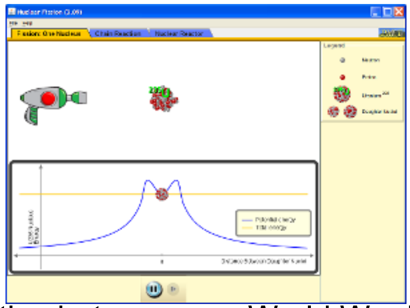
Nuclear Weapons (and Energy)



I know not with what weapons World War III will be fought, but World War IV will be fought with sticks and stones.

- A Einstein

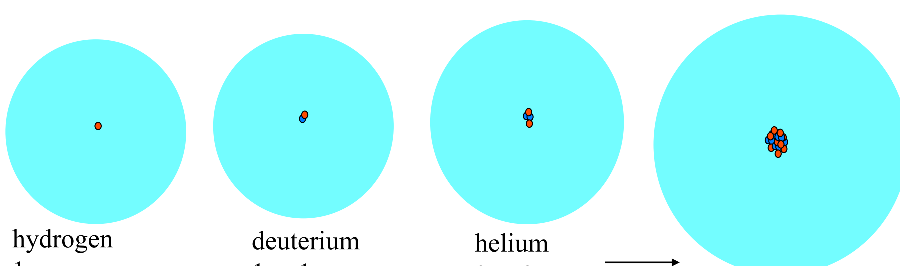
Phys 2130, Day 34:
Questions?
Nuclear Weapons and Energy

Reminders:
HW due Thurs…

Each element has different number of protons

Atom ingredients:

- Proton (**positive charge**) – charge = 1.6×10^{-19} Coulombs
  mass = 1.66×10^{-27} kg.
- Neutron (**no charge**) – no charge
  mass = 1.66×10^{-27} kg.
- Electron (**negative charge**) – charge = -1.6×10^{-19} Coulombs
  mass = 9.10×10^{-31} kg



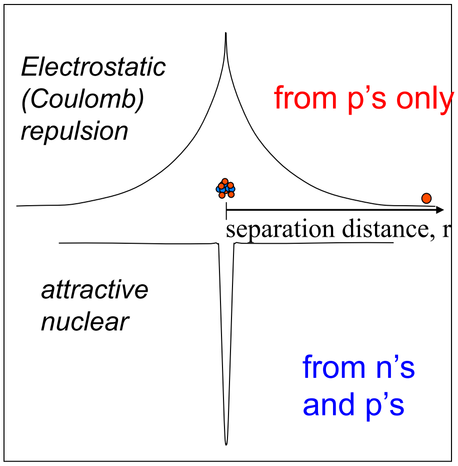
hydrogen
1 p

deuterium
1 p, 1n

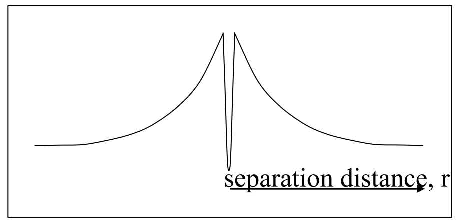
helium
2 p, 2 n

Uranium 238
92 p, 146 n

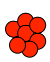
Potential energy curve for atoms



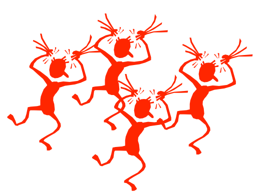
Superposition - real nucleus

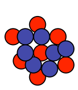


Stabilizing effect of neutrons in the nucleus …
why do you need them?

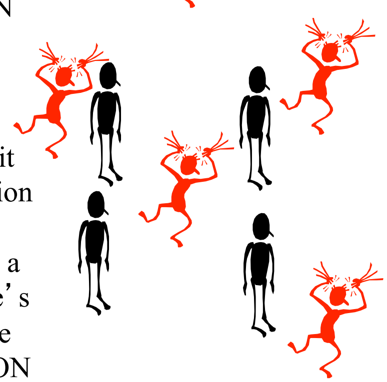


If only have big bunch of protons, proton repelling each other a whole bunch. Like putting a bunch of people who find each other repulsive in same room… UNSTABLE SITUATION





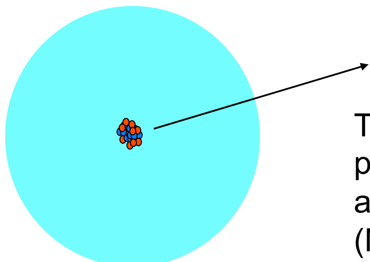
Add neutrons then space protons a bit away from each other, proton repulsion goes down a bit but still have strong nuclear binding forces. Like putting a bunch of neutral people between one's that find each other repulsive in same room… MORE STABLE SITUATION



Radioactive decay

- Proton (**positive charge**)
- Neutron (**no charge**)

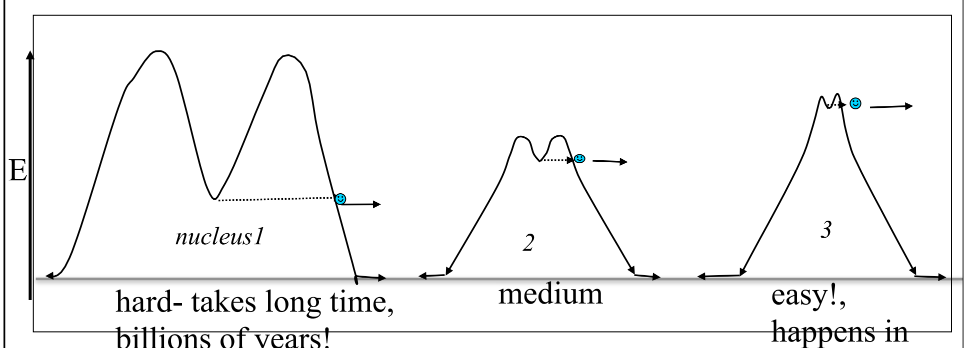
Radon-222
86 protons,
136 neutrons



In alpha-decay, an alpha-particle is emitted from the nucleus.

