How nuclear reactor works

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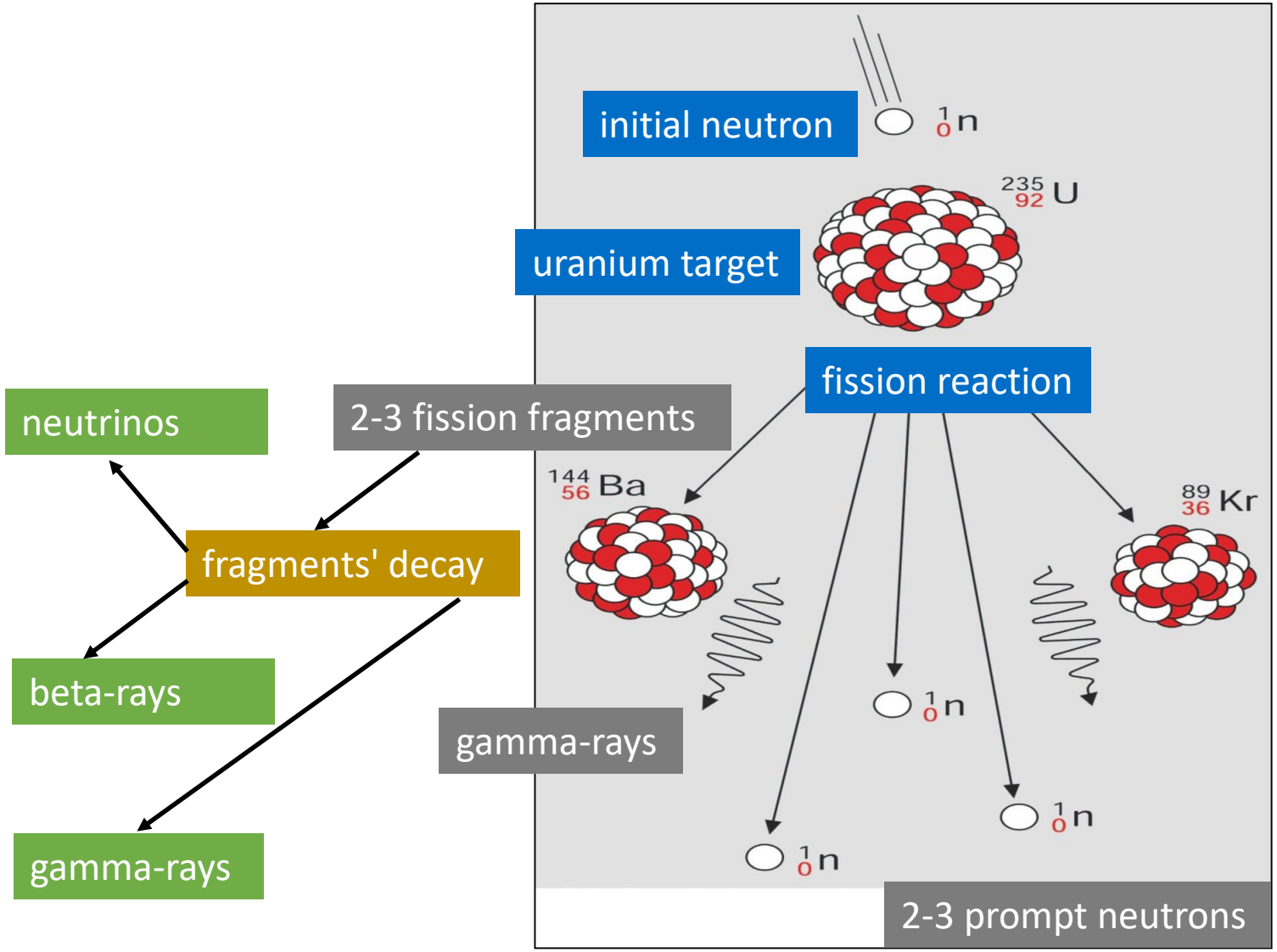
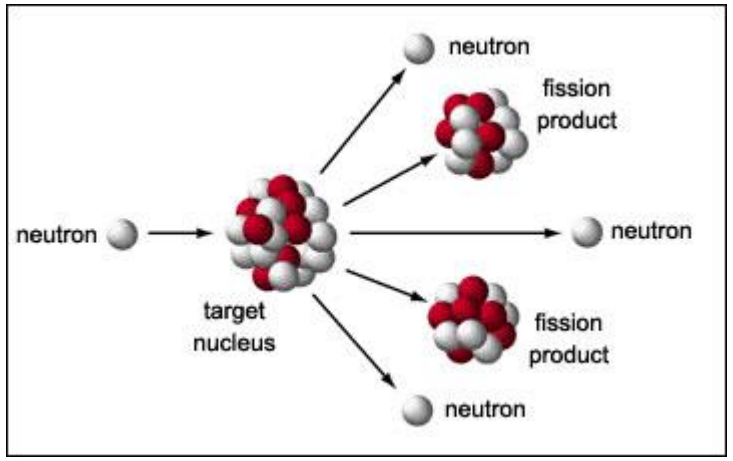
Fission reaction

