L 26 – Nuclear Physics 2

At the end of this lecture you should:

- Have met and understood how to use Einstein's equation $\Delta E = \Delta m c^2$
- Understand the phrases *binding energy* and *mass defect*
- Understand how energy can be released from nuclear reactions by *fission* and *fusion*
- Have a basic knowledge of the '*binding energy per nucleon*' curve and be able to interpret it
- Know what the terms *critical mass, moderator, coolant* and *chain reaction* mean in relation to production of energy from a *nuclear reactor*
- Be aware of the main steps of *hydrogen fusion* in the sun

ANNOUNCMENTS

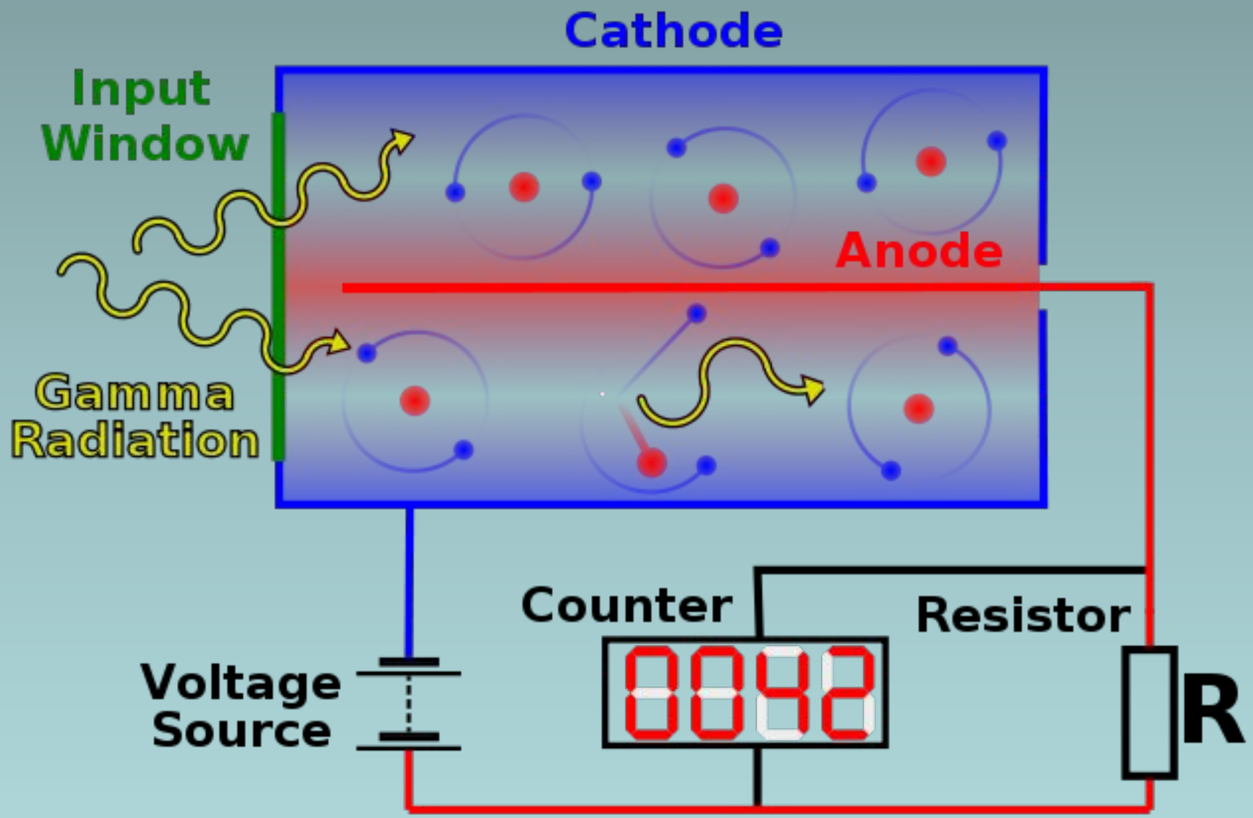
- CW Test on CW 11, 12
  (Special Relativity and Nuclear Physics)
  on Monday 27 Feb during normal lecture times.
  Come to same room as last term CW Tests

- No Labs This Week
- New Textbooks are now available at Library
  (College Physics, Serway, 10^{th} Edition)

Detecting radiation and nuclear energy

e.g., Geiger Muller tube

- Mica window
- Low pressure gas
- High voltage
- Anode/cathode
- High E field
- Massive ionization
- Electron avalanche
- Pulse


Cathode
Input
Window
Anode
Gamma
Radiation
Counter
Resistor
Voltage
Source
R

Atomic mass unit

One atomic mass unit (amu or u) is equal to a mass of

$$1u = 1.661 \times 10^{-27}\ kg$$

This small mass can be measured using a **mass spectrometer**

Example 1:

$$1u = 1.661 \times 10^{-27} \text{ kg}$$

Find its equivalence in

a) Joules of Energy, and
b) MeV of Energy

Example 2:

Using mass spectrometry, physicists have measured the masses of nuclei, protons and neutrons accurately. An alpha particle has a mass of 4.002603 u, a proton 1.007276 u and a neutron 1.008665 u. How is this possible?

