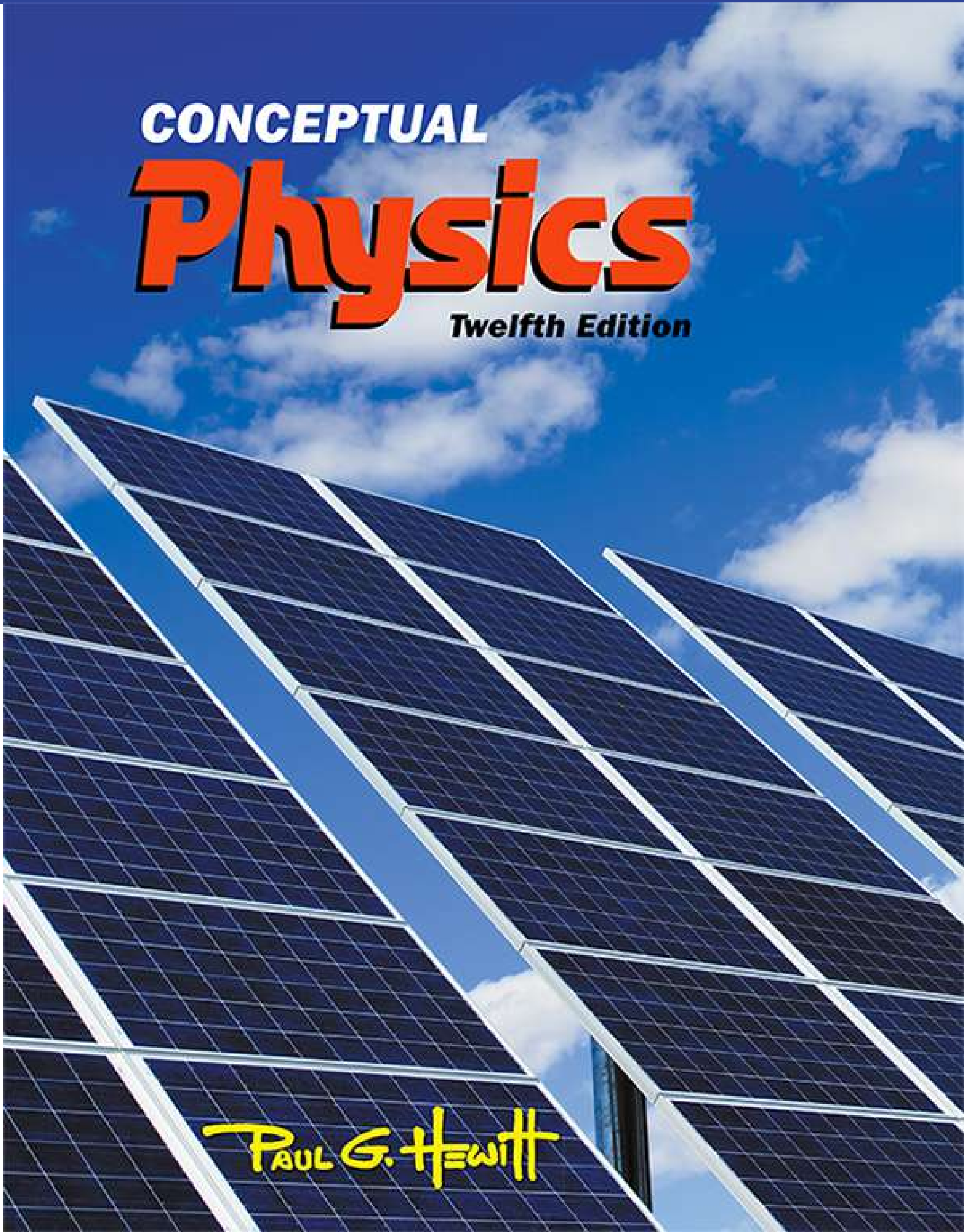
Lecture Outline

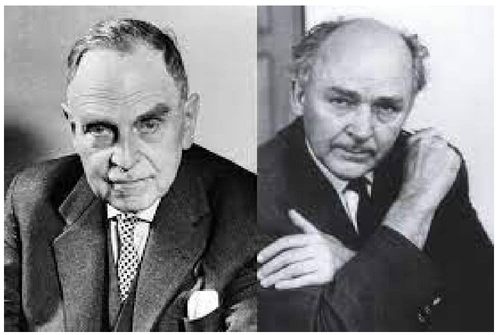


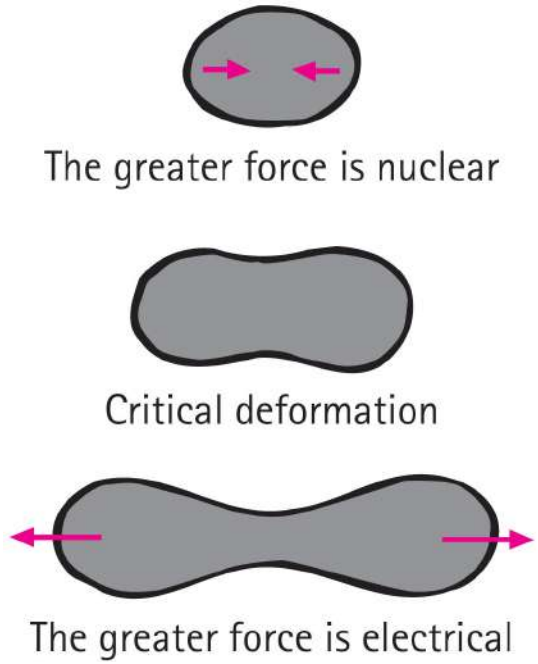
Chapter 34: Nuclear Fission and Fusion

Part 1

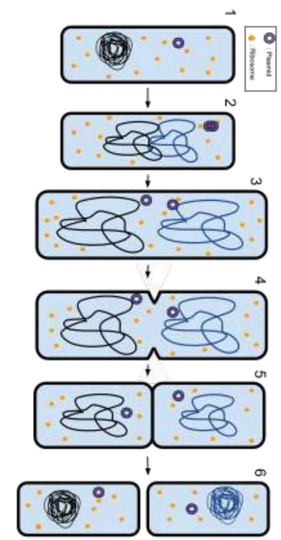
Nuclear Fission

- German scientists Otto Hahn and Fritz Strassmann in 1938 accidentally discovered nuclear fission.



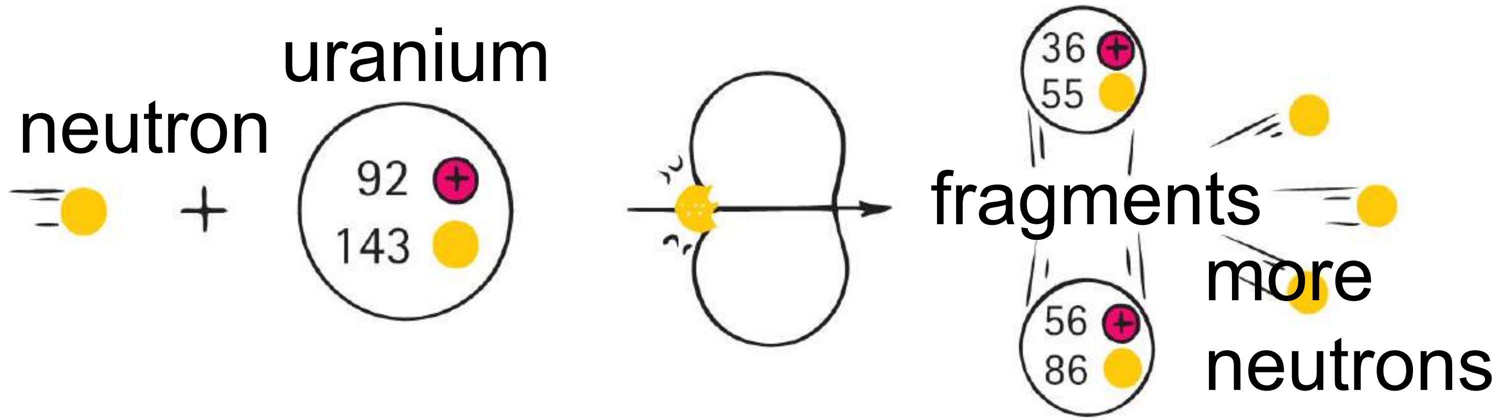


biological fission



Lise Meitner and Otto Frisch explained the process and gave it the name nuclear *fission*.

