# MOTIVATION:

(I)

Energy released in 1 single fission event: 200MeV:
fission of 1 gm U235 energy release
= 200 (MeV/atom)*1.6E-19(MJ/MeV)*6.023E23(atom/mole)(/235(g/mole)
= 200*(1.6*6.023)*(1E-19*1E23)/235 MJ/g
~ 200*10*1E4/235 MJ/g ~ 1E5 MJ/g : energy release per unit mass is called burnup in reactor phy.
In contrast, 1gm coal complete combustion gives 30MJ/kg = .03MJ/g (4eV/C12 combusion)
So, energy from 1 gm fission ~ 1E5/.03 ~ 3E6 times energy from 1gm coal

Practically: 1gm coal -> 100cc water from 30deg C to 100deg C (Just boiling temperature)
1 gm U235-> 3lakh litre water from 30deg C to 100 deg C( ,, )

Trick: Slowly release this energy
Question: How to control the speed of this process??

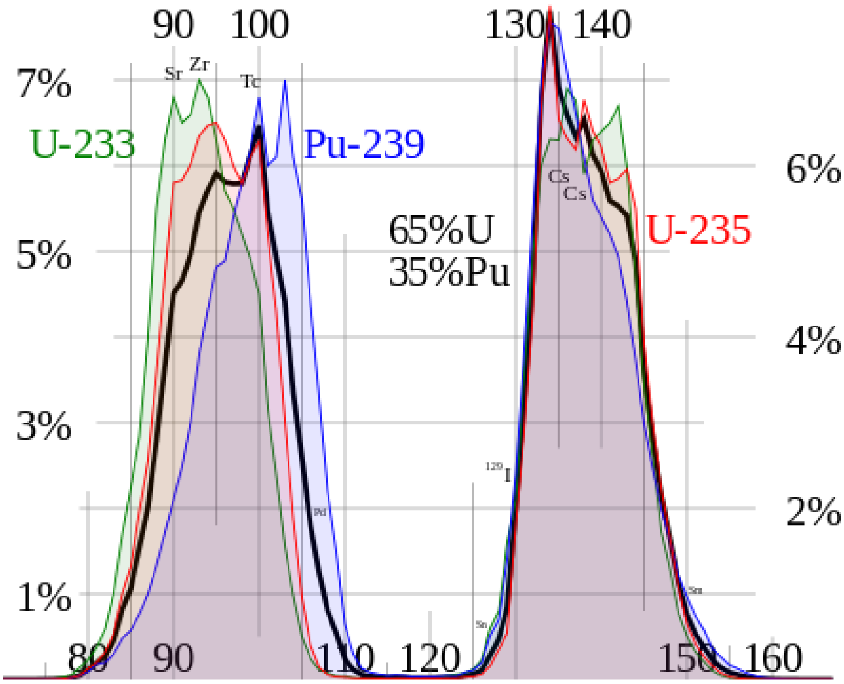
Remarks to remember:
(1) 1 Watt energy is produced by 3.1E10 fissions
(2) 1gm fission produces 1MWD energy

(II)

U235+n = nucleus 1 + nucleus 2 + 2 or 3 neutrons + 200MeV energy
text books: 92-U-135 = (56-Ba-144) + (36-Kr-90) + 2 (0-n-1) + energy

This is a probabilistic event.

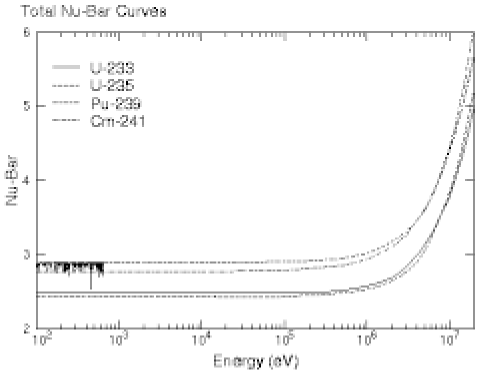
(1) nucleus 1 and nucleus 2:




According to yield curve (M curve), two peaks: first near Zirconium (A~100), another near Xenon (A~135). First peak is around 6%, second is around 7%.

(2) neutron (prompt), number distribution:
2 or 3, on average 2.5 (U235)

| | $\bar{\nu}_{thrmal}$ |
|---|---|
| U233 | 2.48 |
| U235 | 2.41 |
| Pu239 | 2.86 |




Behaviour is same for up to MeV energy of incoming neutron. Increases afterwards.