Mass defect

In any type of nuclear transformation,

reactants $\longrightarrow$ products

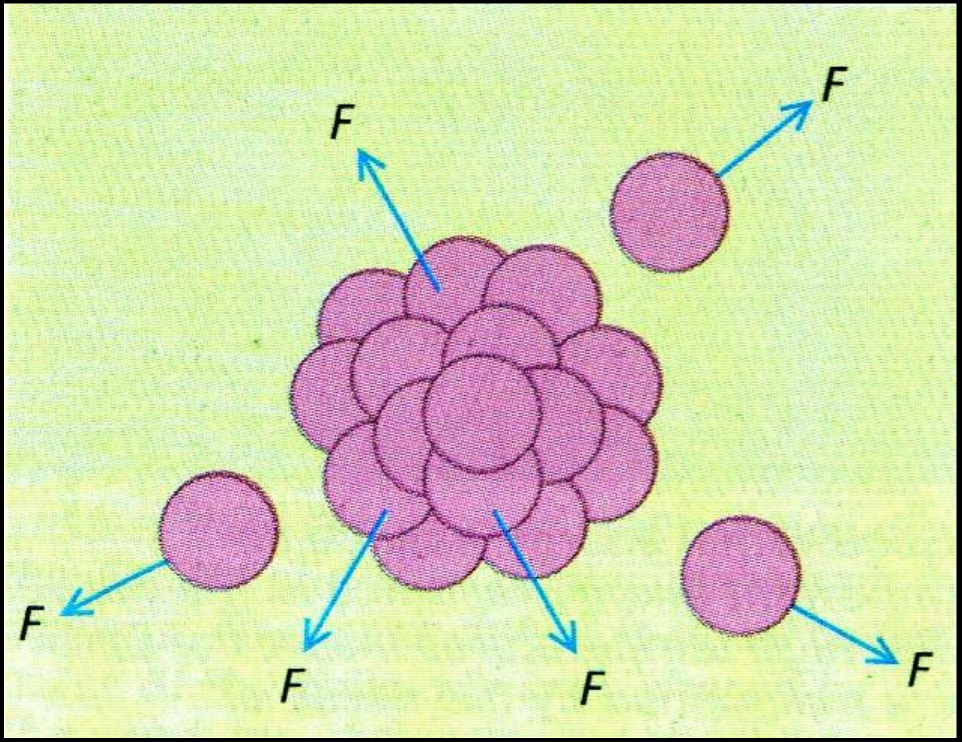
(sum of rest masses of reactants)

— (sum of rest masses of products)

MASS DEFECT

Nuclear binding energy

Work must be done to remove any nucleon from a nucleus.



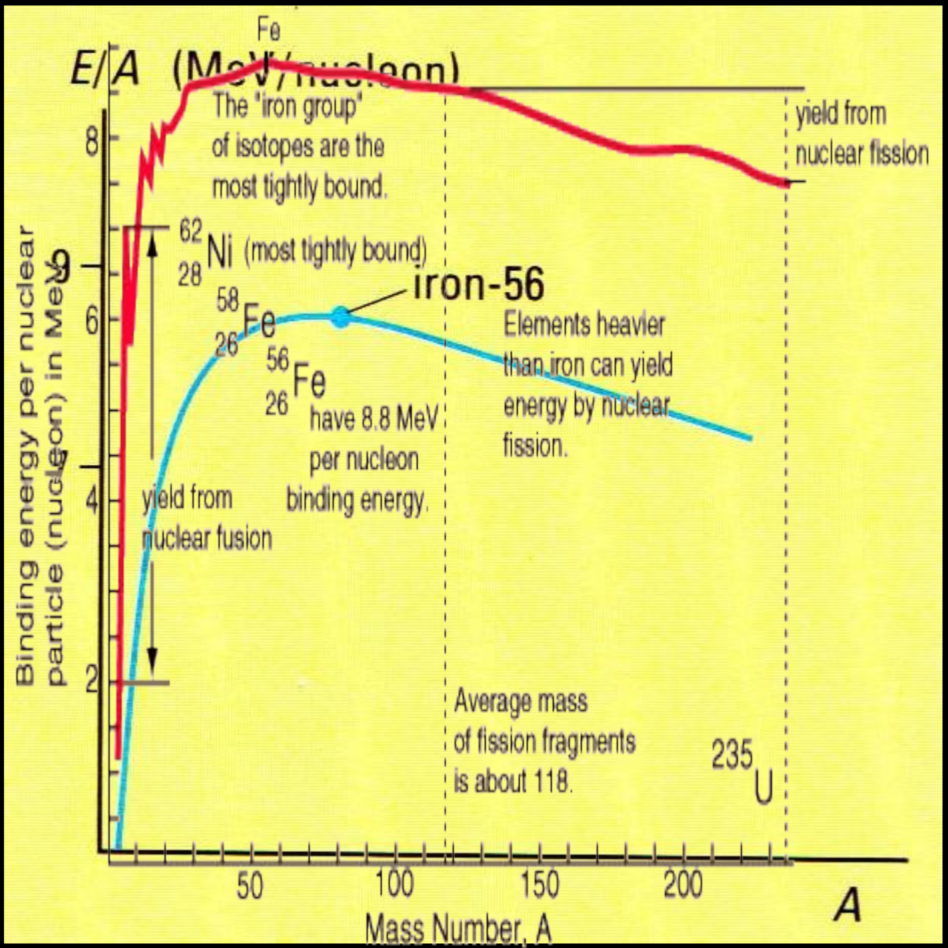
Nuclear binding energy is …

The *nuclear binding energy* is the energy equivalent of the *mass defect.*

Binding energy per nucleon

More convenient to use ‘binding energy per nucleon’.

