Lecture No. → 7

A neutron born in a fission event and then gets continuously scattered in the reactor until it meets its eventual death in either absorption reaction or leaking out of the reactor. Certain number of these neutrons will be absorbed by fissile or fissionable nuclei and induce further fission thereby leading to the birth of new fission neutrons i.e. to a new generation of fission neutrons.

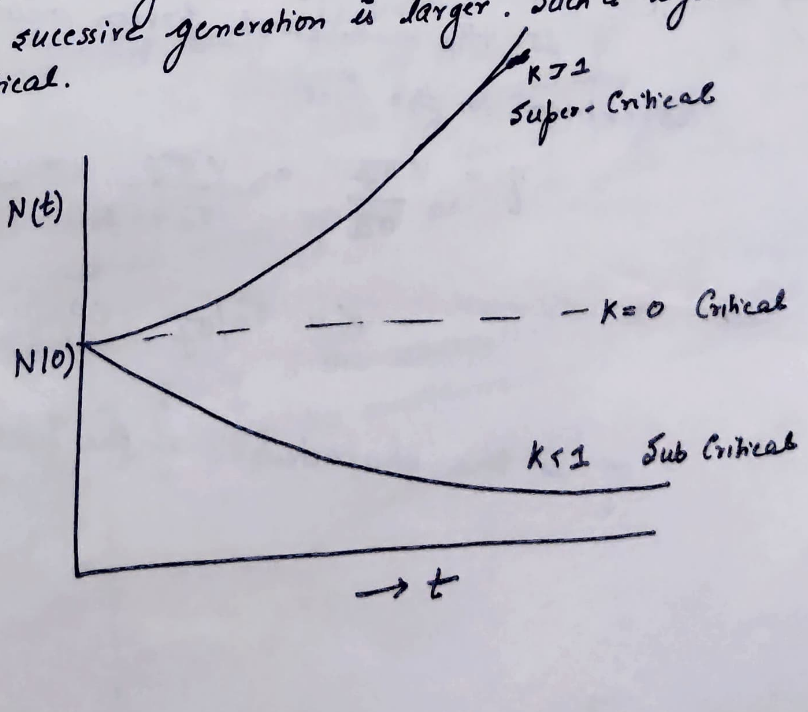
Suppose that we could somehow measure the number of neutrons in two succesive fission neutron generations or cycles i.e. We could then define the ratio of these numbers as 'Multification Factor K characterising the chain reaction'

$$K = \text{Multiplication Factor} = \frac{\text{No. of } n \text{ in one generation or cycle}}{\text{No. of } n \text{ in preceeding generation or cycle}}$$

If $K = 1$, the number of neutrons in any two consecutive fission generations will be the same and hence the chain Reaction is time independent. System is said to be critical. Self sustained reaction.

If $K < 1$, the number of neutrons decreases from one generation to generation and hence the chain reaction dies out. System is said to be Sub-Critical.

If $K > 1$, chain reaction grows without bound as the number of neutrons in each sucessive generation is larger. Such a system is said to be Super-Critical.



A formal calculation of K →

If the medium is infinite, the leakage term is neglected.

$K = K_\infty$.

a) Fast fission factor 'ϵ'

$$\epsilon = \frac{\text{fission by (thermal + fast) neutrons}}{\text{fission by thermal neutrons only}}$$

or

$\epsilon > 1 \quad \sim 1.05$

ratio of the fast neutrons produced by fissions at all energies to the number of fast neutrons produced in a thermal fission.

b) Resonance Escape Probability 'p'

p = fraction of neutrons that manage to slow down from fission to thermal energies without being absorbed

c) Thermal Utilisation Factor 'f'

$$f = \frac{\text{thermal neutrons absorbed in fuel}}{\text{Total thermal neutrons absorbed}}$$

d) Reproduction Factor η

η is the number of fission neutrons produced per absorption in the fuel.

$$\eta = \frac{\nu \sigma_f}{\sigma_a} = \frac{\nu \sigma_f}{\sigma_c + \sigma_f} = \frac{\nu}{1 + \sigma_c/\sigma_f} = \frac{\nu}{1+\alpha}$$

$\alpha = \sigma_c/\sigma_f$ capture to fission ratio

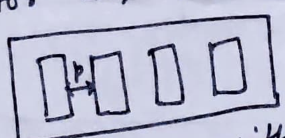
η is the characteristic of the fuel.

	Thermal ν	Thermal η	Fast ν	Fast η
U-233	2.49	2.29	2.58	2.40
U-235	2.42	2.07	2.51	2.35
Pu-239	2.93	2.15	3.04	2.90

	σ_f	σ_c	σ_a	α
U-233	531	48	579	0.09
U-235	582	99	681	0.170
Pu-239	743	269	1012	0.362

Homogenous Reactor → Uranium Nitrate Solution

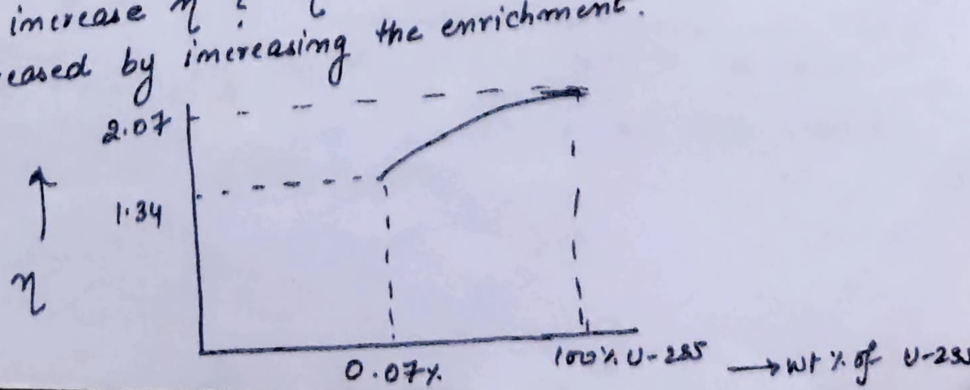
Hetergenous Reactor → Fuel rods are lumped



Aim is to make reactor with minimum amount of reactor fuel ie. reduce critical mass.