A typical uranium fission reaction:



$$ {}^{1}_{0}n + {}^{235}_{92}U \rightarrow {}^{91}_{36}Kr + {}^{142}_{56}Ba + 3({}^{1}_{0}n) $$

mass numbers: $1 + 235 = 91 + 142 + 3x1$

atomic numbers: $0 + 92 = 36 + 56 + 3x0$

Fission of 1 uranium nucleus releases 7 million x the energy released by the explosion of 1 TNT molecule

Energy comes from $E = mc^2$ (details later)

Energy goes *mostly into KE of fragments*, and a little into the KE of the neutrons and some γ–ray energy

Nuclear Fission
CHECK YOUR NEIGHBOR, Continued-3

When a uranium nucleus undergoes fission, the energy released is primarily in the form of

A. gamma radiation.
B. kinetic energy of fission fragments.
C. kinetic energy of ejected neutrons.
D. All of the above about equally.

Nuclear Fission
CHECK YOUR ANSWER, Continued-3

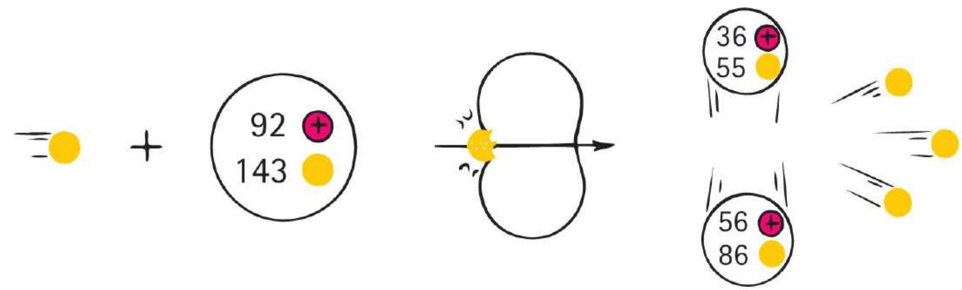
When a uranium nucleus undergoes fission, the energy released is primarily in the form of

B. **kinetic energy of fission fragments.**

Explanation:

Kinetic energy of fragments is what becomes heat energy. Interestingly, gamma-ray energy is tiny in comparison. Neutrons, although important for the chain reaction, contribute a small part of the energy release. Choice D is likely a guess.

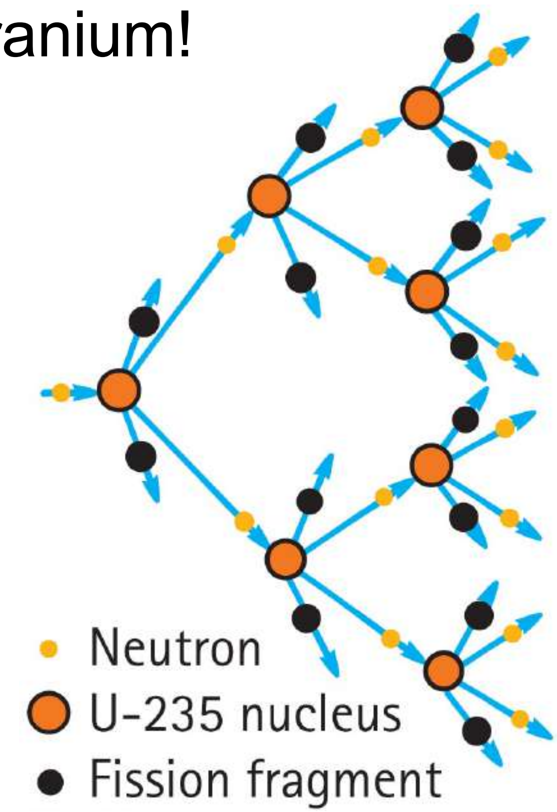
Neutrons: no charge
→ not repelled by nucleus
→ make good "bullets"



$^{1}_{0}n + ^{235}_{92}U \rightarrow ^{91}_{36}Kr + ^{142}_{56}Ba + 3(^{1}_{0}n)$

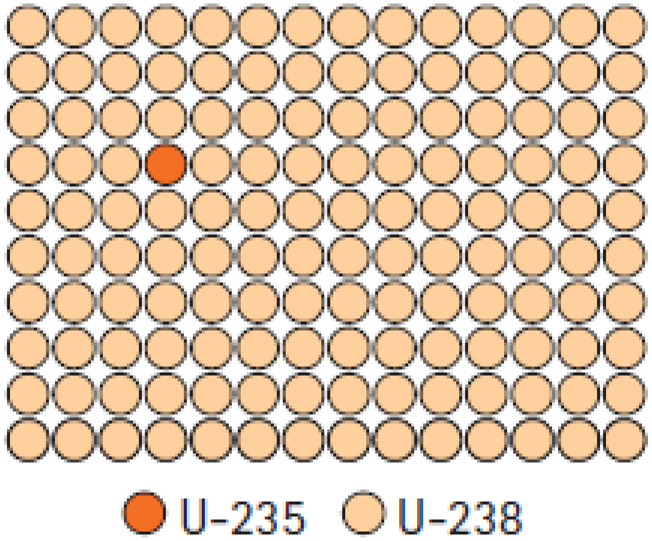
IMPORTANT :
Each fissioning produces 2-3 more neutrons
Each new neutron can fission more uranium!

- **Chain reaction**—a self-sustaining reaction in which the products of one reaction event (a fission) stimulate further reaction events (more fissions):



U-235 vs U-238

- A chain reaction doesn't happen in uranium ore deposits because most uranium is the heavier isotope U-238.

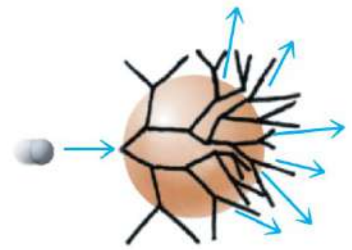


- U-238 does not undergo fission when it absorbs a neutron.
- Less than 1% of all naturally occurring uranium ore is U-235 (the kind that fissions).
- Enriching the ore increases the % of U-235.

Classwork

1. Why doesn't a chain reaction normally occur in uranium mines?

- Chain reaction in uranium
  - Small amount, chain reaction fizzles.
  - *Subcritical* mass
  - Too much surface area compared to volume
  - *Critical* amount, chain reaction produces an explosion.



critical mass = smallest amount that will sustain a chain reaction

Any more than critical → *supercritical* (explosion)

Classwork

2. Why is a chain reaction more likely to occur in a big piece of uranium than in a small piece?

3. What is meant by the idea of a critical mass?

4. Which will leak more neutrons: two separate pieces of uranium or the same pieces stuck together?

Nuclear Fission
CHECK YOUR NEIGHBOR

The greater the surface area of a piece of fission material, the

A. less likely an explosion.
B. more likely an explosion.
C. Neither A nor B; mass, rather than surface area is significant.
D. None of the above.

Nuclear Fission
CHECK YOUR ANSWER

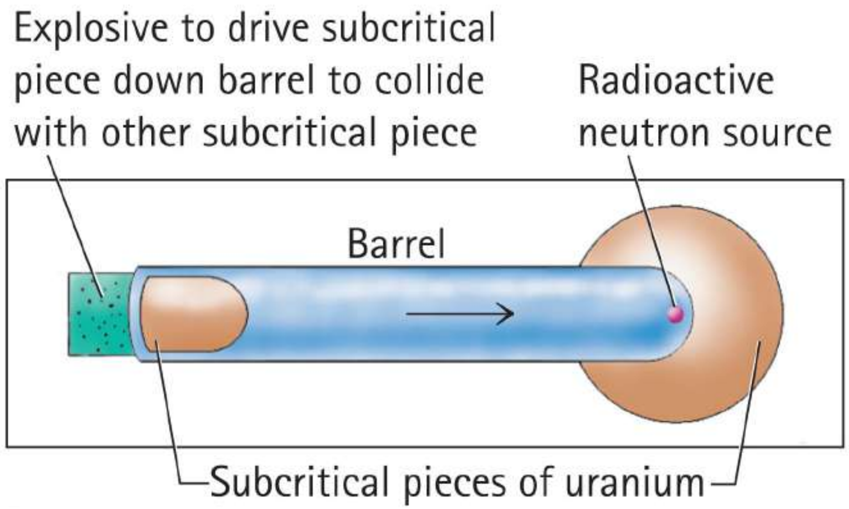
The greater the surface area of a piece of fission material, the

A. **less likely an explosion.**

Explanation:

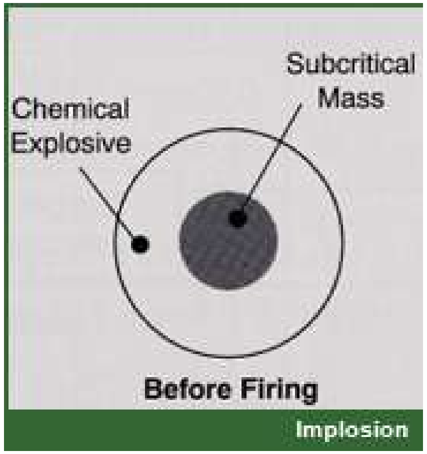
When a chain reaction occurs, it fizzles out when neutrons escape a surface. Therefore, the greater the surface area, the less likely an explosion will occur.