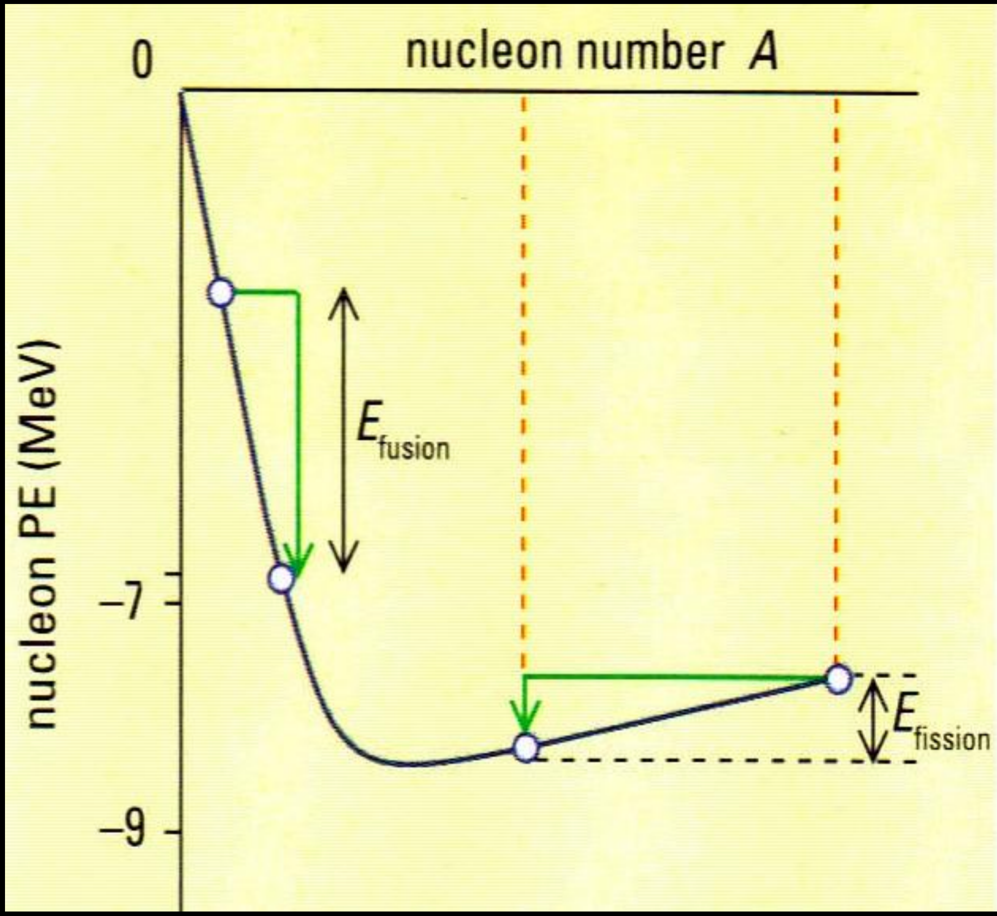
Mostly between 7 to 9 MeV per nucleon



Energy Difference of Fusion and Fission

Effect of fusion and fission

Both decrease the average nucleon PE (increasing binding energy per nucleon). PE lost is emitted as gamma rays and KE of particles.