1) Increase in size but this unphysical. So to reduce leakage, reflectors are used. The purpose of the reflector is to decrease the loss of neutrons from the core by scattering back many of those which have escaped. Hence, use of reflector results in a decrease in critical mass of the fissile nuclide. Moderator is used as a reflector.

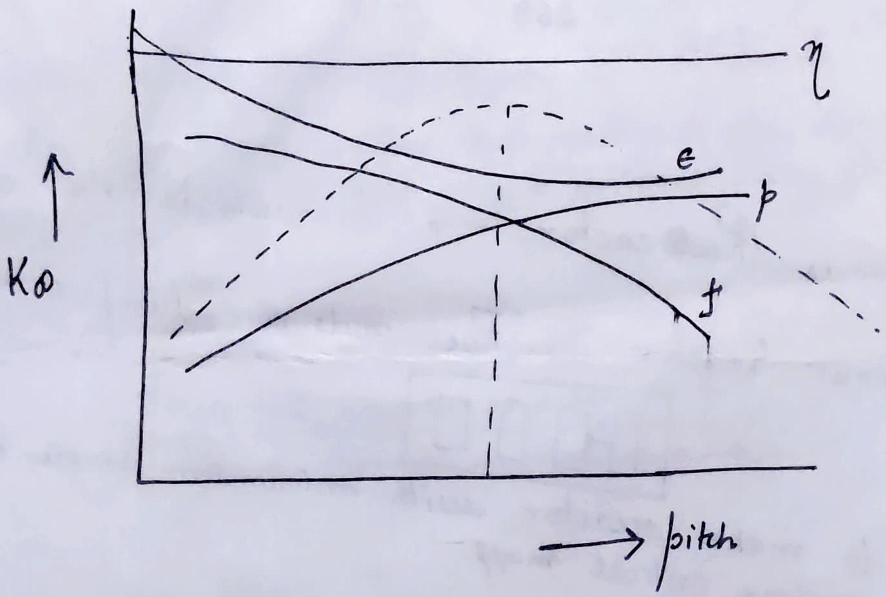
2) How to increase η? η is the characteristic of the fuel. η is increased by increasing the enrichment.



3) $\epsilon \rightarrow$ fast fission factor can be increased if the neutron sees the fuel before the moderator ie. by placing the rods closer. i.e. less fuel pitch

4) $p \rightarrow$ resonance escape probability increases by increasing the pitch and by using fuel of thicker diameter. due to the spatial self shielding effect.

5) $f \rightarrow$ fuel utilisation factor increases by decreasing the fuel pin pitch.



Neutron Cycle

Let at any instant of time there are N_0 fast neutrons in the system. Fast neutrons cause further fission in U-238
So, we define a factor ϵ

fast fission factor ϵ = ~~fission~~ Ratio of the fast neutrons produced by fissions at all the energies to the number of fast neutrons produced in a thermal fission.

$\epsilon > 1 \sim 1.05$

So, $N_0 \epsilon$ fast neutrons are available after fast fission.
Now, fast neutrons are being slowed down by moderators. Those neutrons which have energy in the rang 6-7 ev, have the high probability of getting absorbed in the U-238 nucleus in the U-238 nucleus. There is due to Resonance Absorption in the U-238 nucleus. There is also a propability that neutrons escape this resonance absorption. So, if p is the resonance escape probability, then

$p \epsilon N_0$ neutrons are thus available.

These neutrons ($p\epsilon N_0$) neutrons are continuously getting scattered by the moderator nuclei and they are simultan-eously getting leaked out. These neutrons which are getting thermalised have higher probability now of getting absorbed in fuel or in other structural materials. If 'f' is the thermal utilisation factor, which is defined as

$$f = \frac{\text{thermal neutrons absorbed in the fuel}}{\text{Total thermal neutrons absorbed.}}$$

then $fp\epsilon N_0$ neutrons are absorbed in the fuel.

and if η is the number of fission neutrons produced per absorption in the fuel, then

$$\eta = \frac{\nu \sigma_f}{\sigma_a} = \frac{\nu \sigma_f}{(\sigma_c + \sigma_f + \sigma_{n,2n} + \dots)}$$

η is the characteristic of the fuel

at the end of the neutron cycle,

$\eta f \epsilon p$ No fast neutrons are produced

for finite medium, we account for leakage of the neutrons which is defined by

$P_{Th} \cdot P_F$ → P_{Th} → Non leakage probability of thermal neutrons

P_F → Non leakage probability of fast neutrons

	Thermal Neutrons ν	Thermal Neutrons η	Fast Neutrons ν	Fast Neutrons η
U-235	2.42	2.07	2.51	2.35
Pu-239	2.93	2.15	3.04	2.90