- Fission bomb



  - A bomb in which 2 pieces of sub-critical uranium are driven together is a so-called "gun-type" weapon.

  - A more common bomb now is an "implosion weapon,“ in which a subcritical mass is compressed to make it critical.



Manhattan Project

Los Alamos, NM: Where US scientists developed the first nuclear weapons.

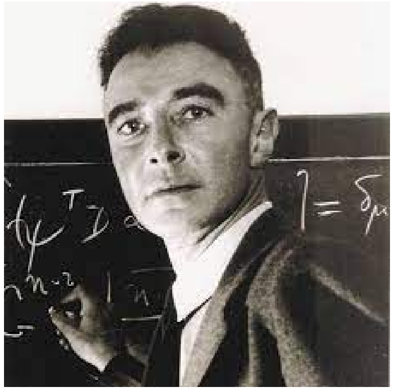
J. Robert Oppenheimer: US physicist who lead the effort

→ Father of the Atomic bomb

First nuclear weapon exploded was an implosion device.

Detonated at Jornada del Muerto in New Mexico, July 16, 1945. Codename: *Trinity*

See video.



Atomic Bombs

Little Boy:

dropped on Hiroshima
6 Aug 1945

gun-type device

dead: 120,000

Fat Man:

dropped on Nagasaki
9 Aug 1945

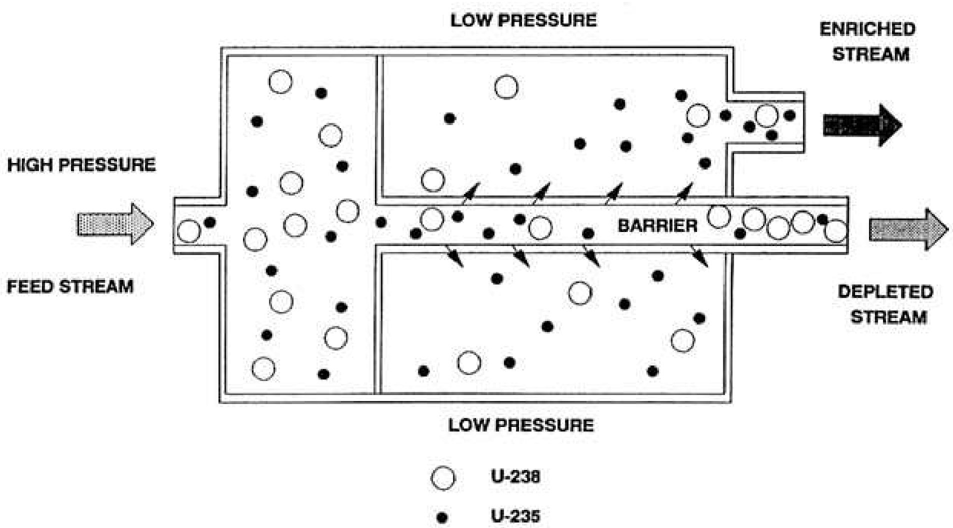
implosion device

dead: 80,000

- Constructing a fission bomb is a formidable task. The difficulty is separating enough U-235 fuel.
- Took 2 years to get enough for first (softball sized)

3 ways to do it:

1. **gaseous diffusion (WW II)**



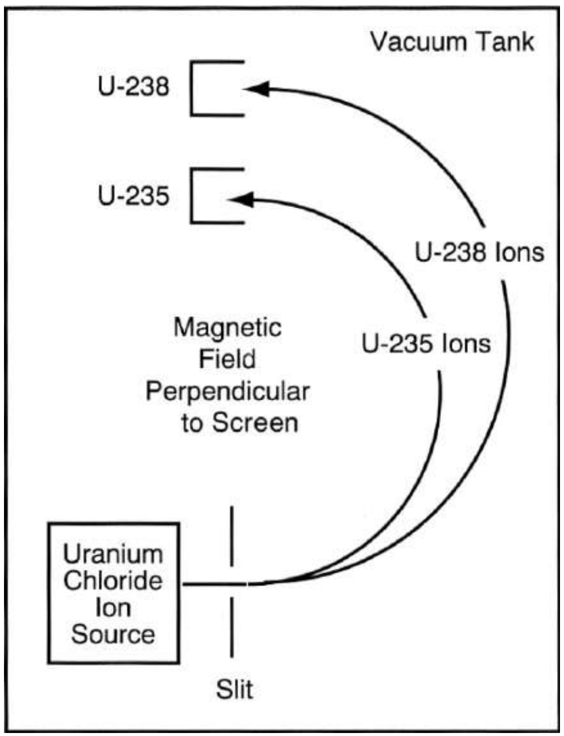
Uranium is combined with fluorine to produce UF_6 gas.

UF_6 that has U-235 is faster than UF_6 with U-238.

It diffuses slightly faster through a thin membrane.

The process is repeated thousands of time.

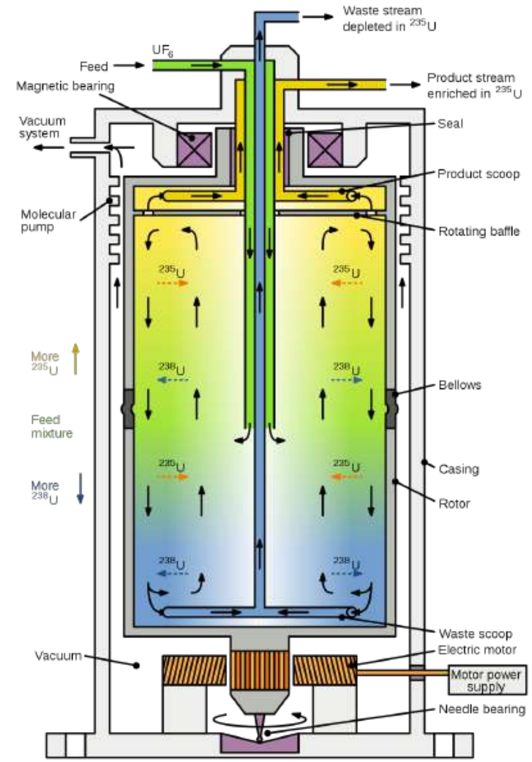
2. **magnetic separation**: Less massive U-235 bends more in magnetic field.



Used for partial enrichment

Done in WWII.

3. **gas centrifuges**: UF_6 gas is spun at high speeds.



U-238 moves to outside

U-235 moves to inside

Classwork

5. What were the two methods used to separate U-235 from U-238 in the Manhattan Project during World War II?

First *controlled* nuclear chain reaction

Carried out by Enrico Fermi underground at the University of Chicago on 2 Dec 1942.