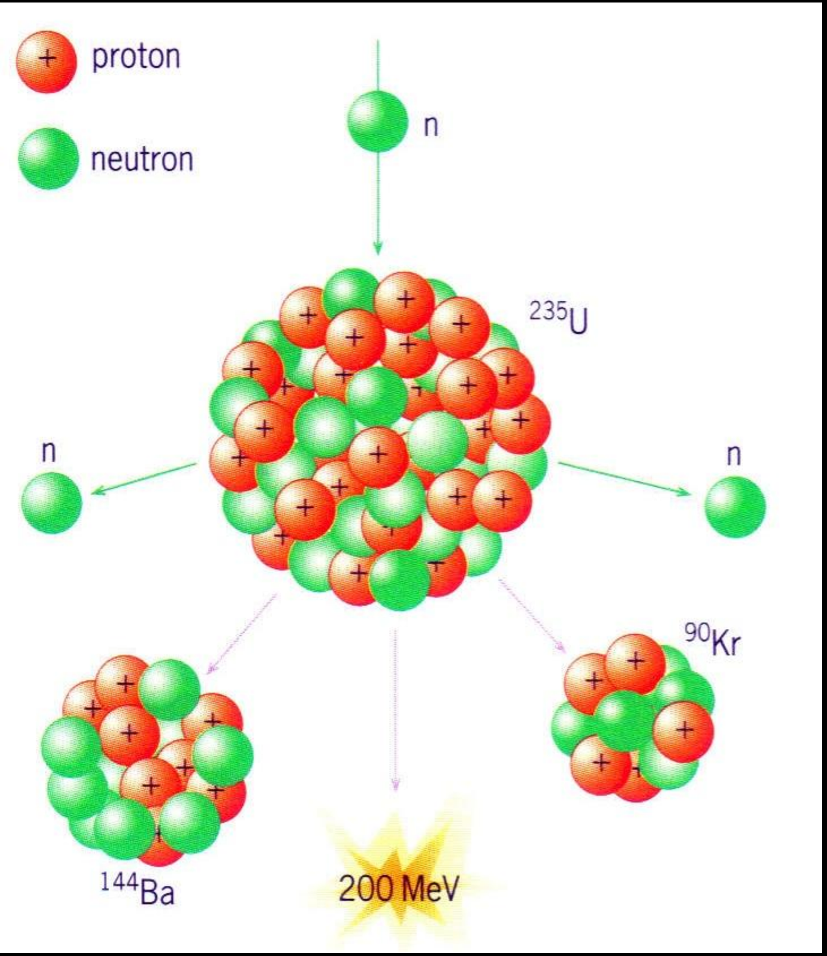


Spontaneous and induced fission

Spontaneous – occurs naturally

Induced – requires a ‘slow’ neutron to react with nucleus

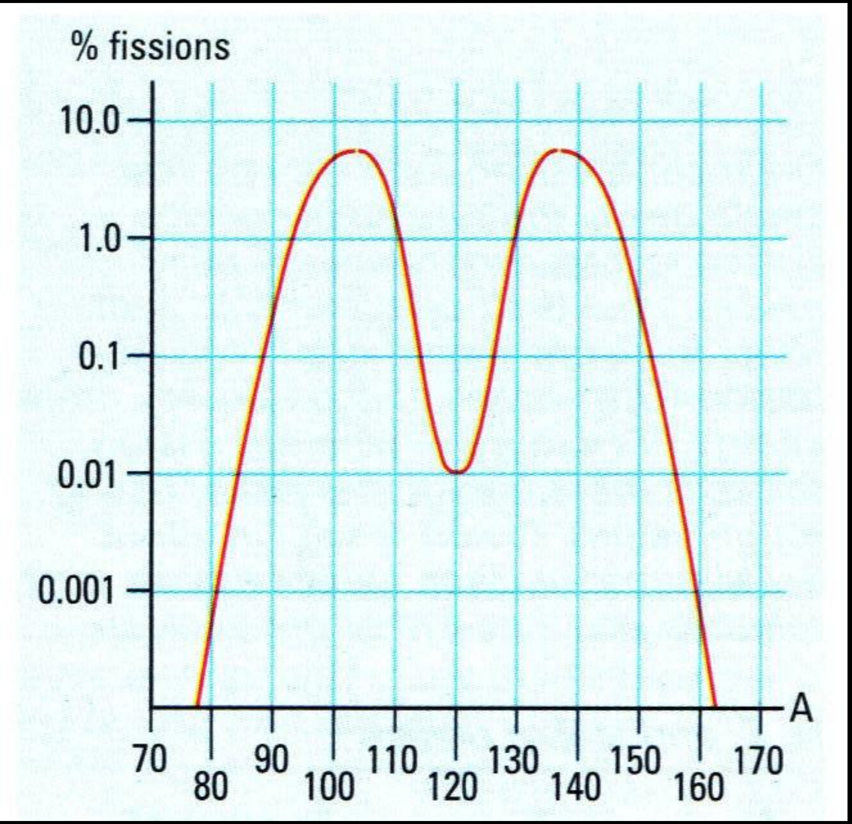
For fission, is only one nuclear transformation possible?



Fission fragments

Many different reactions are possible when U-235 fissions.

How much more probable is it that a fission product has an mass number of 110 than 85?