Energy released from U-235 fission	MeV
Fission fragments (kinetic energy)	168
Neutrons (kinetic energy)	5
Prompt gamma-rays	7
Fission products decay	
- Beta-rays	8
- Gamma-rays	7
- Neutrinos	12
Total released per fission	207
for use in the reactor	195



Fission chain reaction



Thermal reactors

U235 U233 Pu239 Pu241

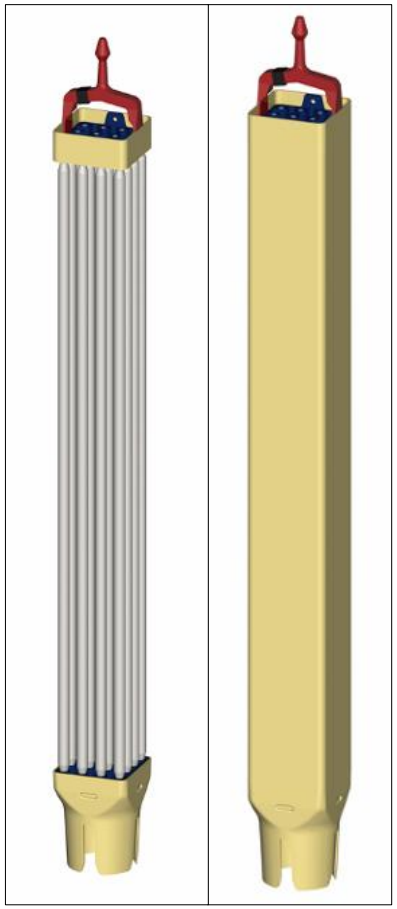
Fast reactors

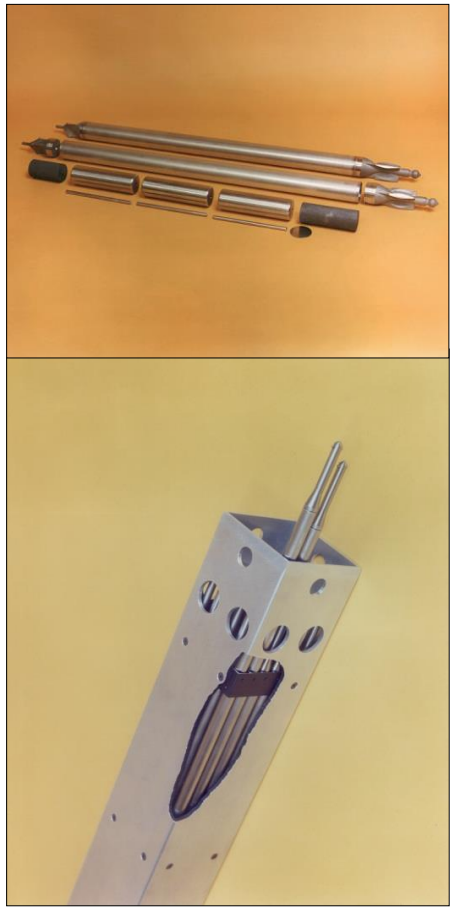
U238

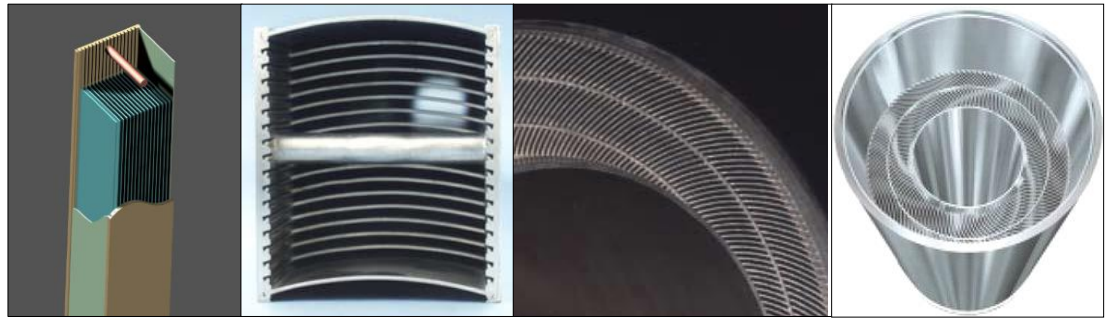
99 % of all reactors in the world are thermal reactors

We need nuclear fuel in a reactor.