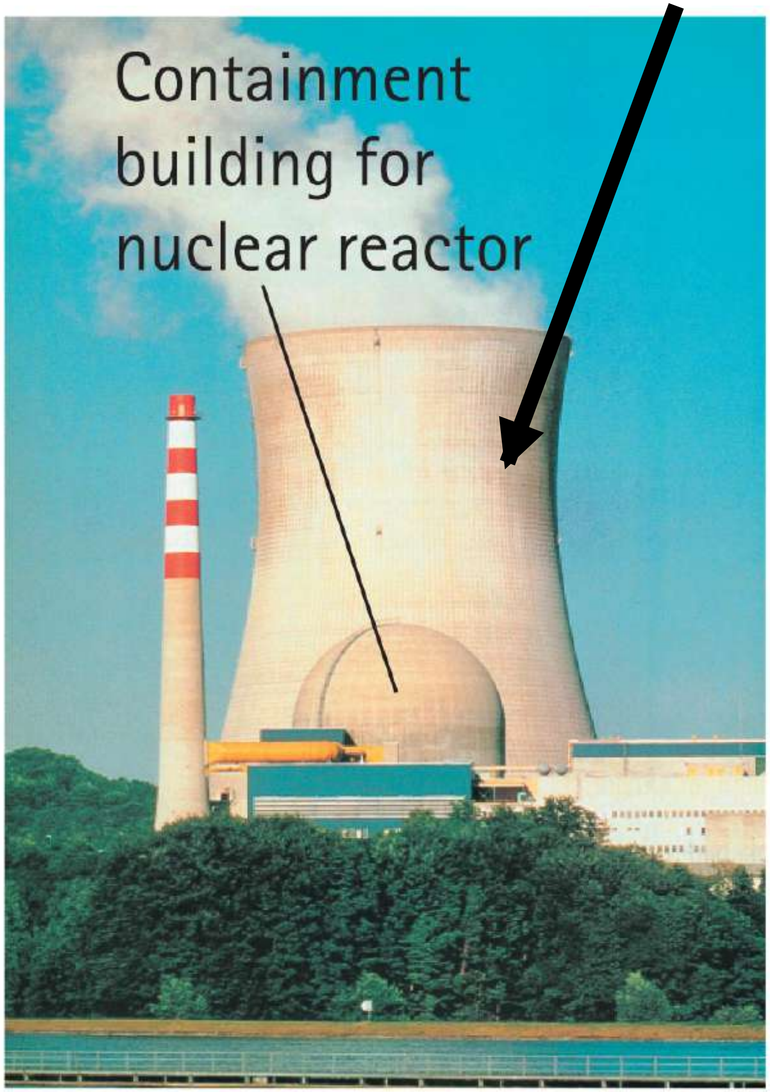
Pile of uranium in graphite bricks

- Nuclear fission reactors today
  - Use a controlled chain reaction to generate heat.
  - About 20% of electric energy in the United States is generated by nuclear fission reactors.
  - In France 70%, Slovakia 54%
  - Belg, Switz, Germ: phase out
  - Minnesota (21%) has 2 plants:

Monticello

Prairie Island

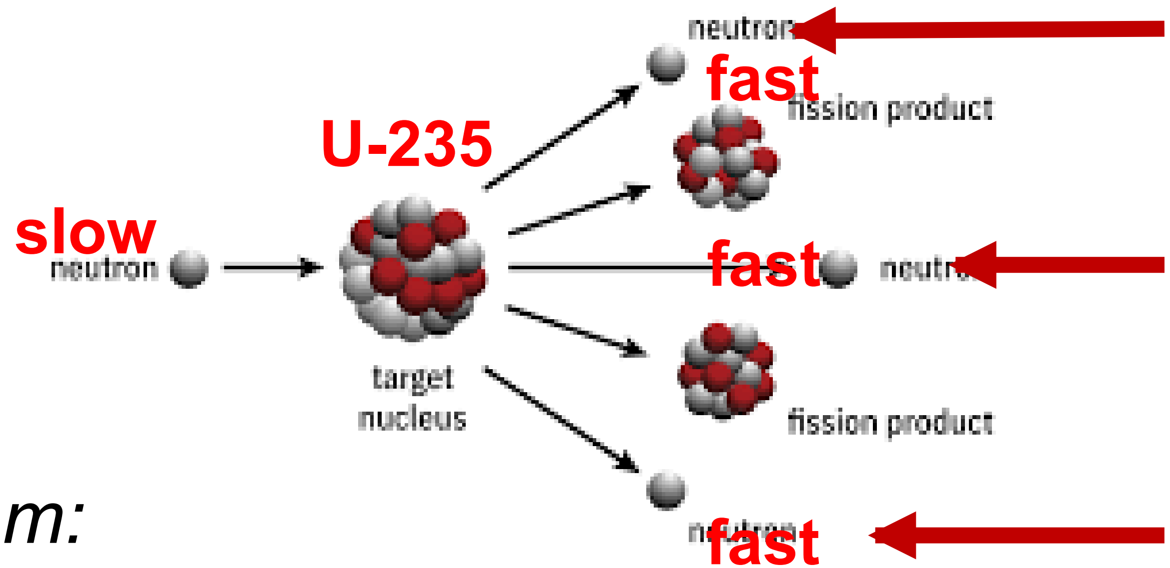
Tower to cool steam



Neutrons are the key to controlling fission:

A nuke planet uses less nuclear material than in a bomb, so the chain reaction must be more efficient.

But neutrons produced by fissioning U-235 are *fast*.

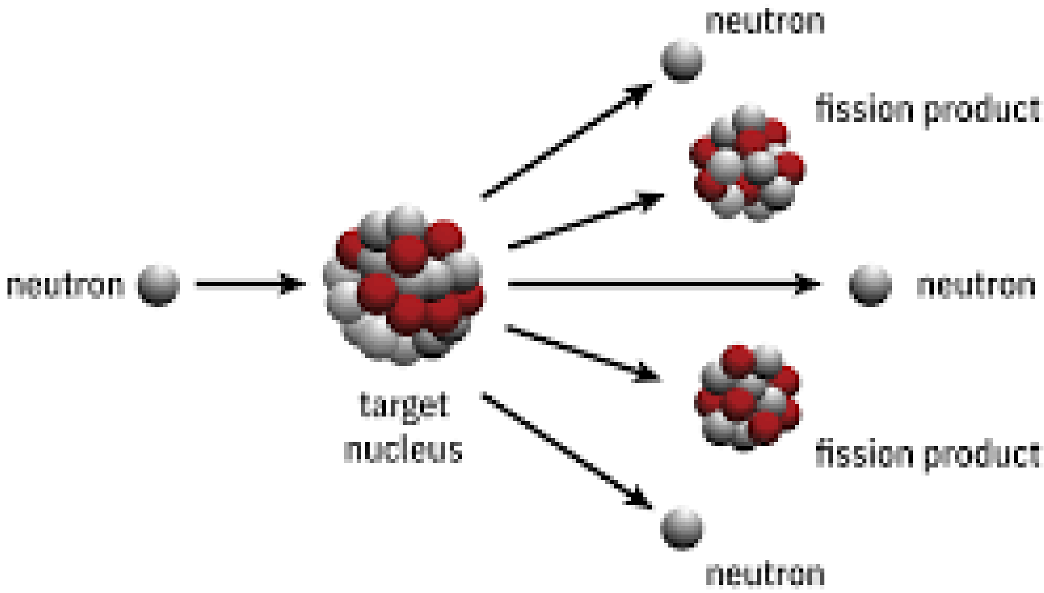


you want these new neutrons to fission more U-235

Problem:

U-238 can absorb fast neutrons, but doesn't fission

U-235 can only absorb *slow* neutrons.



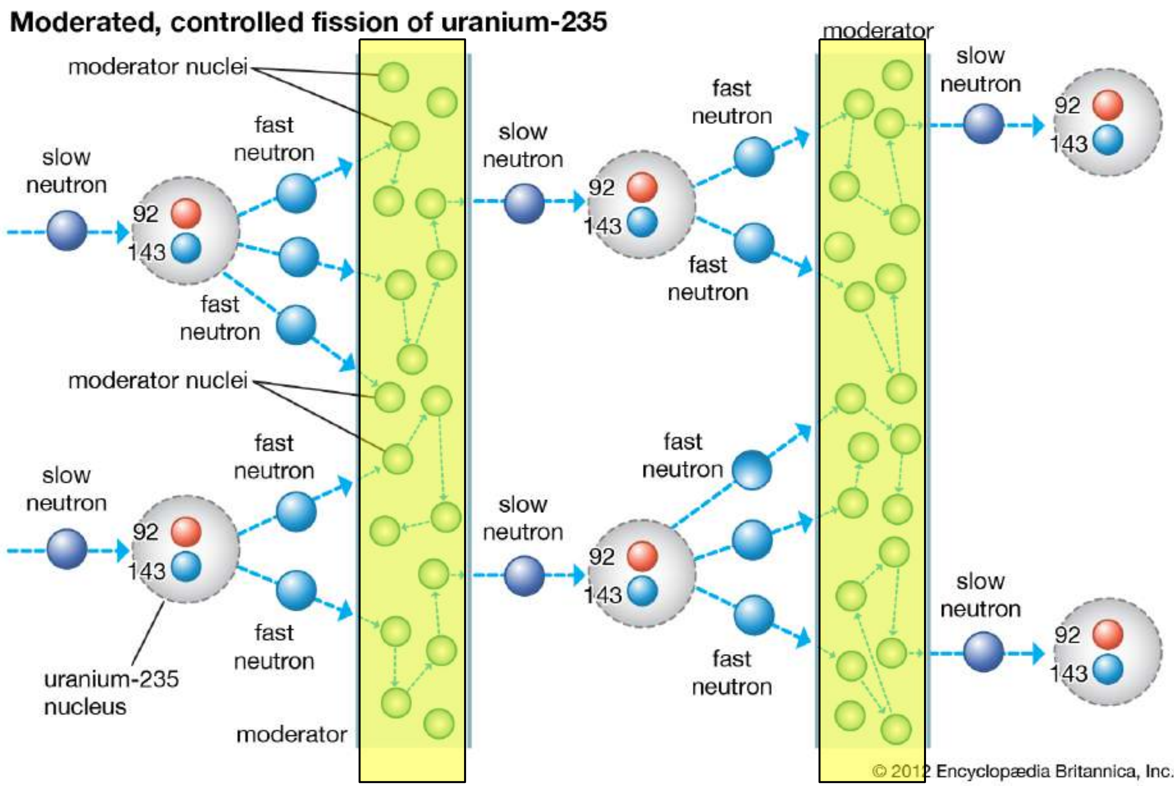
The 3 fates of a neutron produced by fission:

1. It can escape and do nothing
2. Fast neutrons are absorbed by U-238 (no fission)
3. Slow neutrons can fission U-235.

Classwork

6. What are the three possible fates of neutrons in uranium metal?

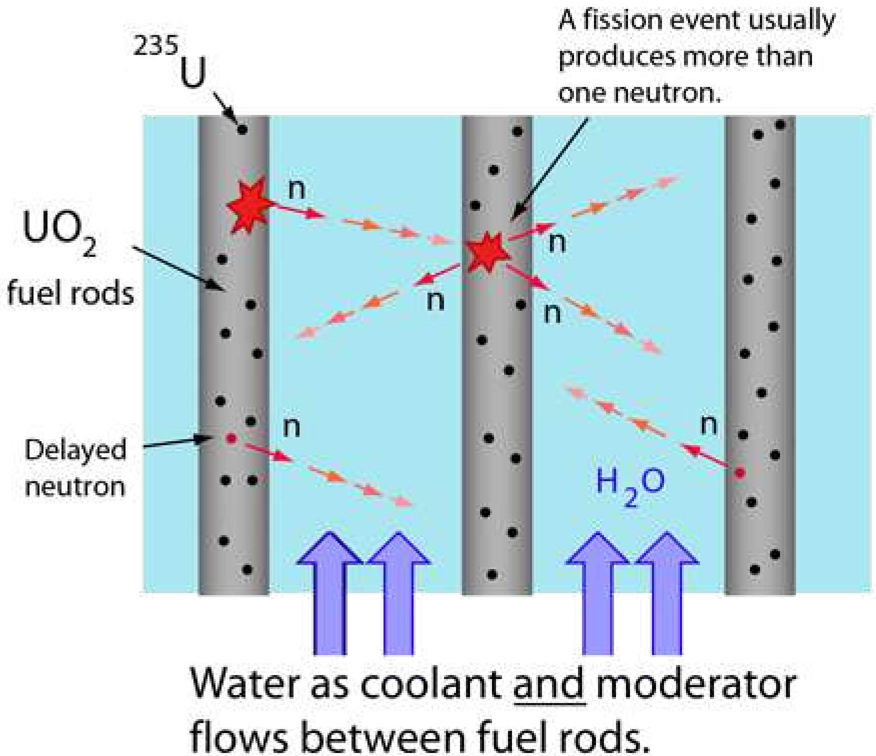
How to slow neutrons:
Collide them with something *about the same size:* the H in water, or carbon (graphite), or deuterium ${}^{2}_{1}H$.



This moderates (slows) the neutrons.
So a material that does this is a *moderator*.
This makes the reaction go *faster* because the slower neutrons are better at splitting U-235.

Moderator vs control rods

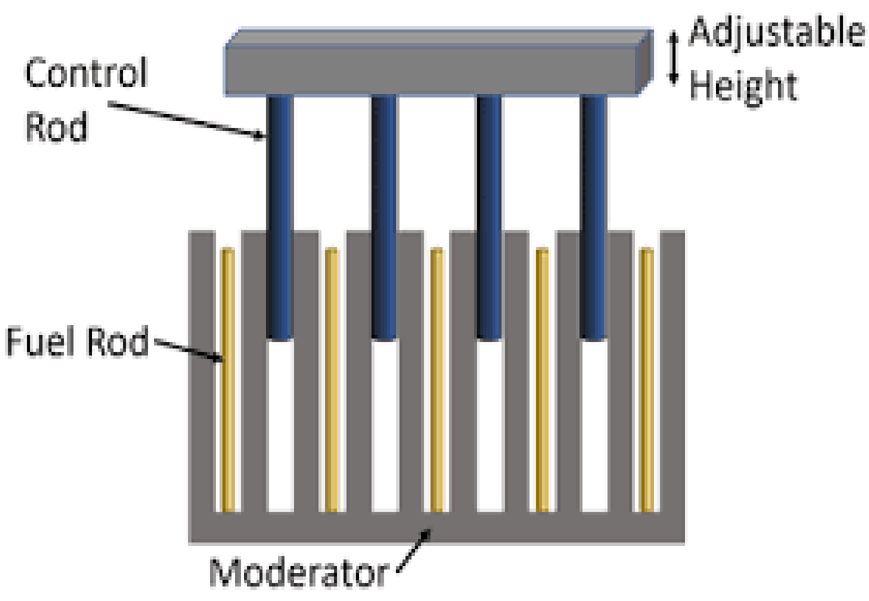
The moderator…



…slows the neutrons:

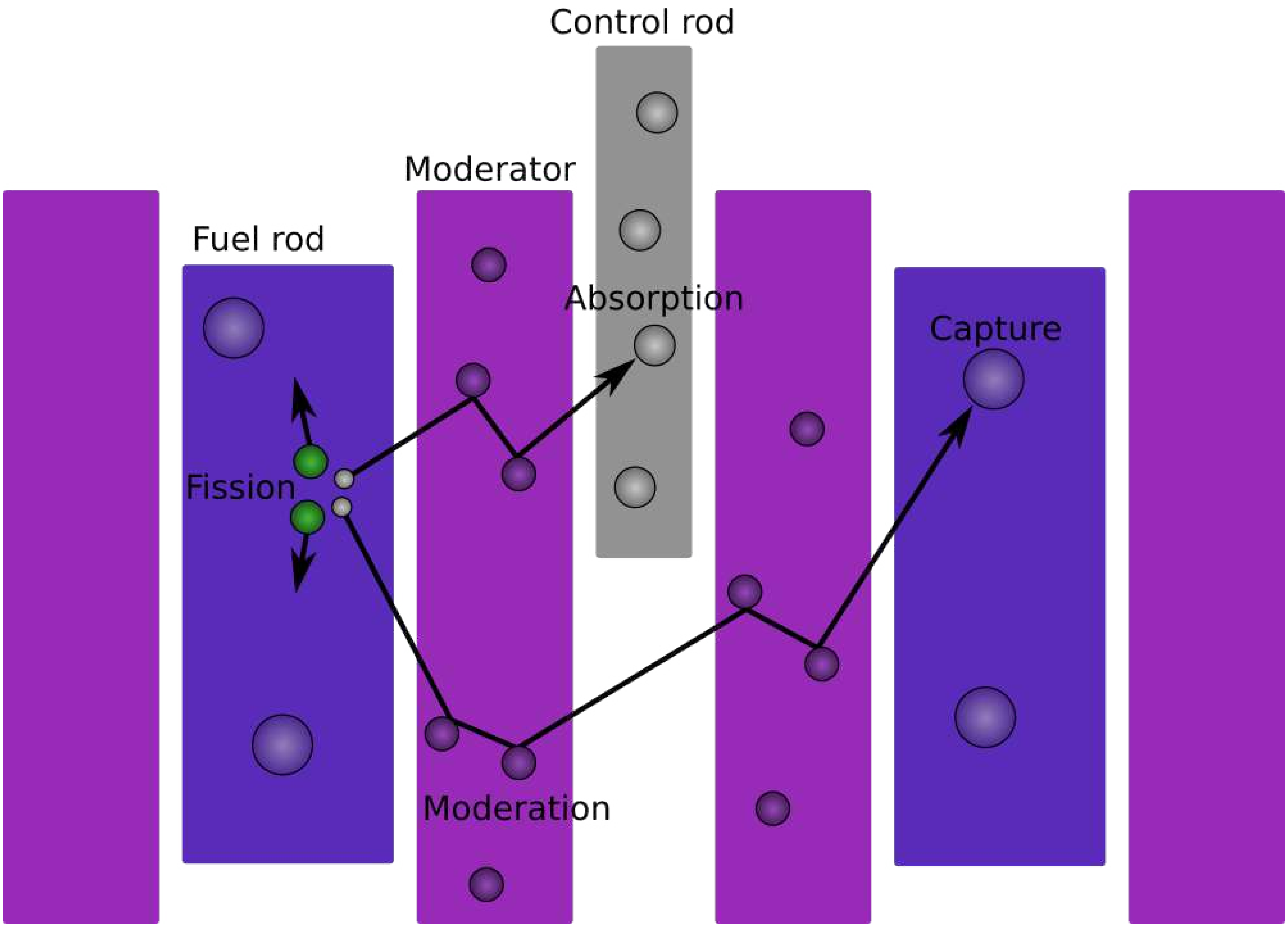
→ speeds up the reaction

The control rods…



…absorb neutrons:

→ slow the reaction down



Control rod
Moderator
Fuel rod
Absorption
Capture
Fission
Moderation

- Today's fission reactors contain 4 components:

1. The nuclear **fuel** is mostly U-238 plus about 3% U-235 (So an explosion unlikely.)

2. The **control rods** are made of a neutron-absorbing material, usually cadmium or boron.

→They remove neutrons and slow the reaction

3. The **moderator**

4. **a fluid** (water) to extract heat from the reactor.

→ Sometimes water is used both as a moderator and a coolant.

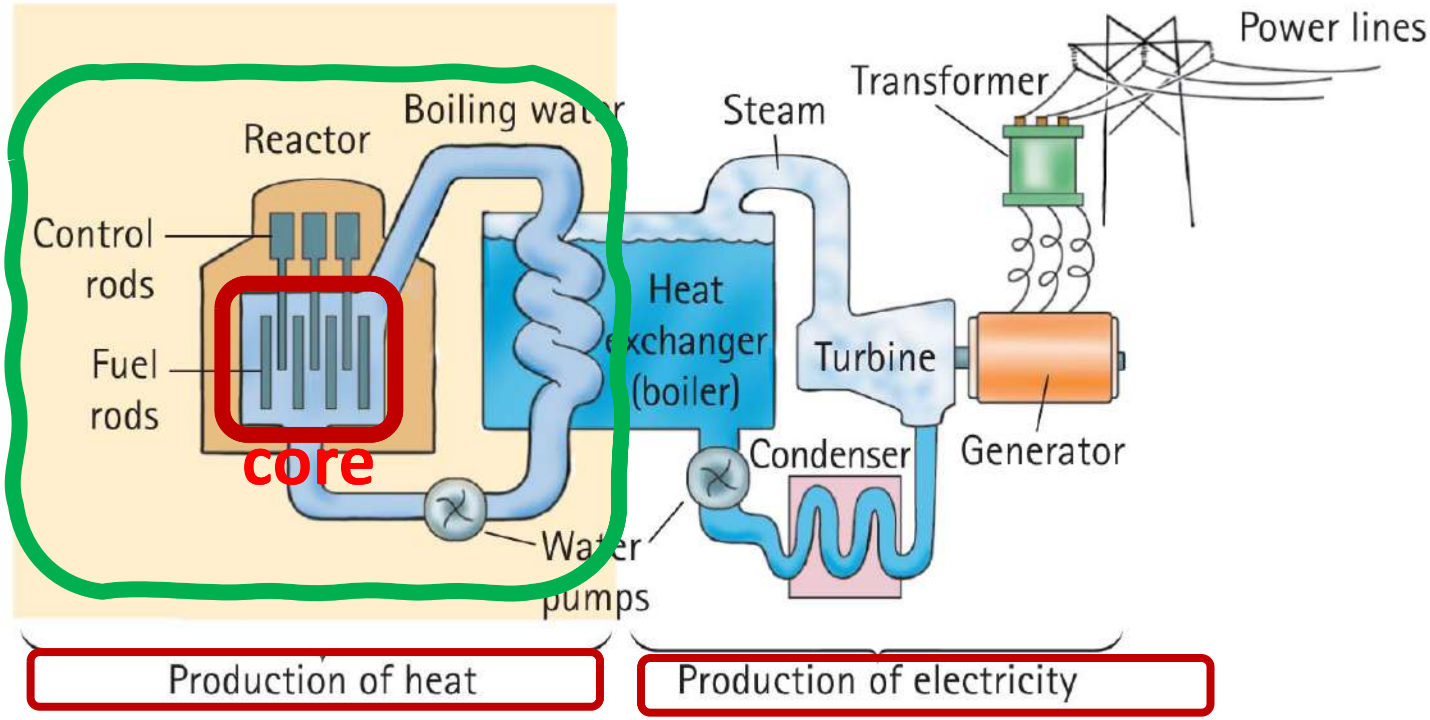
*Both the control rods and the U-238 help to prevent the reactor from getting out of control

Classwork

7. What are the four main components of a fission reactor?

8. What components are the safeguards to prevent a reactor from generating energy out of control?

- Diagram of a typical power plant:



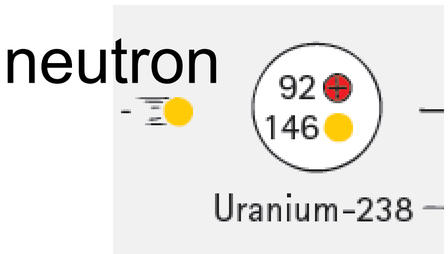
The **core** contains the fuel rods and control rods.

Water circulates around the core. If water cannot remove heat fast enough, core can "melt down."

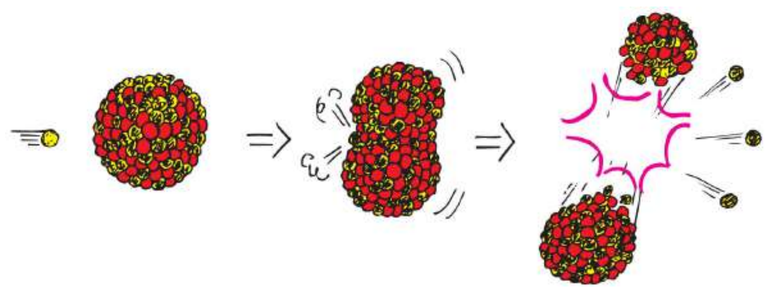
- Two separate water systems are used so no radioactivity reaches the turbine.

Breeder Reactor

- Plutonium Pu-239 can be "bred" from U-238 using neutrons from some fissionable isotope:



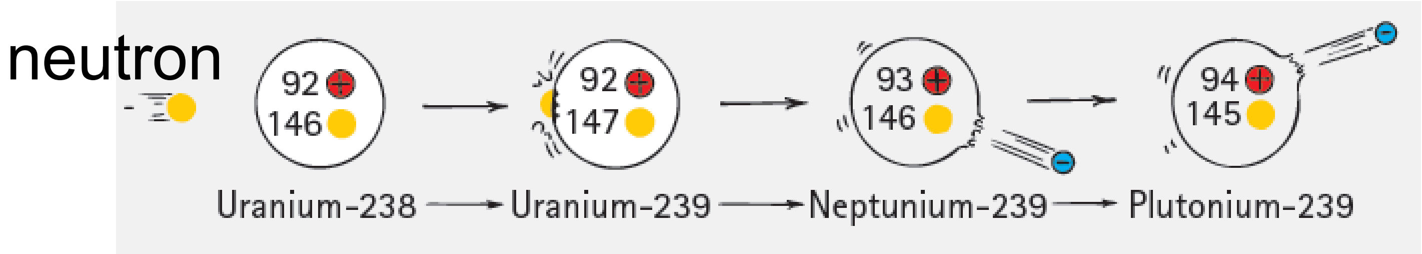
- Plutonium-239, like uranium-235, undergoes fission when it captures a neutron.