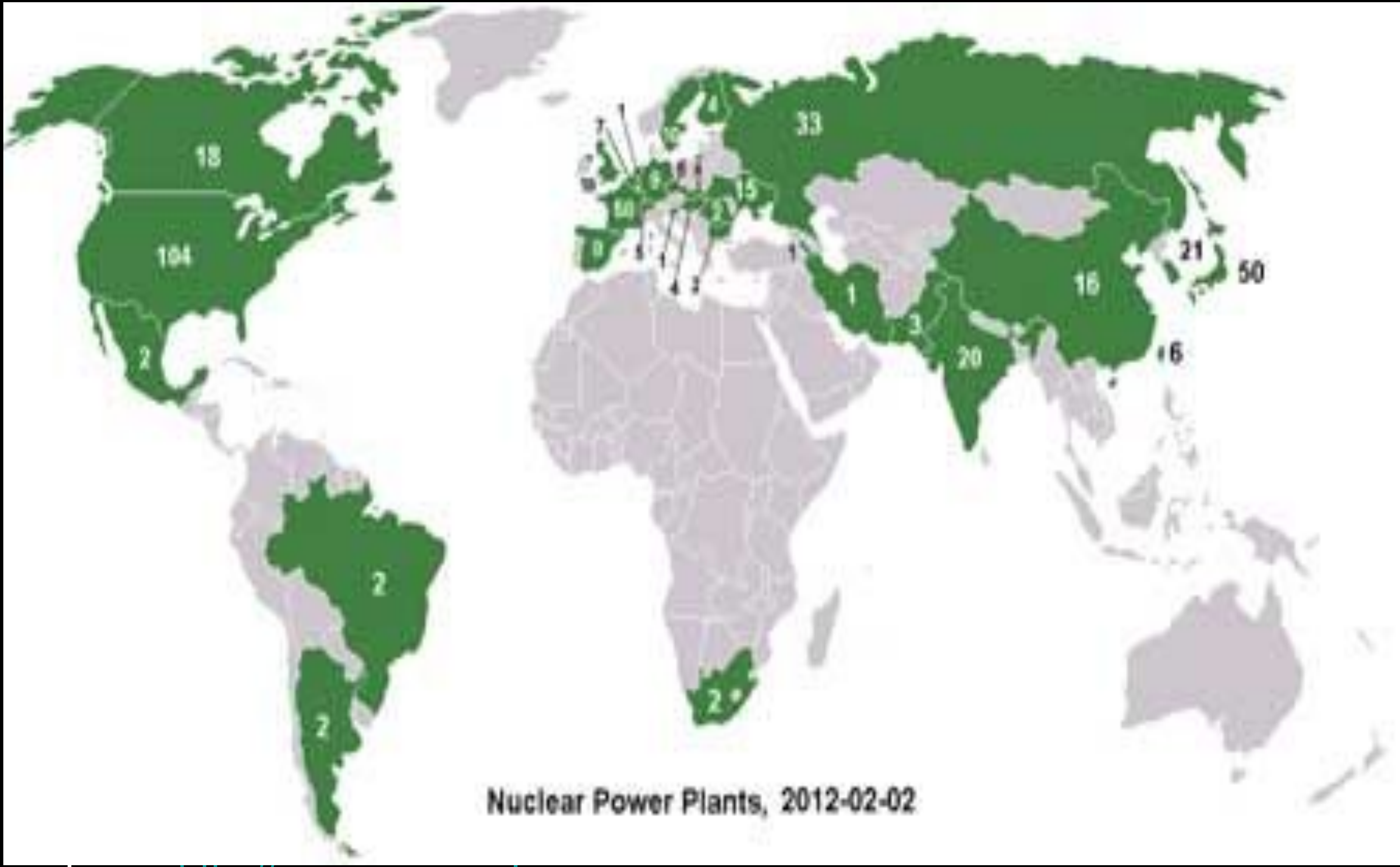


Example 3

a) A possible fission reaction is shown above. Given that the masses of U, La, Br and n are 235.1 u, 148.0 u, 84.90 u and 1.009 u respectively, how much energy in joules is released in each fission?

b) How many joules would be released if all the atoms in 10.00 kg of U-235 undergo fission?

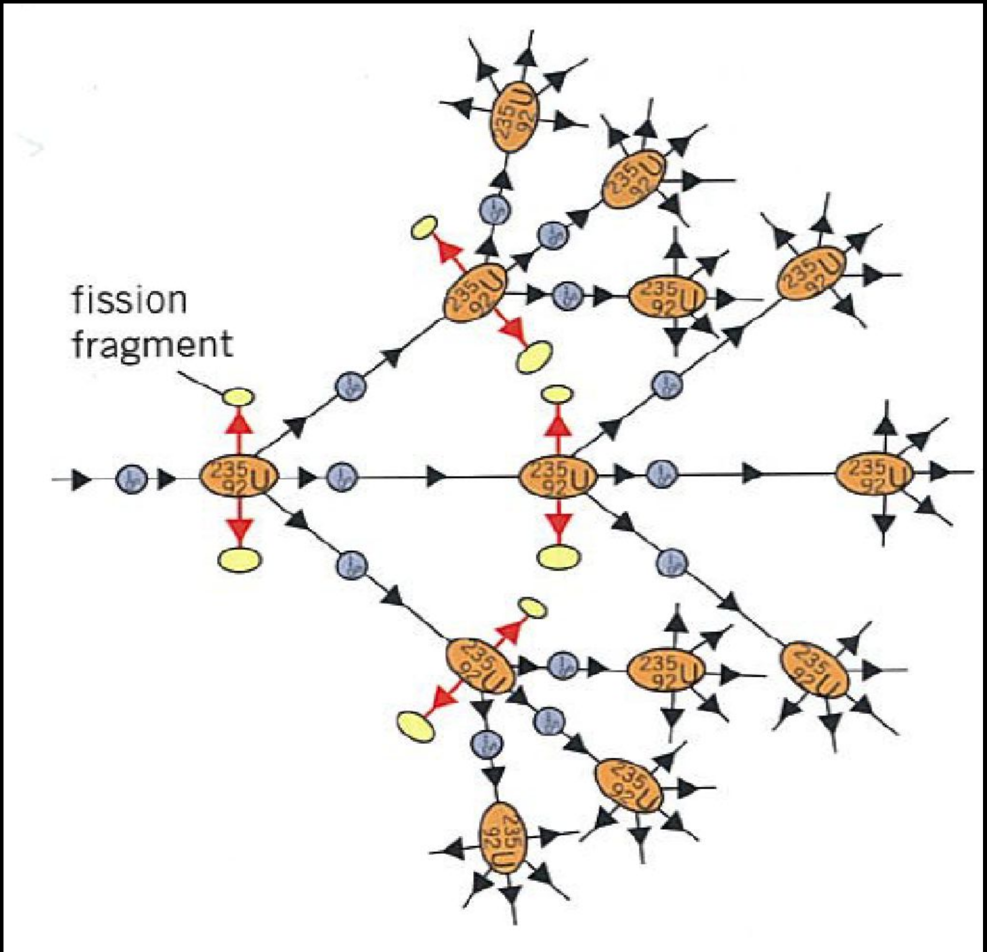
Some facts about reactors



• From: http://www.euronuclear.org

The 'controversial' business of neutrons

In fission, one slow neutron combines with U-235, causing the emission of two or more neutrons. In turn, these neutrons cause two fissions, etc