Fission chain reaction



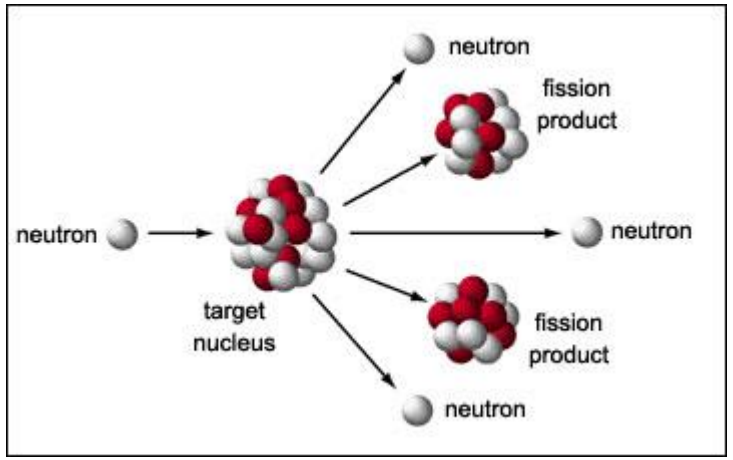


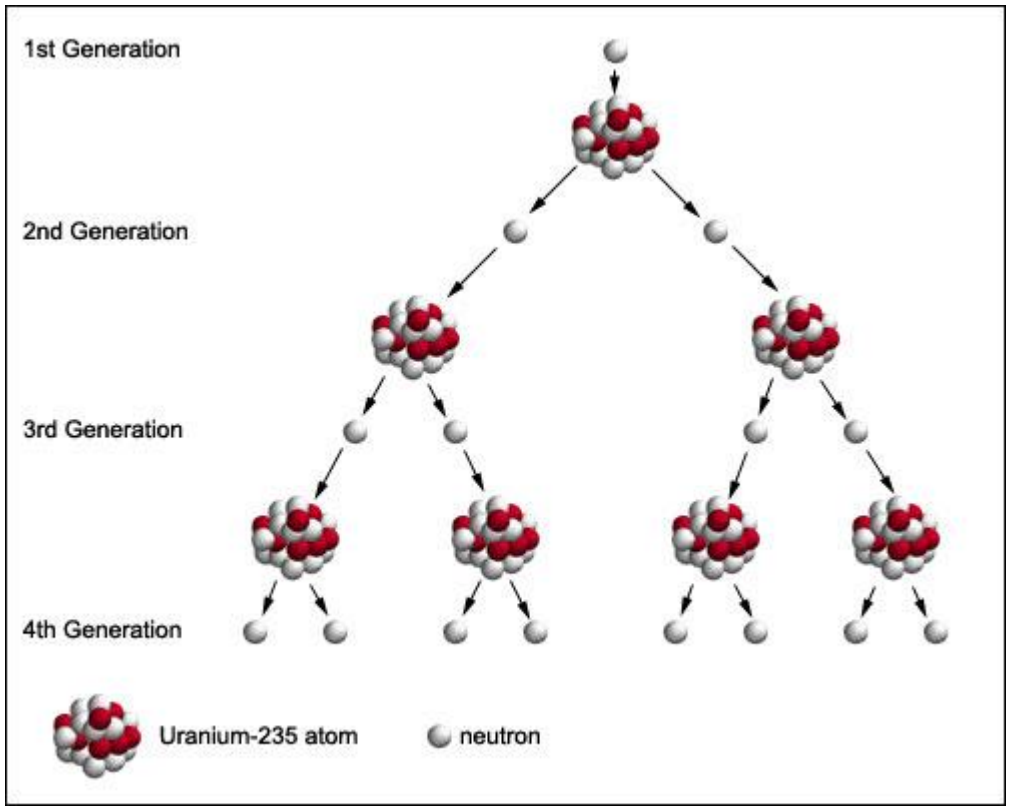


Essential parts of nuclear reactor:

1. Fuel

Fission chain reaction





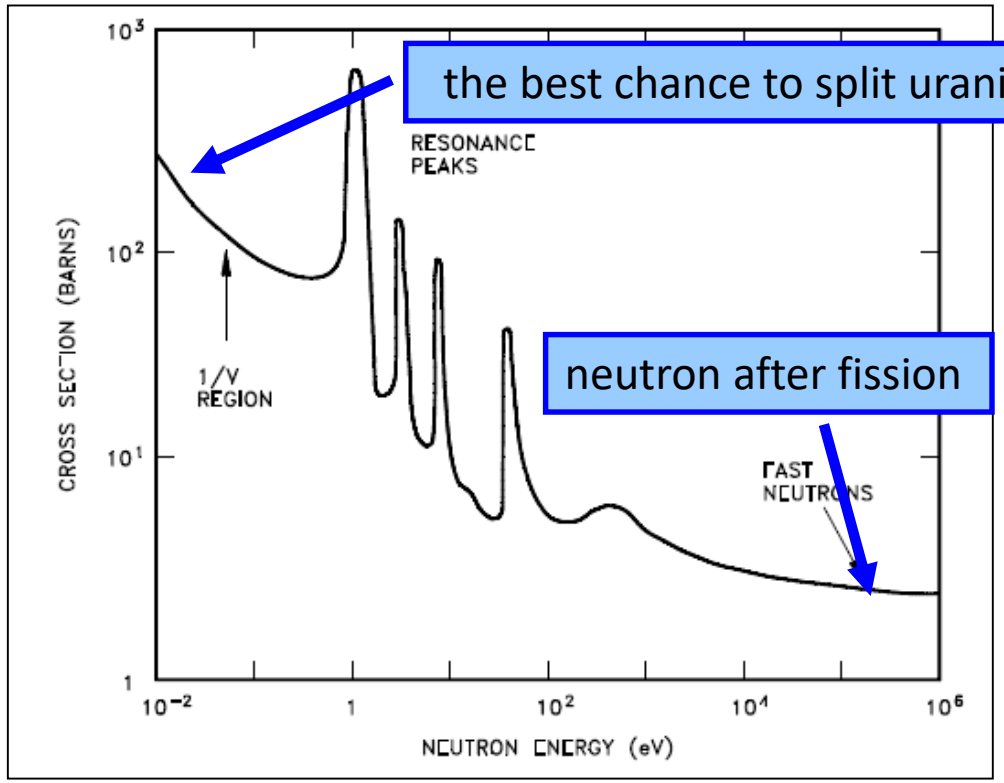
How to keep fission chain reaction?

When neutron splits U235?

When the probability of interaction is high.

