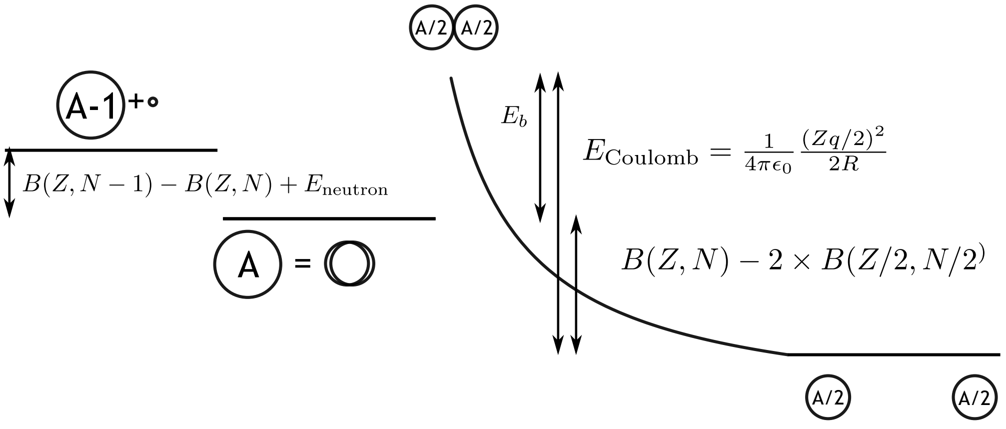
# PHY555 Energy & Environment
# PC 5 Nuclear energy - guidelines

## 1 Orders of magnitude

1. Chemistry : Electron confined around an atom. Nuclear: nucleon (mass x1000) confined in the nucleus (size / $10^5$). Energy scale with $1/mL^2$
2. Curzon Alhborn gives a better estimate than Carnot : $1-\sqrt{300/600}=30\%$. Power plant = 1GWe = 3 GWth = 26 TWh/yr. Each reaction produces $\sim$ 100 MeV and each nucleus weights 235u, so about 1t/yr.
   $1/(7\,10^{-3}) = 150$t (actually, about 200t because only 75% of the introduced 235U is fissioned)
3. 26 TWh / $c^2$ = 1 kg per year

## 2 Nuclear energy - the Bohr-von Weizsacker model

1. See lecture
2. Write $B(\frac{A}{2},\frac{A}{2})$, then estimate $\frac{\partial B/A}{\partial A}$
3. For a fixed $A$, write $B(Z,A-Z)$, then estimate $\left.\frac{\partial B}{\partial Z}\right|_A$ and show $Z < A/2$
4. Compare $B(Z,N)$ and $2\times B(\frac{Z}{2},\frac{N}{2})$
5. & 6



   This simple model over estimates the barrier, which is around 6 MeV pour uranium (both 235 and 238) - to be compared to the excess of energy resulting from the absorption of a neutron

## 3 Conventional reactor design

1. The neutron energy required for $^{238}$U fission is $\gtrsim$ 2 MeV, so the fission cross section is very small (<1b) even with most energetic neutrons. Even small impurities are likely to have a larger probability to capture a neutron than U238 to undergo fission.

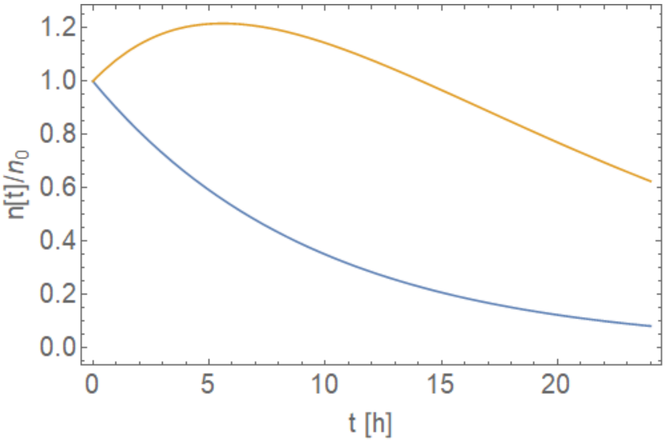
2. Calculate the probability $\eta$ for an interacting neutron to trigger U235 fission, rather than any other process (U235 capture, U238 capture. A necessary condition is that at least one of the 2.5 neutron triggers a new reaction so $\nu\eta > 1$.

3. Estimate the number of collisions required to slow a neutron from 2 MeV to thermal energy. Estimate for each collision the probability that the neutron is absorbed rather than scattered. Calculate the total chance of not absorbing the neutron over the cooling process water requires fewer collisions, but had more chances to capture the neutron than heavy water

4. Xenon poisining
   (a) Super large cross section
   (b) Kinetic equations

$$\frac{dn_I}{dt} = \sigma_U^f \gamma_I \phi n_U - \frac{n_I}{\tau_I}$$
$$\frac{dn_{Xe}}{dt} = \sigma_U^f \gamma_{Xe} \phi n_U + \frac{n_I}{\tau_I} - \frac{n_{Xe}}{\tau_{Xe}} - \sigma_{Xe}^c \phi n_{Xe}$$

   (c) $d/dt = 0$
   (d) At $t = 0^-$, the neutron flux is still on, $n_I$ and $n_{Xe}$ have their stationary values and $\dot{n_{Xe}} = 0$. At $t = 0^+$, the neutron flux is brought to 0. The amount of Xenon will increase if the neutron flux used to reduce the density of Xenon Reducing the neutron flux thus first increases Xenon density



Up: $n_{Xe}(t)/n_{Xe}(0)$. Down $n_I(t)/n_I(0)$

## 4 Plutonium: wastes or resource?

1. Linear increase.

2. Still linear increase, with a smaller slope

3. Fast breeder
   (a) Normalisation : $p_b + p_f + p_c = 1$. Breeding condition : $p_b = p_f + p_c$
   (b) Criticality $\geq 1$ requires $\nu p_f \geq 1$
   (c) breeding= fission + capture