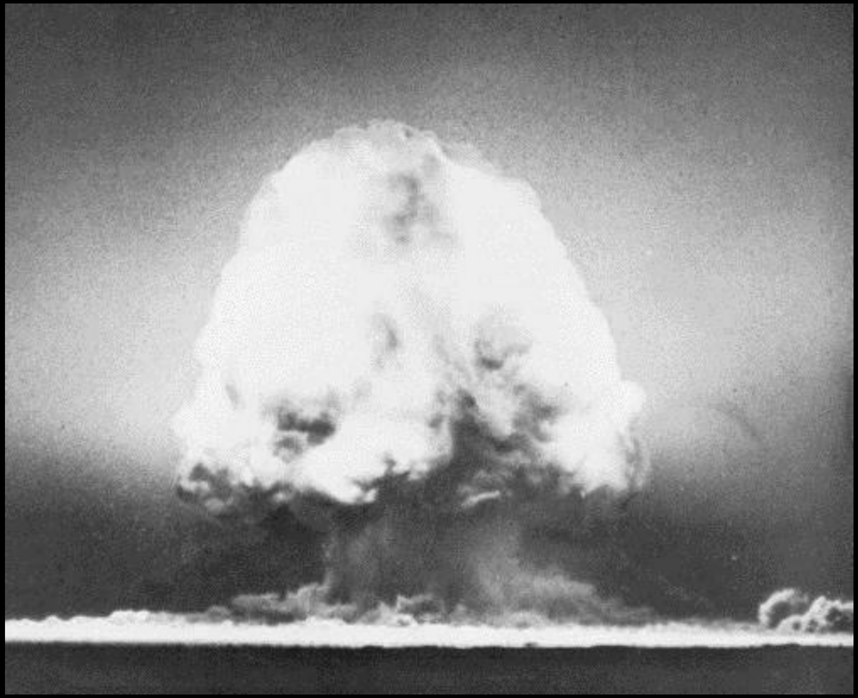


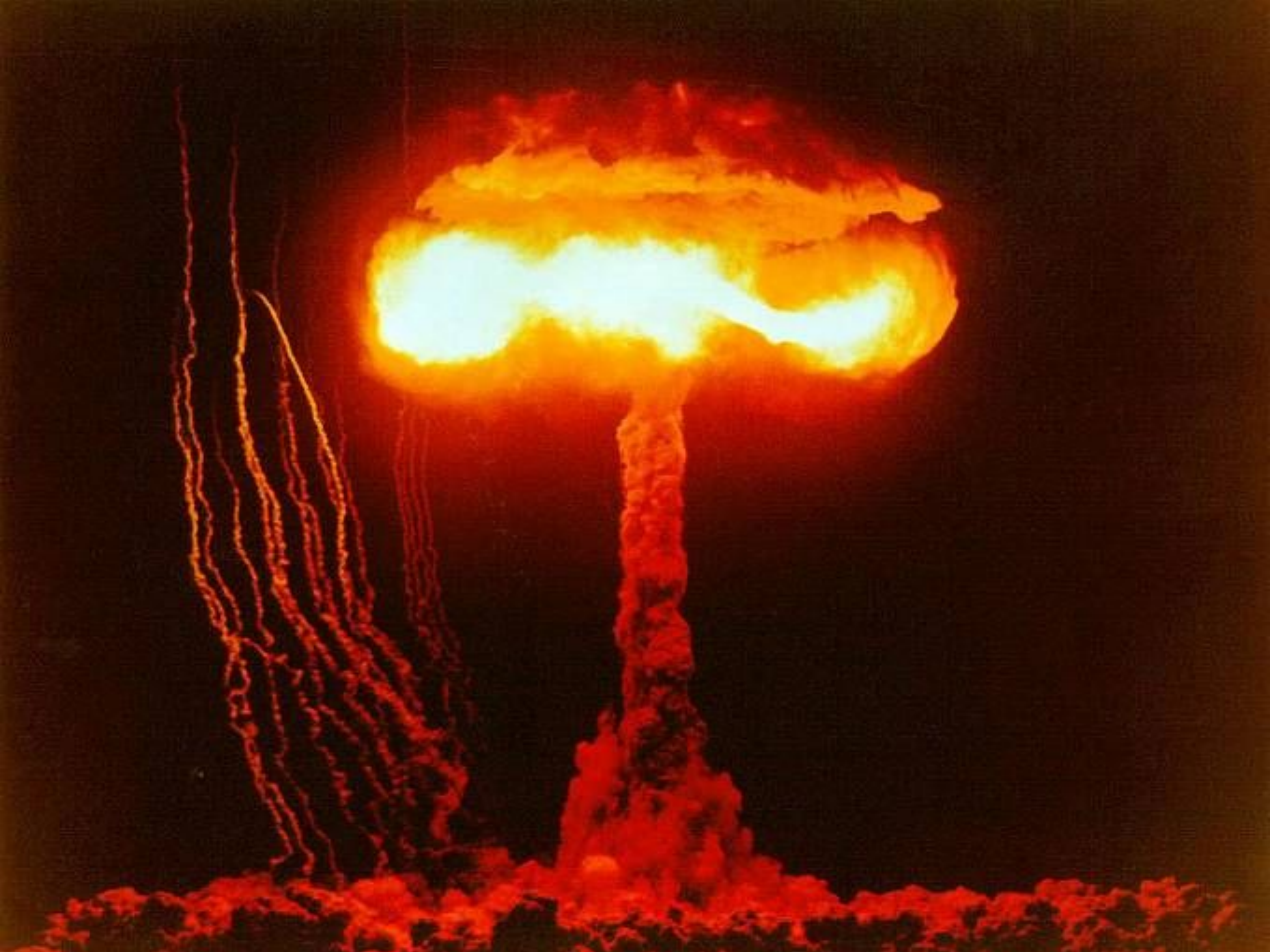
We obtain a ***chain reaction***

If uncontrolled in a large amount of U-235, a chain reaction leads to…