Fission chain reaction

Probability of interaction = cross section

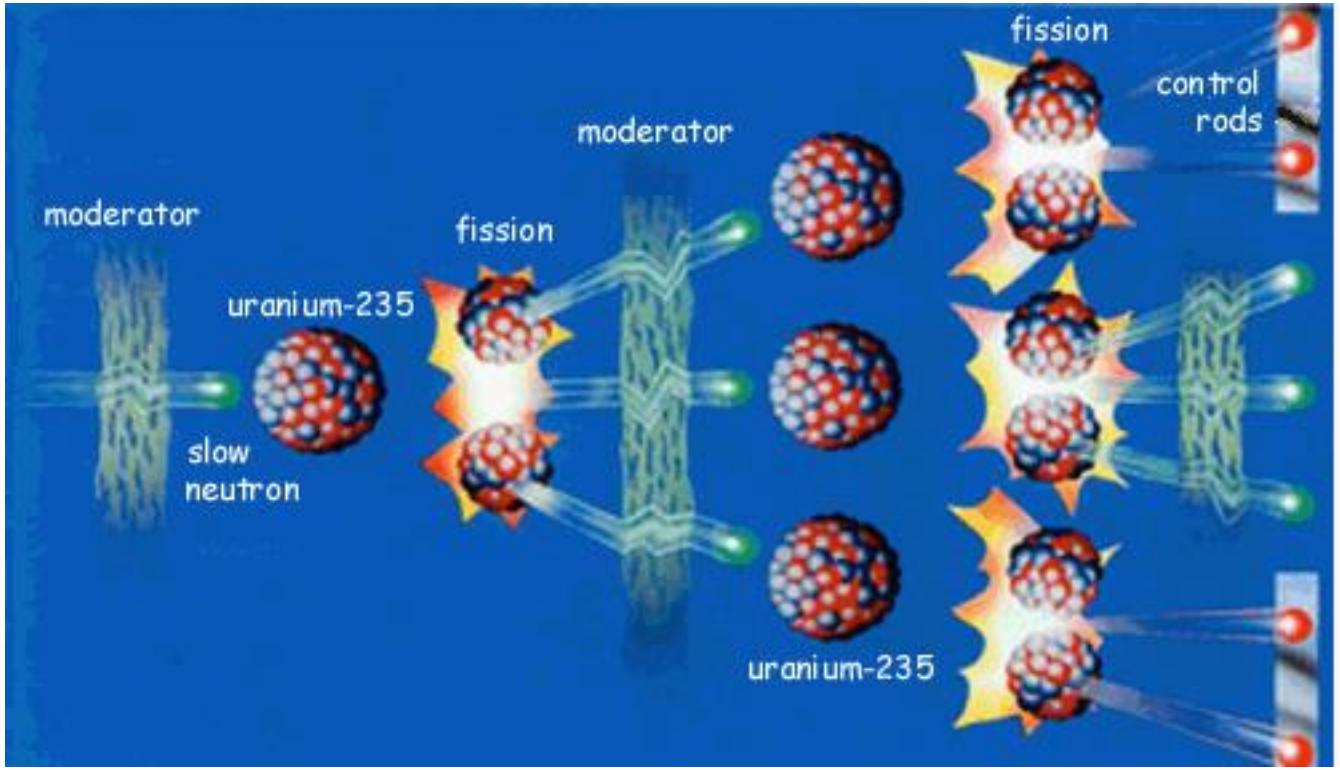


Typical neutron absorption at uranium

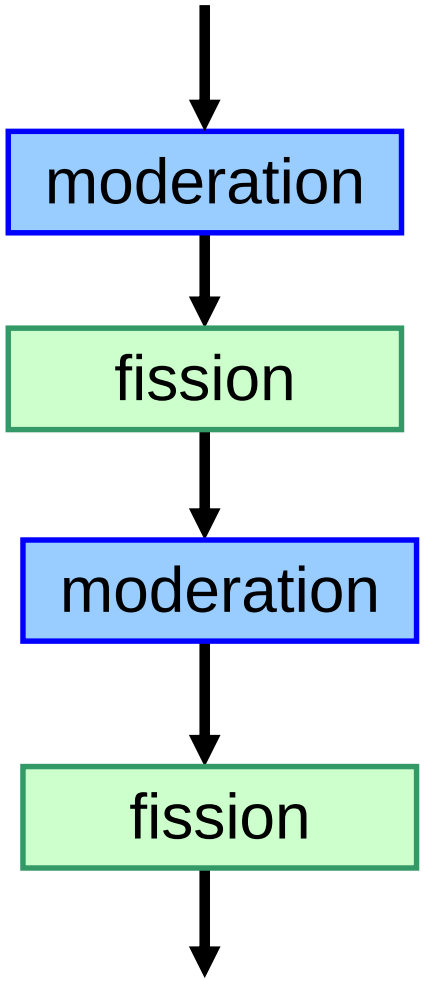
Need to slow down or moderate or loose of energy of the neutron.

We need moderator in a reactor.

Fission chain reaction



Moderation and fission in the reactor



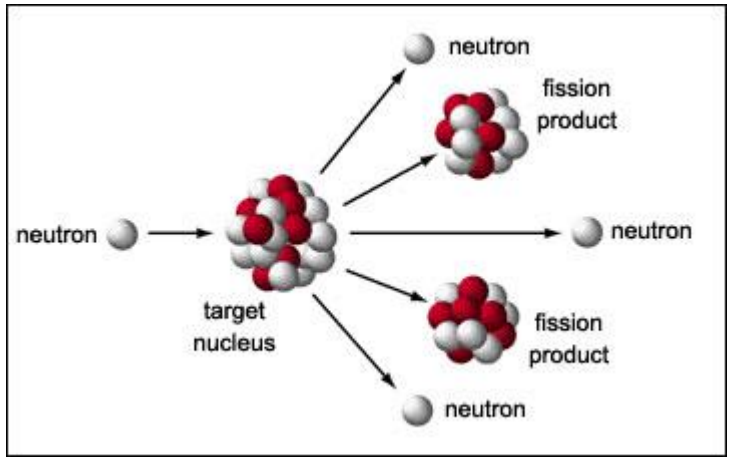
Fission chain reaction

- Moderator is used to slow down the energy of the neutrons from fission (average 2 MeV) to the thermal energy (0.025 eV).
- The best moderators are materials with low mass number (H, D, C,..).
- Moderators (the most common):
  - Light water - H_2O
  - Heavy water - D_2O
  - Graphite
  - Polyethylene
  - Paraffin

Essential parts of nuclear reactor:

1. Fuel
2. Moderator

Fission chain reaction



fragments with high kinetics energy

↓

fragments' slowdown

↓

thermal energy released

thermal energy released = heat - necessary cooling

We need coolant in a reactor.

