Fission and reactors

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Fission process

An example:

1. the ^{235}U captures a thermal neutron.
2. It becomes ^{236}U$*$ with excess energy causing violent oscillations.
3. The ^{236}U$*$ becomes distorted enough for Coulomb repulsion to increase the distortion, overcoming the short-range nuclear force.
4. The nucleus splits into two fragments, also emitting several neutrons.

The most probable fragments are $A \approx 140$ and $A \approx 95$.

Estimate of fission yield

We can estimate the energy release using the curve of binding energy/nucleon. See fig. 13.10. For heavy nuclei ($A \approx 240$) it is about 7.6 MeV, for intermediate mass like the fragments, it is about 8.5 MeV. So

$$Q \approx (240 \text{ nucleons}) \left(8.5 \frac{\text{MeV}}{\text{nucleon}} - 7.6 \frac{\text{MeV}}{\text{nucleon}} \right) = 200 \text{ MeV}.$$

About 85% of the KE is in the heavy fragments. The energy release/atom is about a million times greater than the amount per molecule in chemical reactions.

Nuclear reactors

Designed to maintain a **self-sustained chain reaction.**

Most use uranium as fuel. Natural uranium is only 0.7% ^{235}U, so it is usually *enriched.*

In order for reaction to continue, at least one of the neutrons released in a fission must be absorbed by ^{235}U to produce another fission.

The **reproduction constant** K is the average number of neutrons per fission that produce another fission.

“Neutron accounting”

- $K = 1$ the reactor is **critical,** and reaction is sustained.

- $K < 1$ it is **subcritical,** reaction dies out.

- $K > 1$ it is **supercritical,** runaway reaction.

In order to extract power, the reactor must be *slightly* supercritical.

Regulating neutron energy

Neutrons from fission have energy about 2 MeV, so they must be slowed to increase chance of capture. This is done by a **moderator** of low atomic weight interspersed in the reactor core.

Neutron capture

Other elements in the core may capture neutrons without fission. Moderating the energy may reduce this for some isotopes. This loss of neutrons must be taken into account.

This is also used to convert non-fissionable isotopes to fuel, which usually must be chemically refined after removal from the reactor.

Neutron leakage

Neutrons may leave the core before reaction. This can be controlled by using the proper surface area/volume ratio for the reaction used.

Power control

Done with **control rods** of a material that strongly absorbs neutrons. K must be maintained very near 1 to avoid runaway.

An important role is played by **delayed neutrons**—those released by rapid decay of the fission fragments. The delay in their release makes control easier for $K \approx 1$ by slowing the rate of the reaction near criticality for a properly designed reactor.