Why mushrooms?

Atomic bombs (using fission)

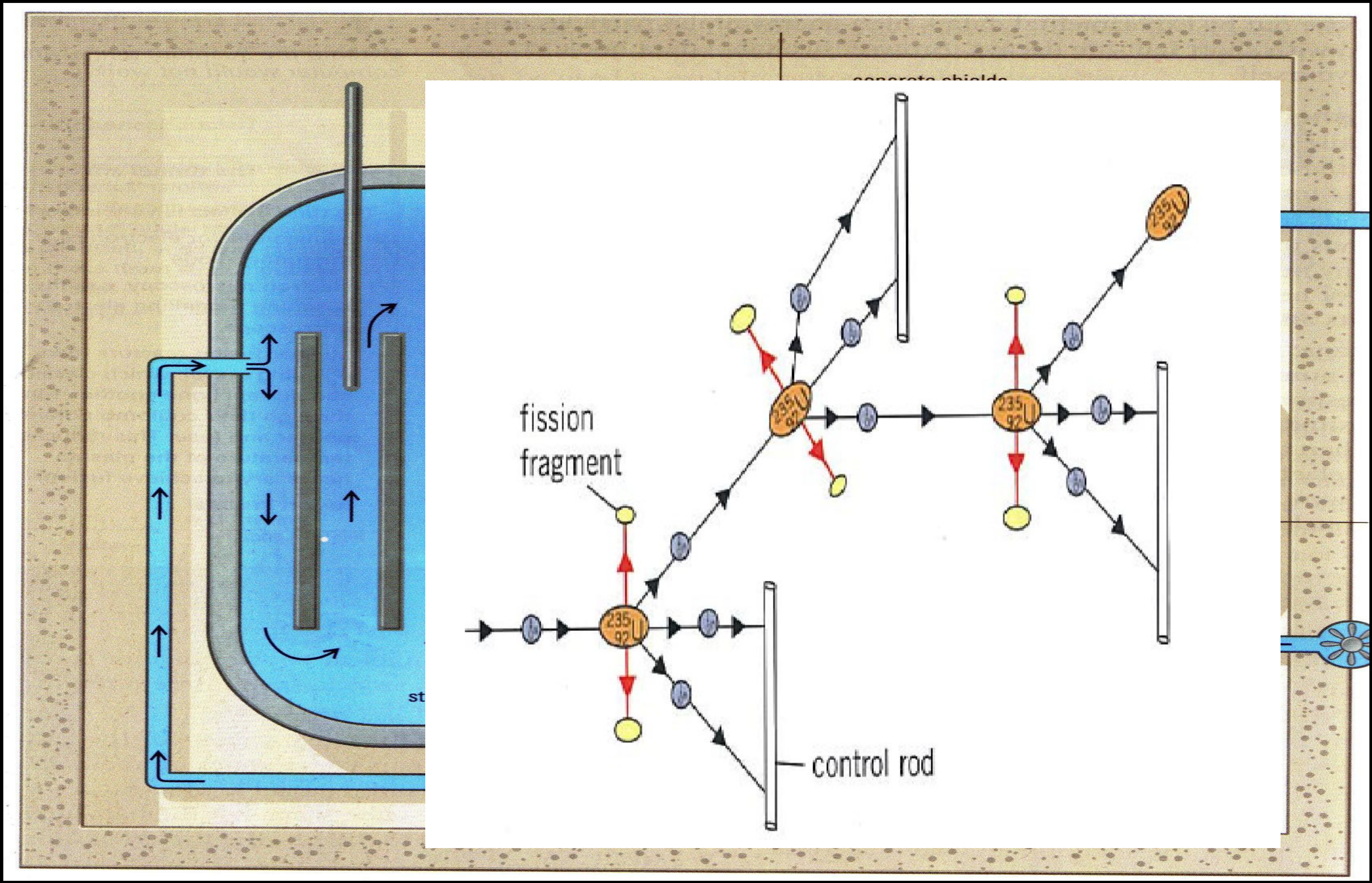




What do you know about the history of nuclear tests within Kazakh territory?