- Fissioning the Pu-239 then releases more neutrons, which can breed more Pu-239 from U-238, etc.

→ The process releases energy and breeds more fuel!

Classwork



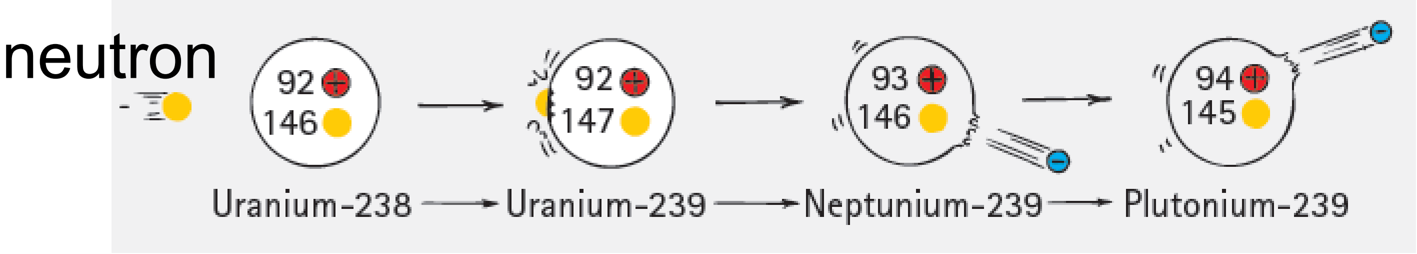
9. What isotope is produced when U-238 absorbs a neutron?

10. What isotope is produced when U-239 emits a beta particle?

11. What isotope is produced when Np-239 emits a beta particle?

12. What do U-235 and Pu-239 have in common?

Classwork



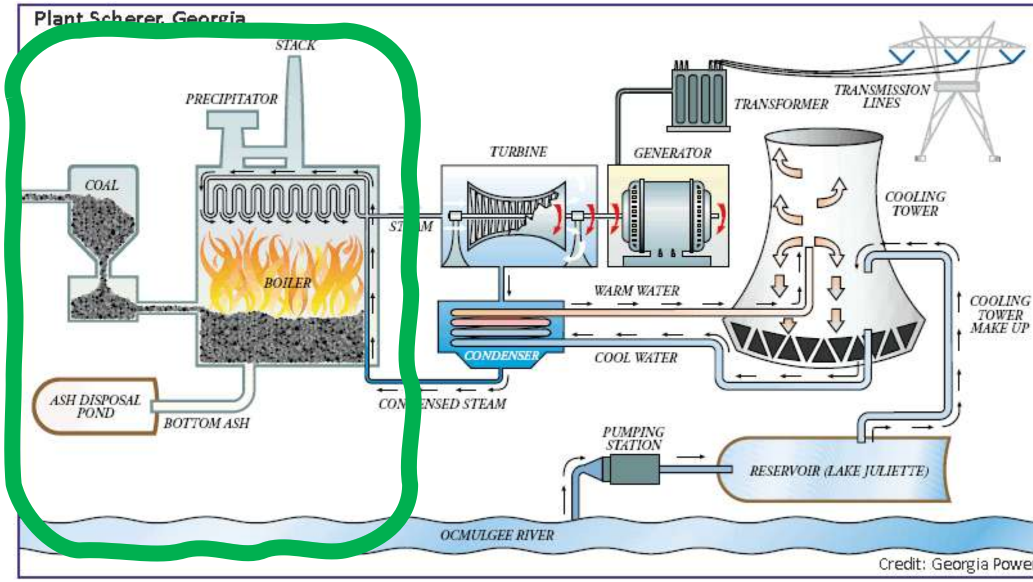
13. What is the effect of placing small amounts of fissionable isotopes with large amounts of U-238?

14. Name two isotopes that undergo nuclear fission.

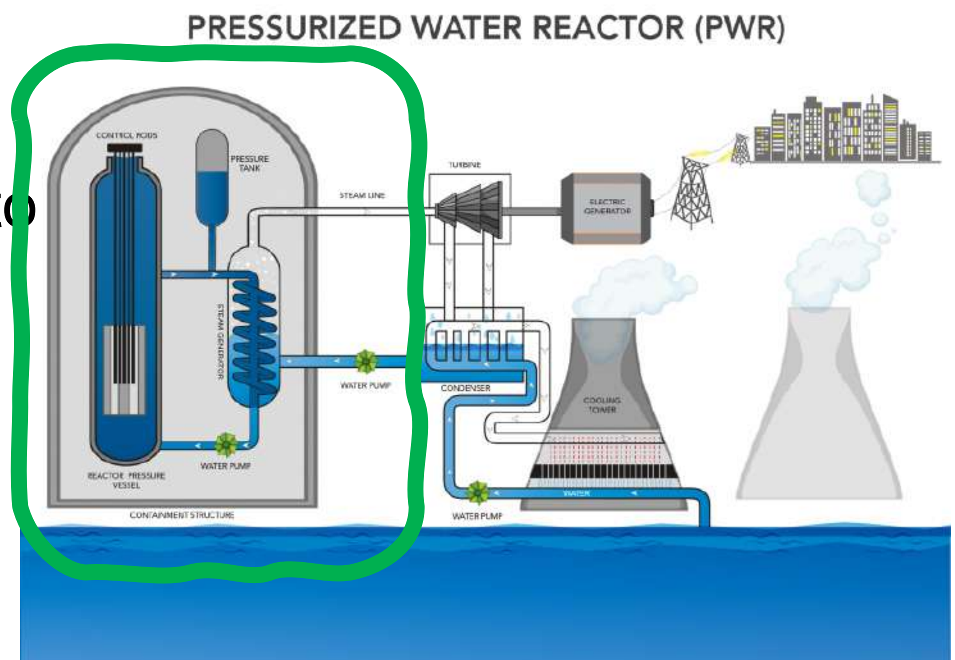
15. What element reacts in a breeder reactor to breed nuclear fuel?

Power plants:

Coal plant:
Burn coal, use heat to boil water. Then use steam to drive electric generators.



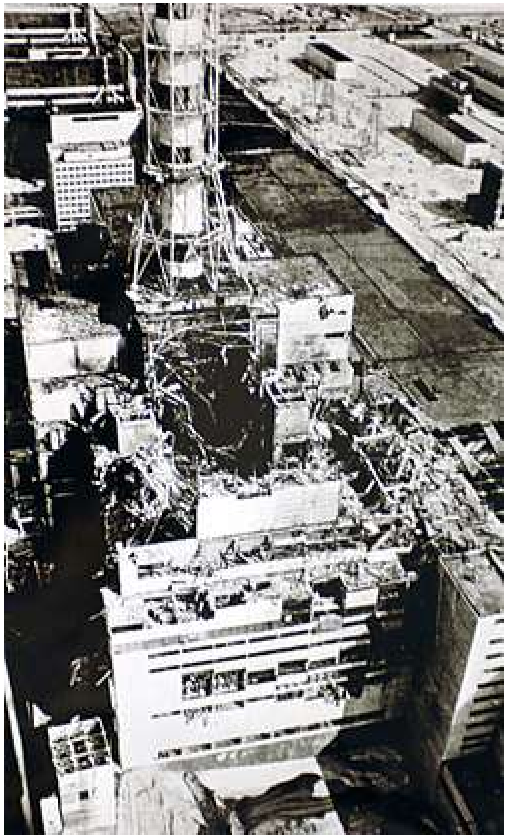
Nuke plant:
Fission uranium, use heat to boil water. Then use steam to drive electric generators.