(3) Released energy distribution:
Can be described from binding energy curve: U235 has 7.6MeV/A, Fps has 8.5MeV/A
Energy release ~ (8.5-7.6)*235 ~ 211MeV

In what form the energy shows up: (break up of energy)

| | | |
|---|---|---|
| Kinetic energy of the Fps | ~ 84% | Heat |
| Kinetic energy of the prompt neutrons | ~ 2.5% | Heat/gamma/leak |
| Beta particles from Fps | ~ 3.5% | heat/leak |
| Prompt gamma | ~ 2.5% | electron->heat/leak |
| Delayed gamma | ~ 2.5% | ,, |
| Neutrinos | ~ 5% | Leaks out-> compensated partly by capture |

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Matter-photon interactions: Pair production [ $Z^2(E-1.02[MeV])$ ], Compton effect $\frac{Z}{E}$ ,

Photoelectric effect $\frac{Z^n}{E^3}$ , n between 3 to 5.

(prob in descending order at high energy)

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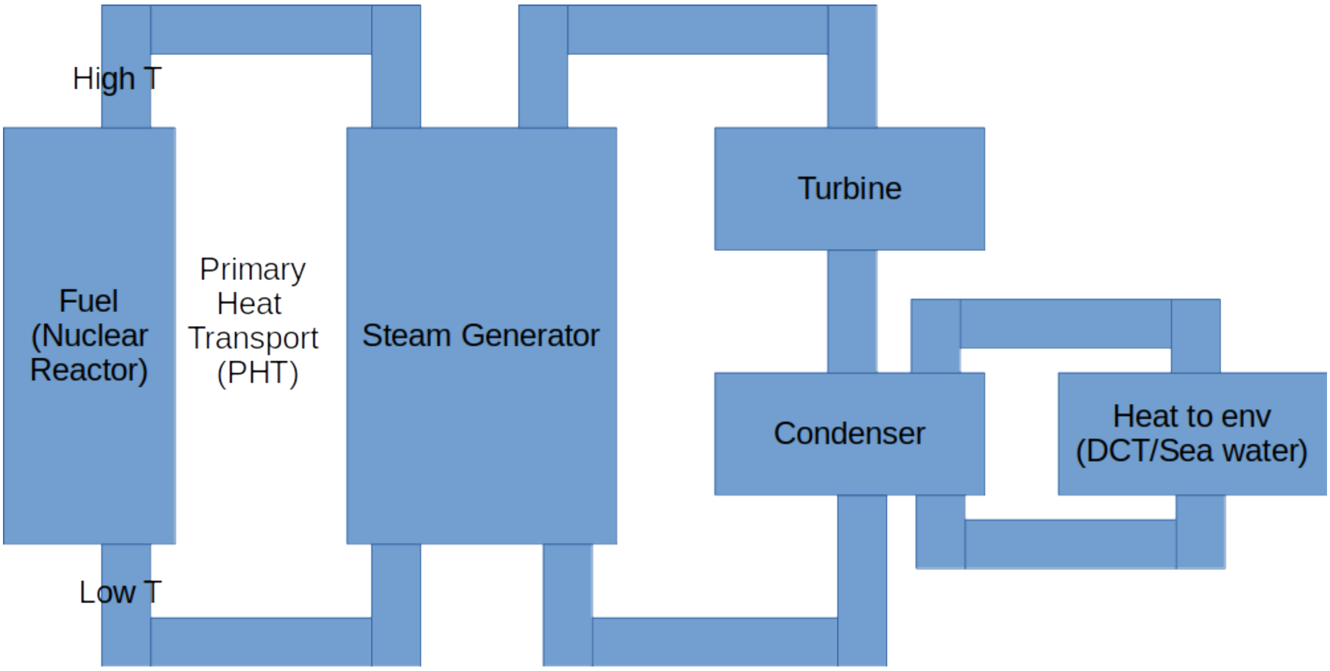
Radiative capture (n,gamma) releases excess energy and leaves compound nucleus in ground state. This partly compensates the loss by leaks of neutrons and others (gamma, beta etc)




CONCLUSION: On average ~200MeV is available in heat form. This energy is deposited in the the U material/ materials surrounding it. This is taken out using a fluid (gas/liquid) called coolant. Arrangement of fluid and fuel and other materials depends vastly upon how good the coolant is and the physical, chemical and irradiation properties of the materials.

The most popular is PWR, where water is used as a coolant. The water goes in the fuel area at low T, takes up heat , T increases, comes out of the fuel area, goes into steam generator where the heat is diffused to another loop of water through metal barrier (pipes). The barrier is to prevent mixup of coolants -> to prevent any unintentional radioactivity to secondary loop.