Semipalatinsk Test Site

Nuclear reactors - controlled fission



Fusion

Fusion occurs in the sun: the proton cycle.

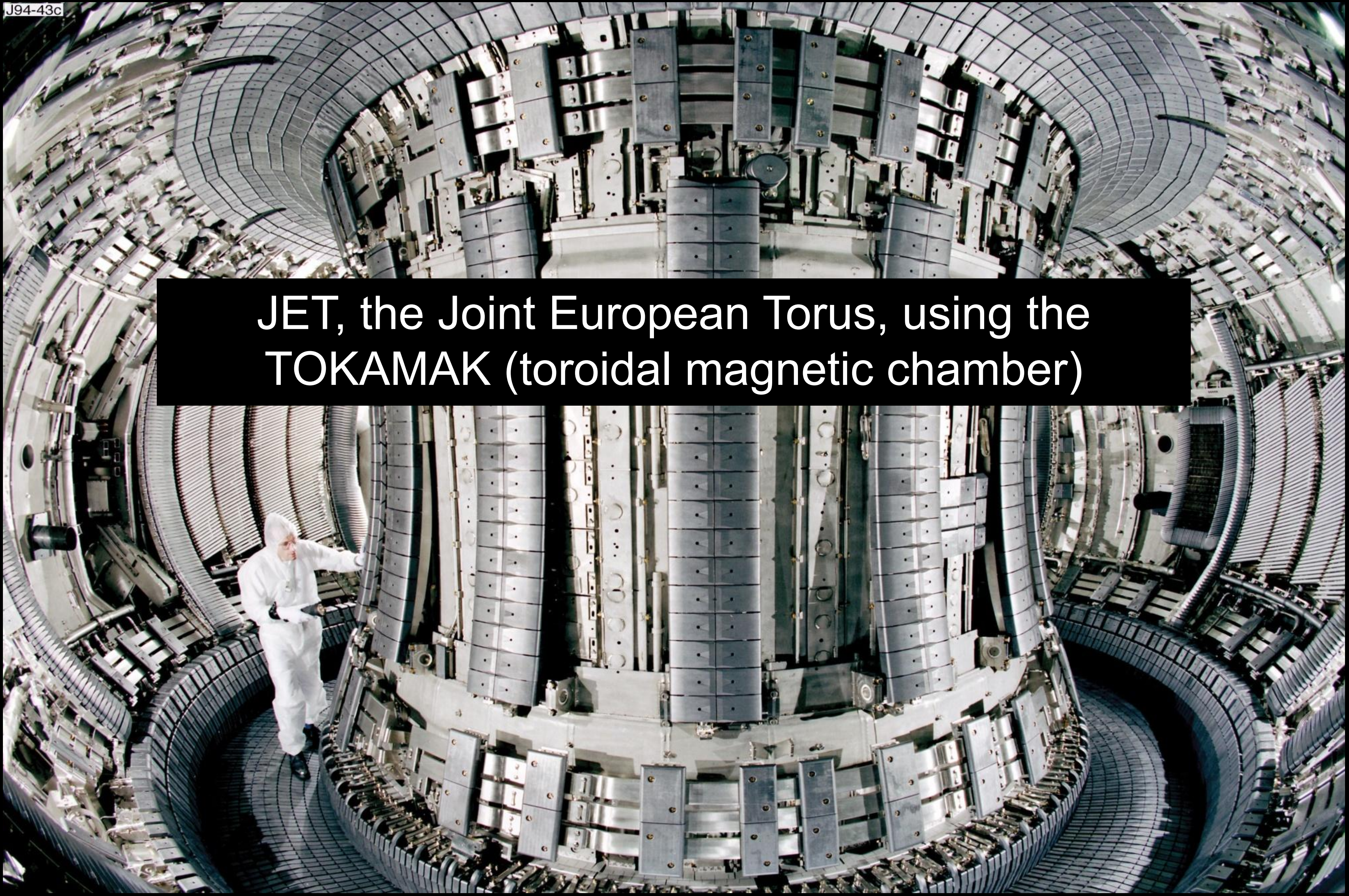
Fusion has been used in an uncontrolled way in the hydrogen bomb. A fission detonator was used to create high temperature and enable fusion.

A challenge for this century is to recreate and control fusion. One interesting reaction to use is:

$$ {}^{2}_{1}H + {}^{3}_{1}H + \longrightarrow {}^{4}_{2}He + {}^{1}_{0}n + Q $$

In this case Q is 18.0 MeV

Simulating fusion



JET, the Joint European Torus, using the TOKAMAK (toroidal magnetic chamber)

READING   Adams and Allday: 8.26 to 8.32, inclusive.

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Numerical Answers to Example Questions

- Ex 1) Equivalencies are $c^2 = 931$ MeV
  $c^2 = 1.49 \times 10^{-10}$ J
- Ex 2) Mass Defect = 0.029287 u (27.3 MeV)
- Ex 3) a) with mass defect 0.182 u, each fission releases 2.71×10^{-11} J (169 MeV)
  b) 10.0 kg of U 235 with complete fission releases 6.96×10^{14} J (4.33×10^{27} MeV)

Note: This is equivalent to 35 k tonnes of coal.