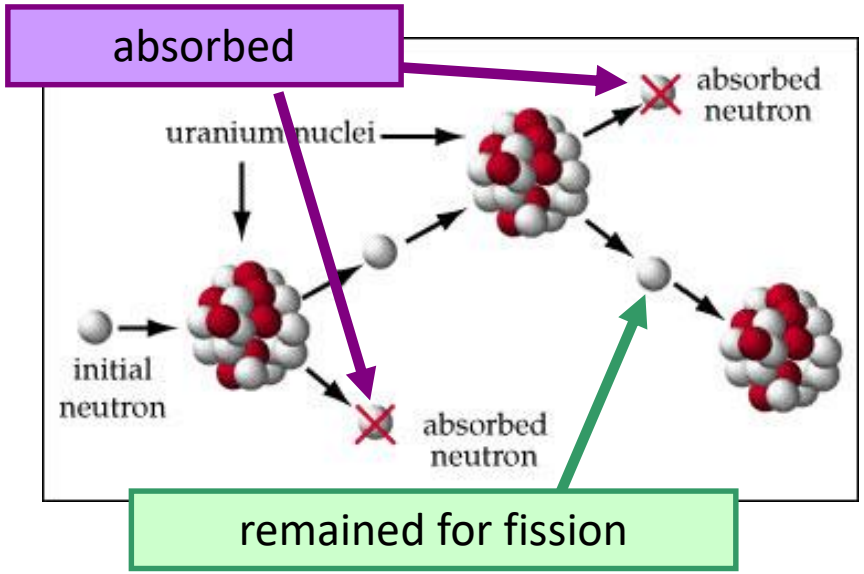
Fission chain reaction

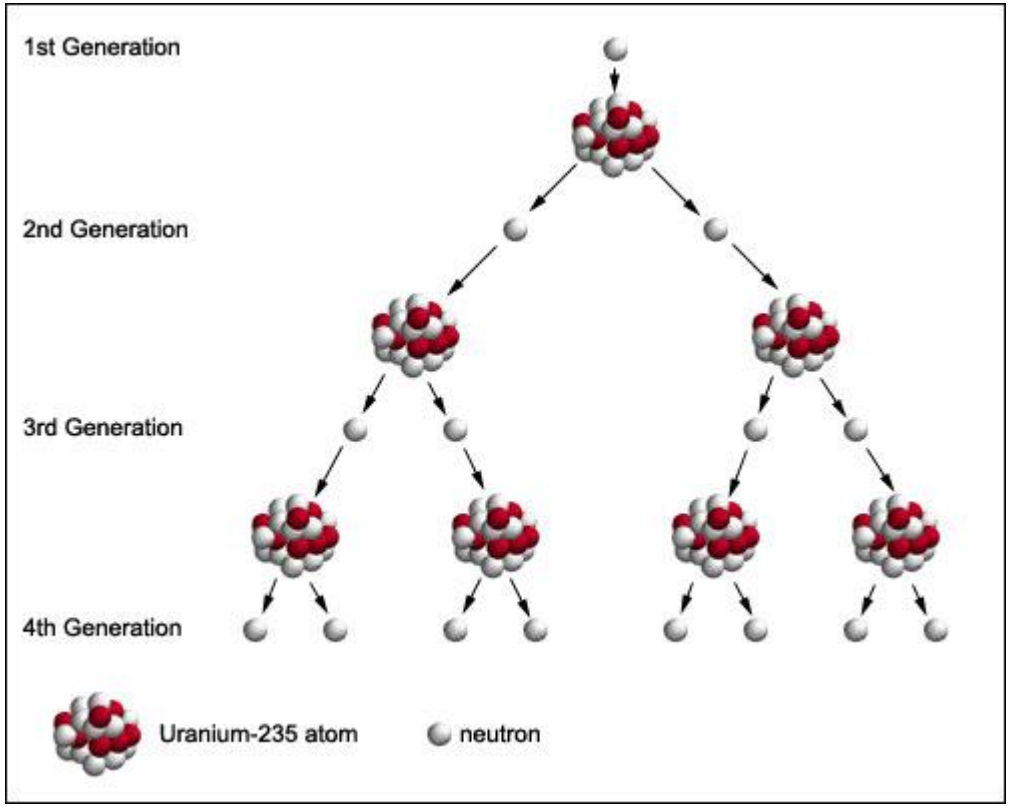
- Coolant is used to remove the heat from the core and other parts of the reactor where heat may be produced.
- Research reactors' coolants (the most common):
  - Water - H_2O
  - Heavy water - D_2O
  - Liquid metal - sodium - in fast reactors only
- Power reactors' coolants (the most common):
  - Water - H_2O
  - Heavy water - D_2O
  - Gas - CO_2
  - Liquid metal - sodium - in fast reactors only

Essential parts of nuclear reactor:

1. Fuel
2. Moderator
3. Coolant

Fission chain reaction





Control of a reactor = control of neutron absorption

Neutron absorber is in control rod

We need need control rods in a reactor.

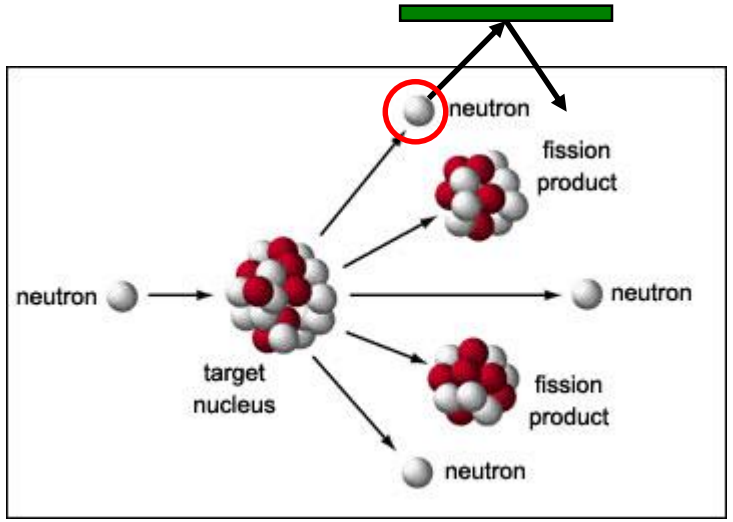
Fission chain reaction

- Absorber is used to control the fission chain reaction and keep reactor under the control.
- The main control of the reactor is by control rods which contain neutron absorber.
- Absorbers (the most common):
  - Boron
  - Cadmium
  - Hafnium

Essential parts of nuclear reactor:

1. Fuel
2. Moderator
3. Coolant
4. Absorber, control rod

Fission chain reaction



Neutron is close a border

Neutron can leave a core

What we can do?

