Nuclear Reactors

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Induced fission by thermal neutrons

Possibility of a chain reaction

When the uranium-235 nucleus undergoes induced fission (by absorption of a neutron), the nucleus splits and as well as the two smaller nuclei formed, several neutrons are emitted; on average there are 2.5. (The number depends on the fission products formed.) If these neutrons go on to cause further fission, by being absorbed by more uranium-235 nuclei, then a chain reaction occurs.

As more than one neutron per fission is released, the reaction will get out of control quickly if left alone. It takes around 1 ms for a neutron released by one fission to be absorbed by another; this means that after only 0.05 s, there would be around 8×10^{19} fissions. To make sure that the reaction only proceeds with one neutron per fission going on to cause further fission, the control rods are placed in the reactor, which absorb the excess neutrons.

Need for a moderator in thermal reactors

Most of the world's reactors are thermal reactors. When a chain reaction occurs, the neutrons emitted by the fissions are *fast neutrons*, that is they have high energies of around 1 MeV. These neutrons are unlikely to cause fission when they collide with other uranium-235 nuclei. They therefore need to be slowed down to energies where they are likely to be captured, which turns out to be less than 1 eV, typically 0.048 eV. The neutron is slowed by forcing it to collide repeatedly with nuclei of another material, and it loses energy through the collisions. This is achieved by placing large amounts of the moderator in the reactor core. After many collisions of the neutron with the nuclei of the moderator, they are slowed to thermal energies and are called thermal neutrons. They are called thermal as their energy is approximately equal to the thermal kinetic energy of the other particles in the core, roughly equal to kT, where k is Boltsmann's constant, and T is the (absolute) temperature of the neutrons. Thermal neutrons have energies that are most likely to be absorbed by uranium-235 and cause fission.

Critical Mass

If a nuclear fission reaction is to sustain itself, then at least one neutron per fission must go on to cause further fission. This will only occur if there is sufficient material present. The minimum amount of a fissile material needed to allow a self-sustaining fission chain reaction is called the *critical mass*.

When the amount of material is increased

- The amount of neutrons escaping through the surface increases, and thus reduces the likelihood of fission.
- The amount of neutrons remaining in the volume increases, which therefore increases the likelihood of fission.

However, as the amount of material increases, a larger proportion stay in the volume than escape through the surface. Therefore, there is a minimum volume (i.e. mass) where more neutrons can cause fission that escape.

Consider a spherical ball of uranium of radius r. The volume of the sphere increases as a function of r^3, whereas the surface only increases as a function of r^2. For a sphere of uranium-235 the critical mass is about 10 kg, which corresponds to a radius of about 5 cm.

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