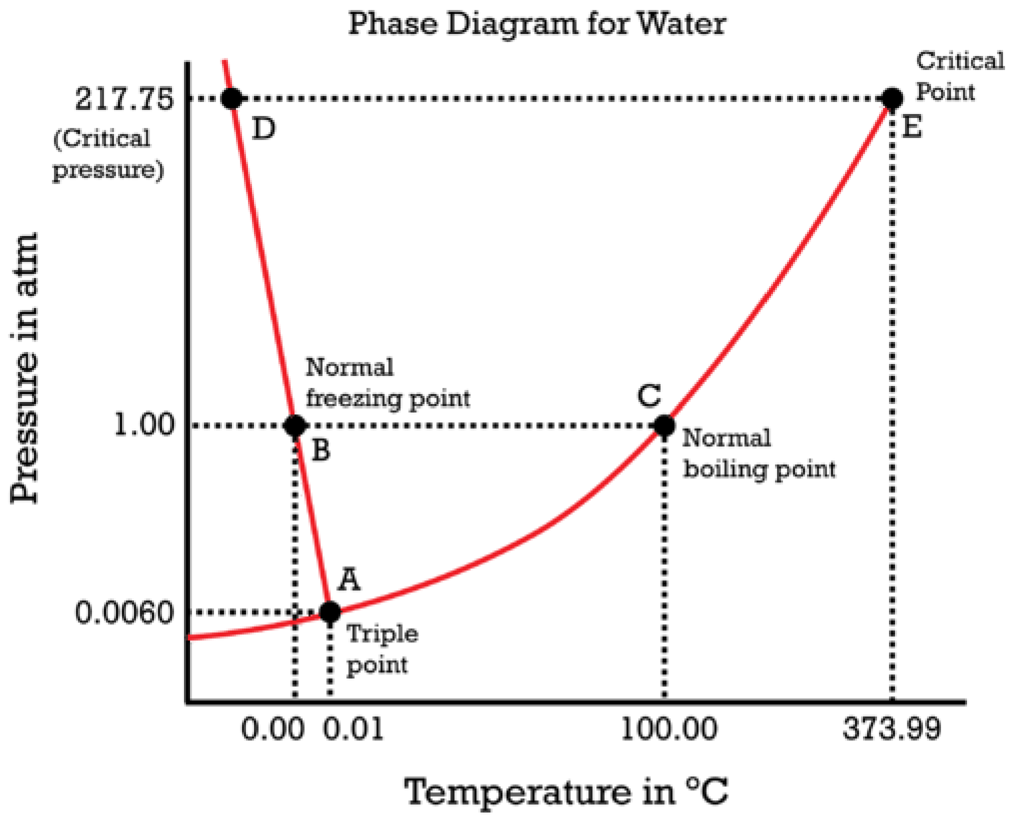
Clearly this is like a thermodynamical heat engine. The primary+secondary+tertiary coolant transfers heat from reactor (hot reservoir) to environment (ultimate heat sink) and on the way converts heat to electical energy (at turbine).

Efficieny of this engine:

$$\eta=1-\frac{T_{cold}}{T_{hot}}$$

$T_{cold}$ : environment temperature ; fixed by nature
$T_{hot}$ : reactor average temperature
To maximize efficiency, $T_{hot}$ should be maximum.

Maximum T is limited by coolant property: **coolant should not evaporate completely.** The maximum temp water can go without boiling is 373deg C (critical point of water)




For safety, the primary heat max temp is taken ~ 325deg C with a pressure of around 15-16 bar. (margin: calculation error, accidental condition etc.)

If fission produced heat deposited in coolant in unit time is P then,

$$P = \dot{m} \times C_v \times (T_{out} - T_{in})$$

$$T_{hot} = \frac{T_{out} + T_{in}}{2}$$

Discussion:

1. Clearly, to have a max efficiency, $T_{hot}$ should be max. Since $T_{out}$ is fixed, $T_{in}$ should also be around $T_{out}$, i.e. ( $T_{out} - T_{in}$ ) should be as low as possible. Generally for reactors which uses water $T_{out} - T_{in} \sim 30\,deg - 35\,deg$ . A higher difference will help in higher P, but efficiency will be poor.
2. $\dot{m}$ is limited by coolant pump power. A powerful coolant pump will enable to extract higher power from the reactor.

Question:

1. Why coolant should not evaporate completely?
2. What happens to neutrons if they come in contact with water and other structural materials?
3. What happens to the fission products that are produced after fission? Do they move to the coolant? If so, what is the consequence?
4. If the system somehow goes out of control, what happens? There is a large reserve of energy, that should not come out abruptly.

Other questions: How to start the reactor and stop the reactor whenever we require? (Coal is not given/ coolant can be sprayed/ oxygen supply can be stopped in thermal reactors, what is the analogous control mechanism in nuclear reactors?)