We can a reflector close to a core

Neutron is reflected back

We need reflector in a reactor.

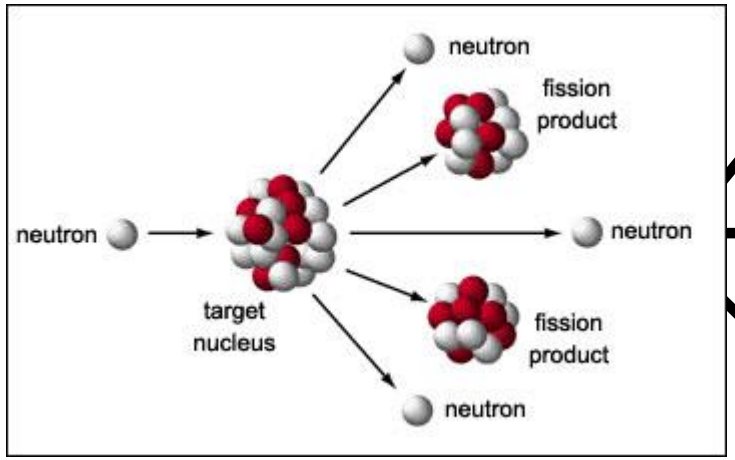
Fission chain reaction

- Reflector is used to reflect neutron back to the core in the case neutron goes out of the core.
- Reflectors (the most common):
  - Beryllium
  - Iron, steel
  - Graphite
  - Water

Essential parts of nuclear reactor:

1. Fuel
2. Moderator
3. Coolant
4. Absorber, control rod
5. Reflector

Fission chain reaction



- neutrons
- beta-rays
- gamma-rays

We need to protect personnel and instrumentation.

We need shielding in a reactor.