Classwork

16. In what way is a nuclear reactor similar to a conventional fossil-fuel plant?

Chernobyl nuclear disaster



26 April 1986:

worst nuclear disaster

bad plant design

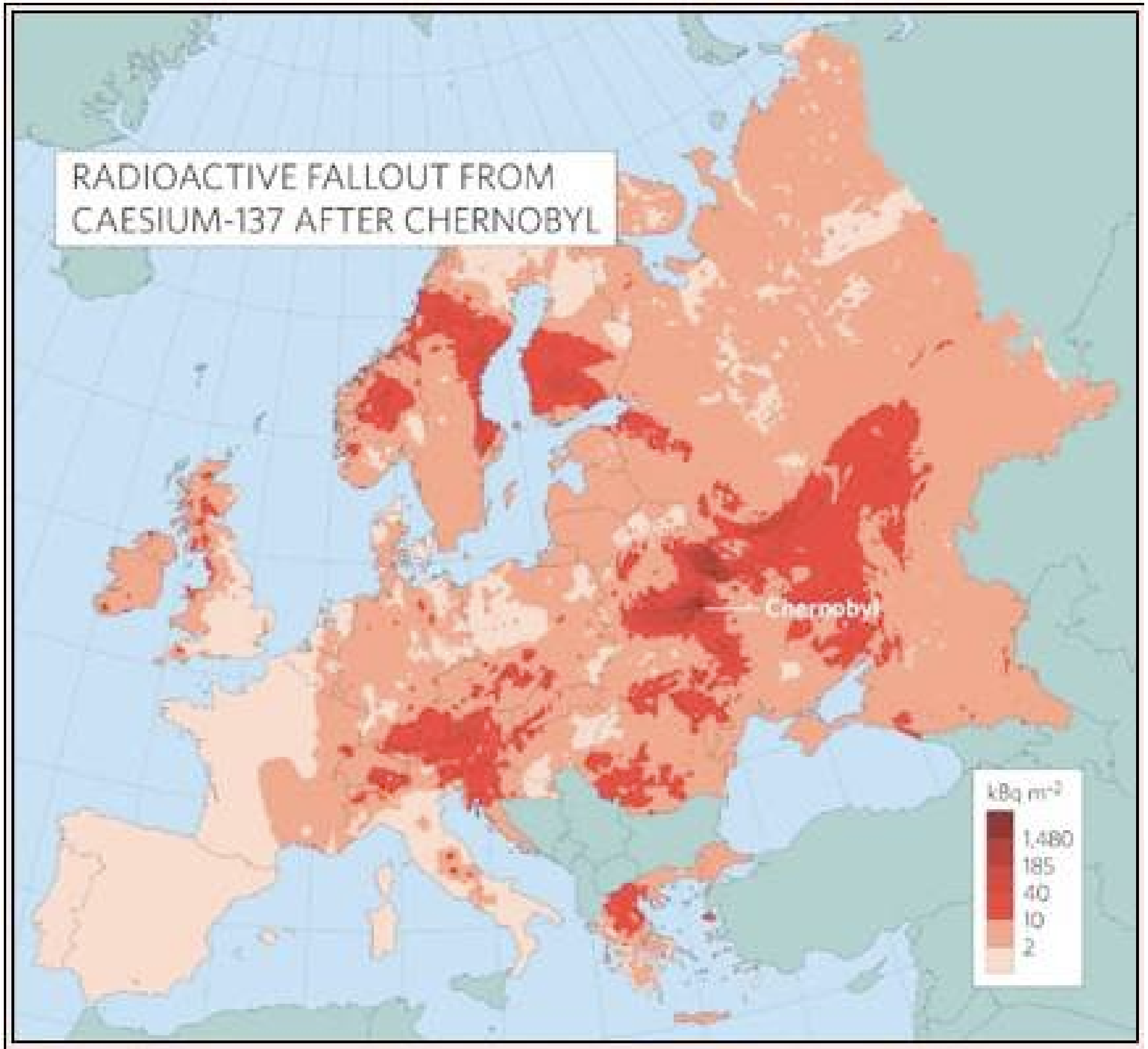
operator error

core of reactor exploded

large amounts of radioactive materials released spread over wide area

Now encased in a concrete sarcophagus

Chernobyl radiation released



J. SMITH & N. A. BERESFORD CHERNOBYL: CATASTROPHE AND CONSEQUENCES (PRAXIS, CHICHESTER, 2005)

First detected in Europe by a …

Fukushima Daiichi nuclear disaster: 2011

Caused by earthquake and tsunami

Reactors shut down, but electricity failed.

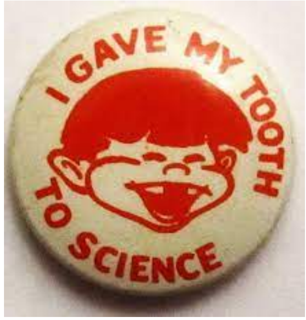
Emergency generator ran the water pumps, but the tsunami flooded them. Reactor core melted down, and explosions released radioactive materials.

Contaminated water went into the Pacific.

Builders failed to meet basic safety precautions.

Most severe nuclear accident since Chernobyl.

Radioactive Fallout: Fission products



Strontium-90: half-life 29 years

Absorbed into bones and teeth

Baby Tooth Survey→ Partial Test ban

Cesium-137: half life of 30 y

easily turned to gas and transported

dissolves in water and soil

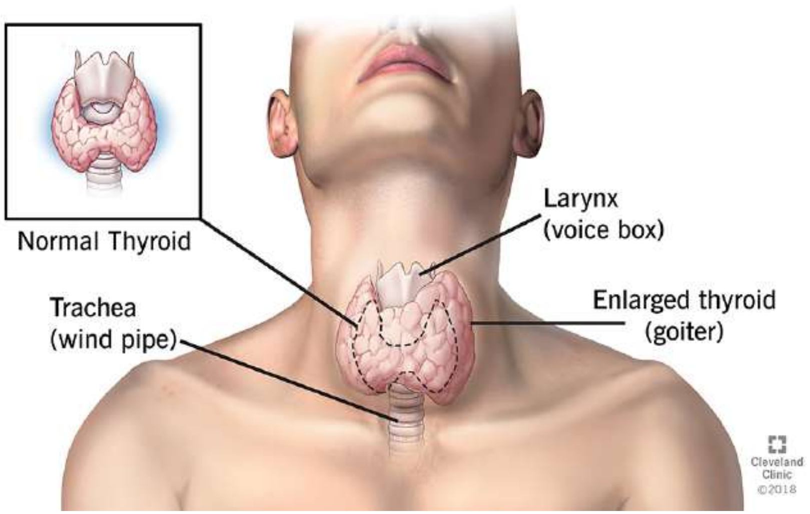
Iodine-131: half life of 8 d

Treatment: KI tablets saturate thyroid

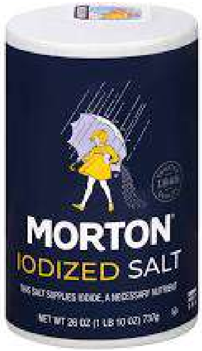
Interesting note: Iodine is needed for thyroid gland to function properly. If you don't get enough iodine….

…you can get goiter:

- enlarged thyroid gland
- due to iodine deficiency, autoimmune diseases, infection, etc.



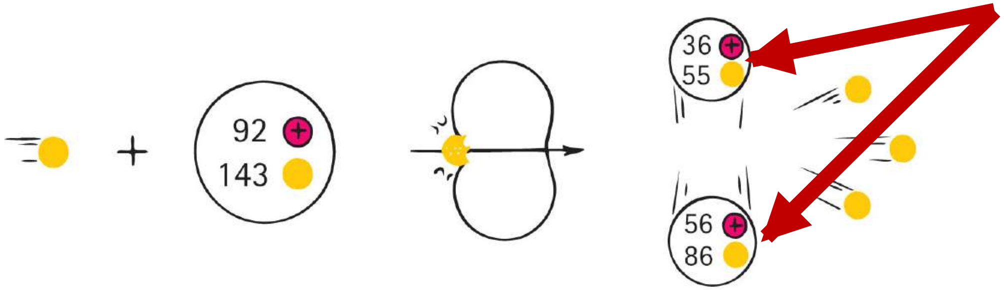
- That is why iodine is added to salt:



- Panicked citizens on the US west coast bought up KI tablets to saturate their thyroid.

- **Fission Power Benefits:**
- plentiful electricity
- saving fossil fuels
- no air pollution: elimination of carbon dioxide, sulfur oxides, etc., put into the air by burning of fossil fuels
- **Fission Power Drawbacks:**
- release of low-level radioactive isotopes into environment
- accident releases large amounts of radioactivity
- nuclear weapons proliferation
- storing radioactive waste :

products have too many neutrons, so they are radioactive



$${}^{1}_{0}n + {}^{235}_{92}U \rightarrow {}^{91}_{36}Kr + {}^{142}_{56}Ba + 3({}^{1}_{0}n)$$

Classwork

17. Cite three main advantages of fission power. Cite four main drawbacks.

Submit classwork now

- Deadline for all 4th quarter work:
- This Thursday

- Final: Both Chapters 33 and 34
- 5th hour: Tuesday 1-3 pm
- 6th hour: Friday 8-10 am
- Final will be two tests—one on each chapter.
- You may use a 3x5 card on the test.