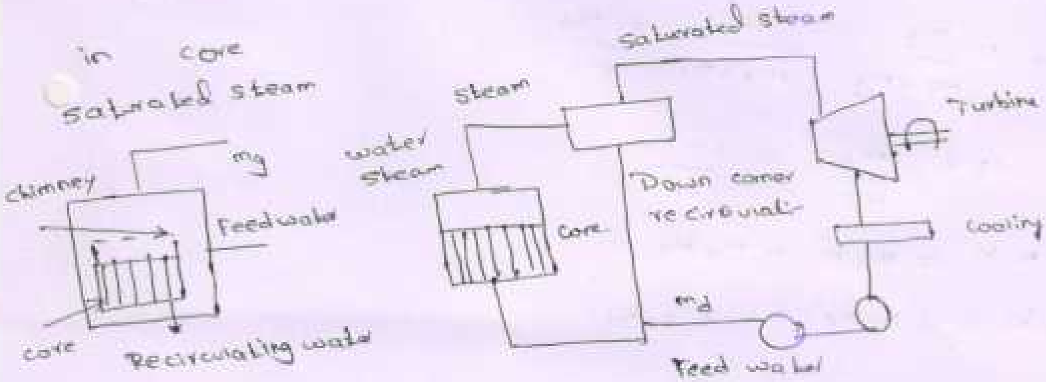
→ Saturated liquid that seperated from vapour at top of reactor in a steam seperator flows downward either internally with in reactor

- This recirculating coolant again either flows naturally due to density difference

- The ratio of recirculated coolant to saturated vapour produced called circulation

- BWR core exit quality varies from 10 to 14 % . circulation of range 6 - 10 .

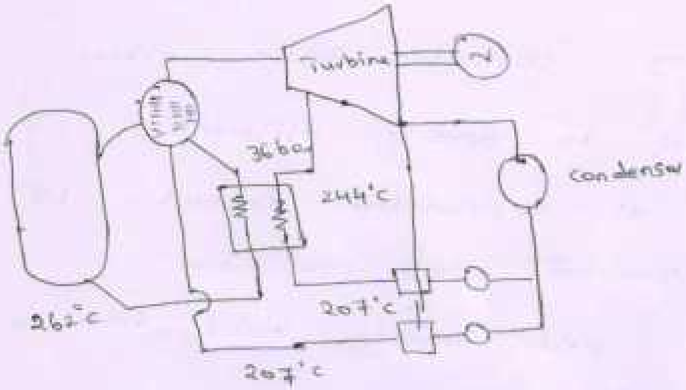
- This is necessary to avoid large void fraction in core



- A slightly subcooled liquid enters the core bottom at rate of mi & rises through core & chimney.

- The chimney is un heated section above core that helps increase pressure for normal circulation.

- Resulting vapour seperates & goes to turbine at rate of mg. while saturated liquid recirculate via down comer the rate of mf.



$m_d = m_g$

$m_g + m_f = m_i$

$$x_e = \frac{m_g}{m_f + m_g} = \frac{m_d}{m_d + m_f} = \frac{m_d}{m_f}$$

$$R = \frac{m_f}{m_g} = \frac{1 - x_e}{x_e}$$

$m_i h_i = m_f h_f + m_d h_d$

$h_i = (1 - x_e) h_f + x_e h_d$

$$x_e = \frac{h_f - h_i}{h_f - h_d}$$

$\Delta h_{sub} = h_f - h_i = x_e (h_f - h_d)$

$\Delta t_{sub} = t_f - t_i$

$Q_t = m(h_f + x_e h_{fg}) - h_i) = m_g (h_g - h_d)$

→ BWR power plants have used dual pressure, direct cycle arrangement there is a decrease in temp of water enter reactor so thus power o/p ↑ with unaltered exit condition

Canada Deuterium uranium reactor (CANDU)

→ The very low neutron capture cross section of heavy water makes it an excellent moderator & coolant & permit use of natural uranium as fuel.

- Reactors of this type good neutron economy result in good breeding ratios high fuel assembly burn up & a reduce in fuel cost

- Disadvantages of heavy water are its very high cost

Heavy water moderated & cooled reactors have been extensively develop in Canada & form basis of nuclear power program in country They are called CANDU - PHW (canadian Deuterium uranium pressurized Heavy water).

→ CANDU reactors have several features that distinguish them from other types. The moderator is contain in cylinderical steel vessel. called calandria with large number of zircaloy tubes through it parallel to its axis which is horizontal.