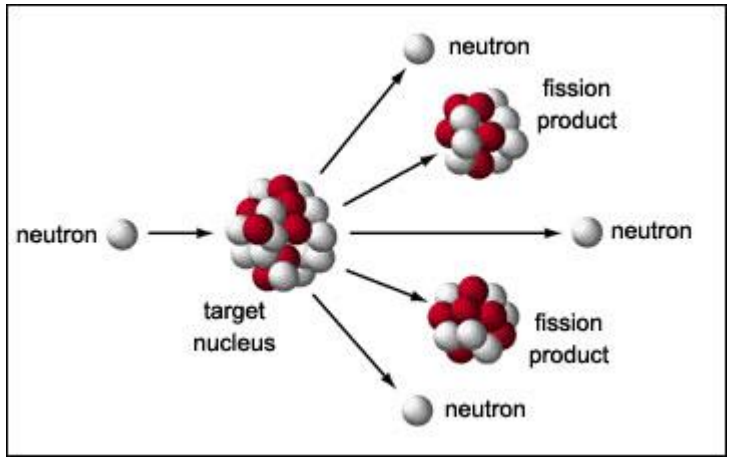
Fission chain reaction

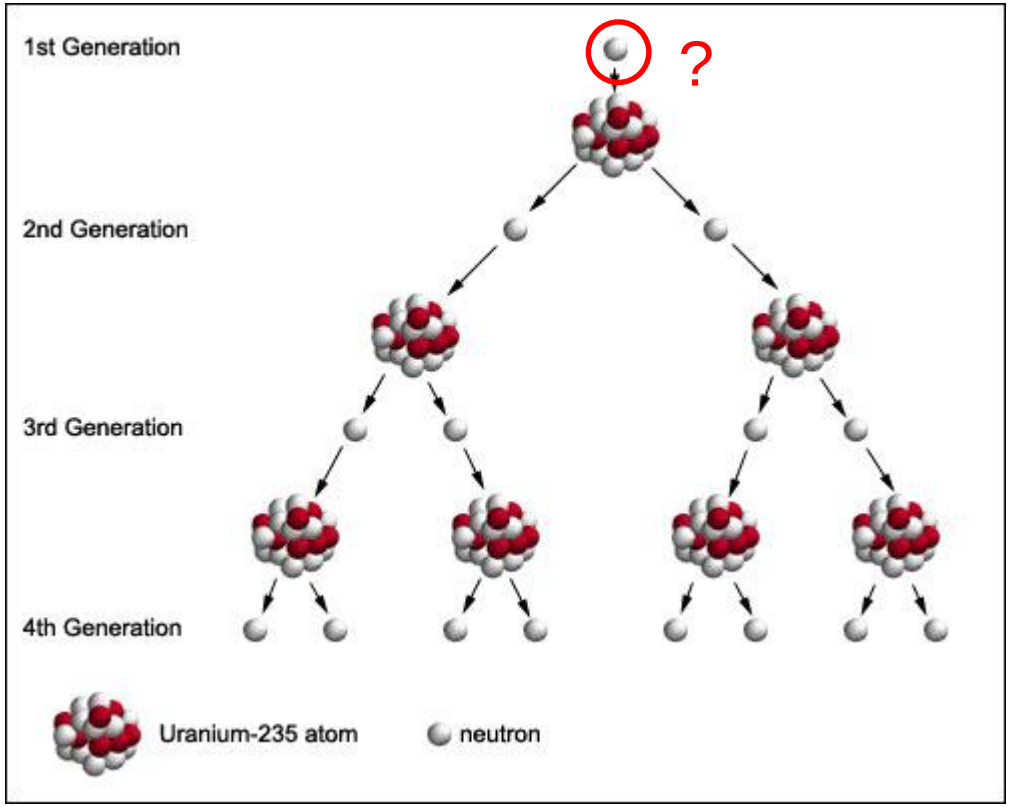
- Shielding is used to protect personnel (people) and instrumentation from all radiation which could origin in the reactor.
- Gamma-rays (the most common):
  - Lead Pb
  - Iron Fe, steel
  - Concrete
  - Water - H_2O
- Neutrons (the most common):
  - Water - H_2O
  - Concrete
  - Boron (added to iron, steel, polyethylene,...)

Essential parts of nuclear reactor:

1. Fuel
2. Moderator
3. Coolant
4. Absorber, control rod
5. Reflector
6. Shielding

Fission chain reaction





Where we can got a first neutron?

We need external neutron source to start up fission chain reaction.

We need neutron source in a reactor.

Fission chain reaction

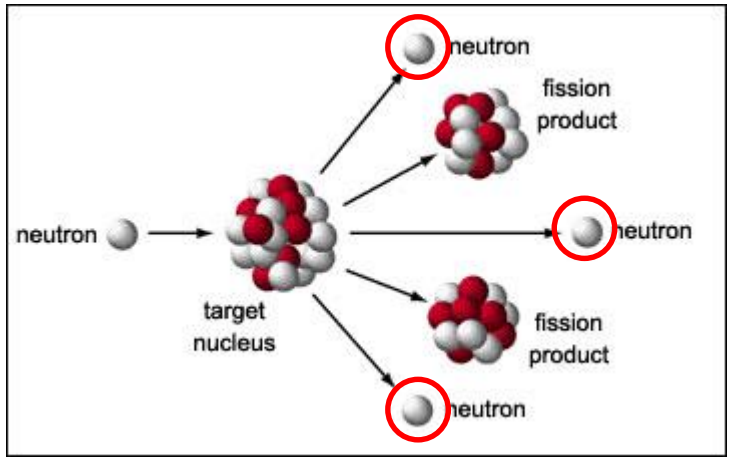
- Neutron source is used to help to start up the fission chain reaction in the core and to keep measurable level of signal in detection systems of the reactor.
- The most common neutron sources:
  - Am-Be neutron source
  - Pu-Be neutron source
  - Cf neutron source

Neutron source at The VR-1 Reactor

Essential parts of nuclear reactor:

1. Fuel
2. Moderator
3. Coolant
4. Absorber, control rod
5. Reflector
6. Shielding
7. Neutron source

Fission chain reaction



How many neutrons we have in a core?

How we can count number of neutrons in a core.

We need neutron detectors in a reactor.

Fission chain reaction

- Neutron detector is used to count how many neutrons are in the core.
- Neutron flux is measured instead the total number of neutrons.
- Neutron detectors are based on different principles and are used in different states and conditions.
- The most common neutron detectors:
  - Fission detector
  - Boron detector
  - He-3 detector
  - ….

Neutron detector at The VR-1 Reactor

Essential parts of nuclear reactor:

1. Fuel
2. Moderator
3. Coolant
4. Absorber, control rod
5. Reflector
6. Shielding
7. Neutron source
8. Neutron detectors

Control of fission chain reactor

- Control system or Instrumentation and control (I&C) is used to control the reactor and keep reactor in safe operation.
- I&C joins all reactor essential parts in order to make one global system for safe control of fission chain reaction

Control system of The VR-1 Reactor

Essential parts of nuclear reactor:

1. Fuel
2. Moderator
3. Coolant
4. Absorber, control rod
5. Reflector
6. Shielding
7. Neutron source
8. Neutron detectors
9. Control system

Nuclear reactor vs. nuclear bomb

What are main differences between nuclear reactor and nuclear bomb?