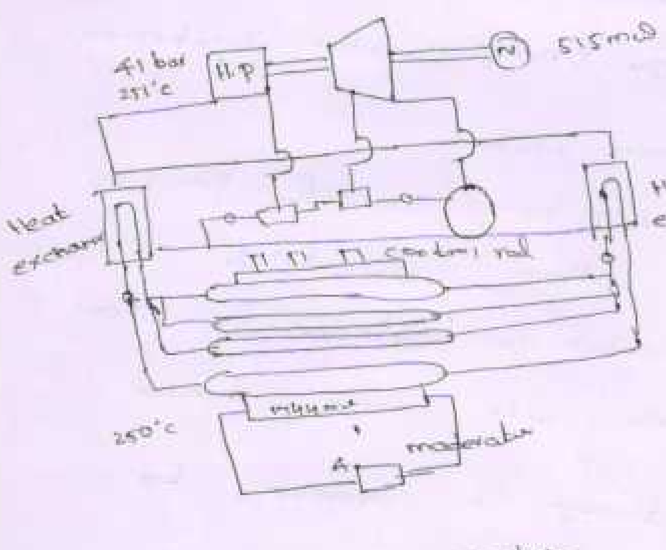
The active core region is approximately 6m high with dia of 7 to 8m.

D_2O coolant enter regular away of pressure tubes at 260°c and 110 bar flow through fuel element & leave pressure tube at 320°c & η% 29%

- Heavy water coolant pressure in reactor is 88.3 bar, inlet & outlet temp 250°c & 290°c. In heat exchanger steam generated at 41 bar pressure. 251°c

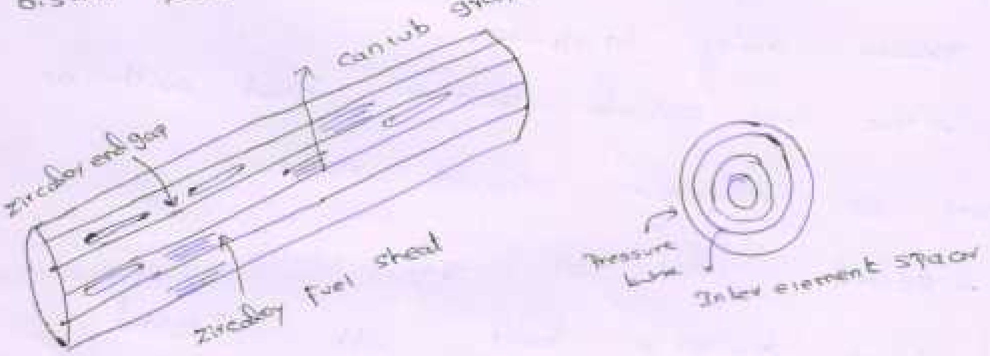
- Thermal power of each reactor is 1744 mw & the net electric o/p is 515 mw

η% is 29.5%.



The Calandria contains up to 380 horizontal pressure tubes called calandria tubes which are welded to tube sheets moderator temperature maintain at 70°c & low pressure maintain at 70°c & low pressure to reduce heavy water losses

The Fuel assembly contain 37" Fuel rods Each rod contain natural uranium dioxide (UO_2) Fuel pellets (0.38) zircaloy cladding Each rod bundle is about 0.1mm diameter & 0.5mm long.

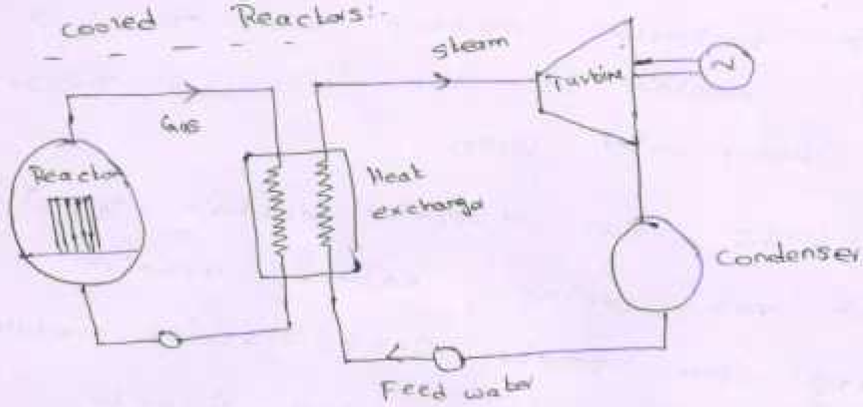


1st stage:- PHWR use natural uranium Fuel to produce electricity & Plutonium Fuel with 96%. un used uranium

2nd stage:- The use of Fast breeder with plutonium as fuel will generate electricity & more plutonium U238 kept as blanket will produce Plutonium U233 fuel from thorium as blanket material

3rd stage:- U-233 will used as fuel & thorium as blanket produce more U233 fuel than fuel consumed in Fast & thermal reactor

Gas cooled Reactors:-



- First gas cooled reactor with CO_2 gas as coolant & graphite as moderator developed in Britian during 1956-69.

- Fuel was natural uranium, clad with an alloy of magnesium called magnox

- several types of gas cooled reactor have been design & built with England; reactor developing an advanced gas cooled system & germany & USA developing helium cooled graphite moderate system

The graphite moderated helium cooled HTGR is design to use U233 as the fissile material & thorium as fertile material

Initially the system would have to

Graphite moderated helium cooled HTGR is designed to use U-233 as Fissile material & thorium as Fertile material. initialy the system would have to Fuelled with U235 sufficient U233 is avail For make up Fuel Becz of very high melting Point of graphite these Fuel element operate at high temp Possible to generate steam at condition east to those in modern coal Fired plant

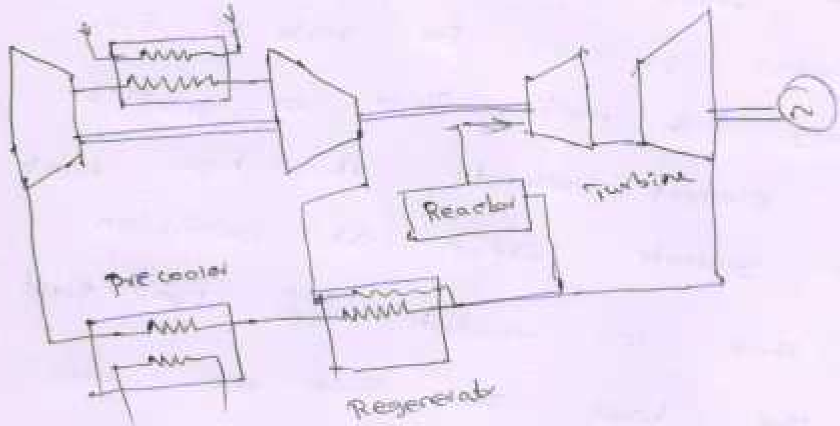
→ The basic Fuel Form are small sphere of Fissile & Fertile material as carbide

– Each sphere is coated with 2 or 3 layers of carbon & silicon carbide to prevent Fission Product From escape From Particle.

→ Helium is suitable coolant in sense that it is chemically inert has good heat transfer Charactor & low neutron absorption.

A direct

Being a monatomic gas it can produce more power for given temp in brayton cycle is higher efficiency.



→ A direct cycle HTGR gas plant.

It incorporate a regenerator is multi stage compression with inter cooling

→ Typical figures for such a cycle are pressure ration 4, turbine inlet pressure 50 bar, turbine inlet temp 900°c compressor inlet temp 50°c. The temp at other points. with u233/th 232 fuel.

HTGR function as a thermal breeder reactor nuclear Power Plants safety:-

→ safety is taken very seriously by those working in nuclear Power Plants

main safety concern is the emission of

uncontrolled radiation in to environment which could cause harm to humans both at

reactor site & off site

→ The handling of eqpt via remote

in core of reactor

– Physical shielding

→ Limit on time a worker spend in area with

significant radiation level

→ Monitoring of individual doses & work environment

→ safety mechanism of nuclear Power reactor

The design of nuclear reactor

must include Provisions. For human error

nuclear plants in western word use a

defense in depth concept which is system

with multiple safety components each

with backup & design to accomodate

human error

control of Radio activity:.

This requires being able to Control

neutron Flux. The most common way to

reduce neutron Flux is include neutron - absorbing

Control rods. These control rods can be

Partialy inserted in to reactor core to

reduce reactions. In modern Poper power

Plant the insertion of all control rods

in to reactor core occur in Few seconds

thus halting the nuclear reaction as

rapidly as Possible.

2 Maintanance of core cooling:-

- In any nuclear reactor some

sort of cooling is necessary

- Generally nuclear reactors use

water as a coolant.

- How ever some reactors which cannot

use water use sodium or sodium salt

3 Maintanance of barriers that Prevent

the release of radiation

There is a series of physical barrier b/w radio active core & the environment. workers are shielded from radiation via interior concrete walls.

A vacom building is connect to reactor building by pressure relief duct. The vacuum building is a concrete structure & is kept 71mm high atmospheric pressure this means at -ve that if any radiation were to leave from reactor it would be sucked in to vacuum building & there fore prevented from being released in to environment.

Nuclear Power Plant - challenges:-

Nuclear power plant generate large quantities of high radio active material. This is due to left over isotopes which splitting of atom & creation of heavier atom like Plutonium which the nuclear power plant does not utilize

It is called nuclear waste.
The actual quantity of waste o/p is same 1,0000 times less than fossil fuel plant but is more radio active.

→ Humans are exposed to low level radio activity constantly from naturally occuring radio active isotopes & cosmic rays from outer space.

→ However in large doses radiation has many harmful effects.

→ Another challenge for nuclear power is deal with left over, highly radio active & long lived nuclear waste.
It is necessary to isolate the waste from humans & environment for about 100,000 yrs before it decay to safe level

Unit-2 Completed
[signature] 30/6/16.