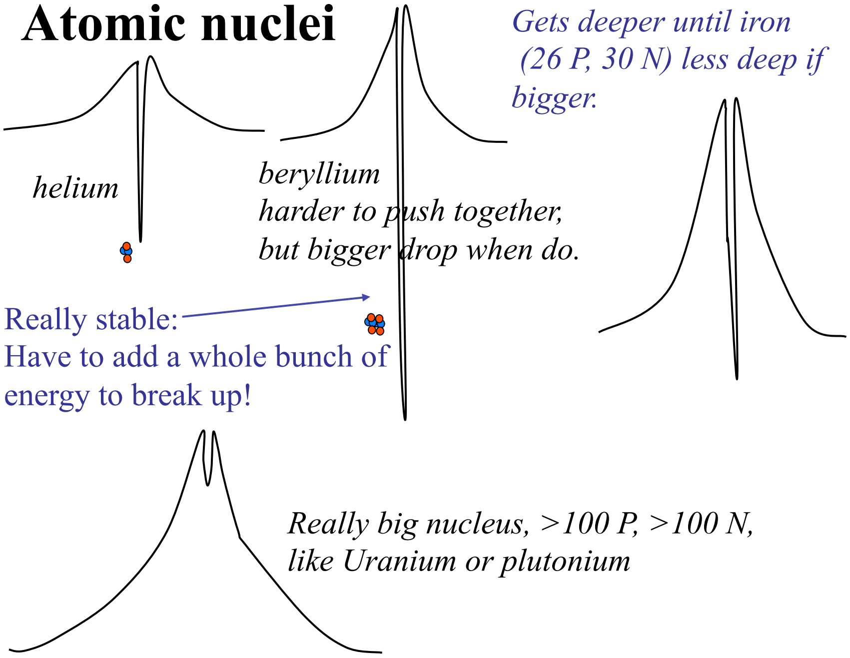
This raises the ratio of neutrons to protons … makes for a more stable atom.
(Neutron are neutral.. no coulomb repulsion, but nuclear force attraction)

Tunneling probability and energy release



How much energy released?
(A) 1 most, 2 second, 3 least
(B) 2 most, 1, 3 least
(C) 3 most, 2, 1 least
(D) 3 most, 1, 2 least

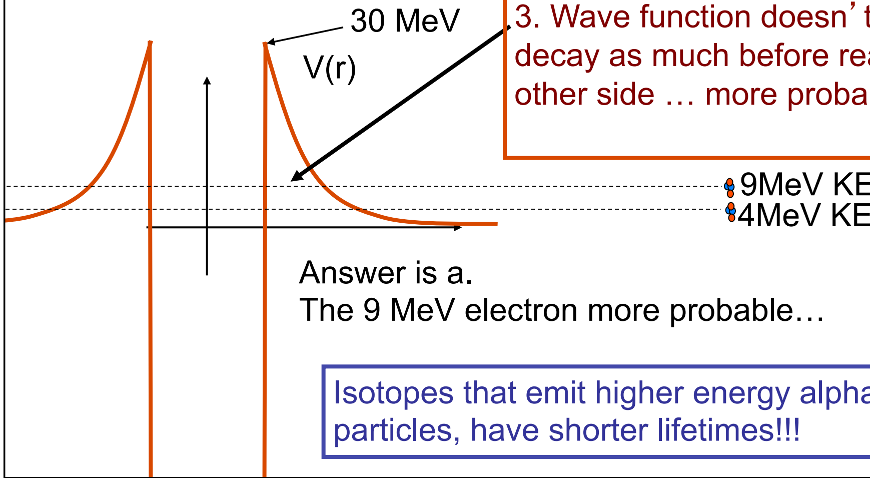
Atomic nuclei



Observe a particles from **different isotopes (same protons, different neutrons),** exit with different amounts of energy.

$$\alpha = \sqrt{\frac{2m}{\hbar^2}(V - E)}$$

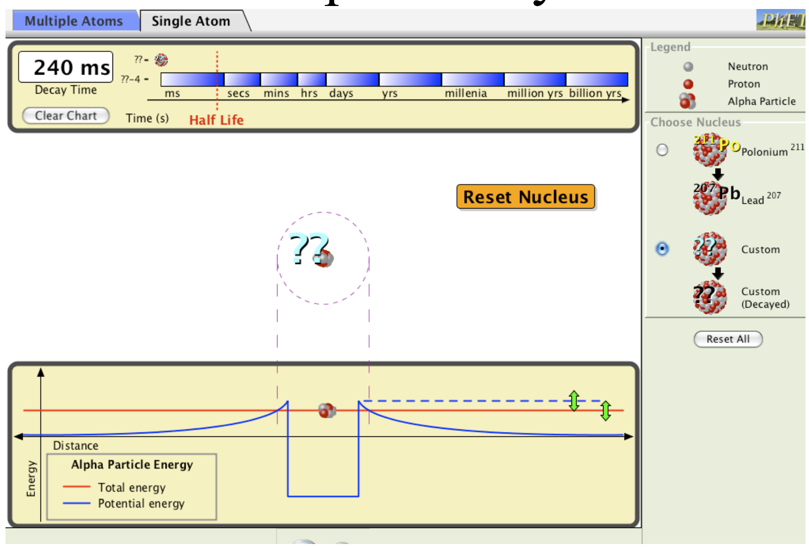
1. Less distance to tunnel,
2. Decay constant always smaller
3. Wave function doesn't decay as much before reaches other side … more probable!



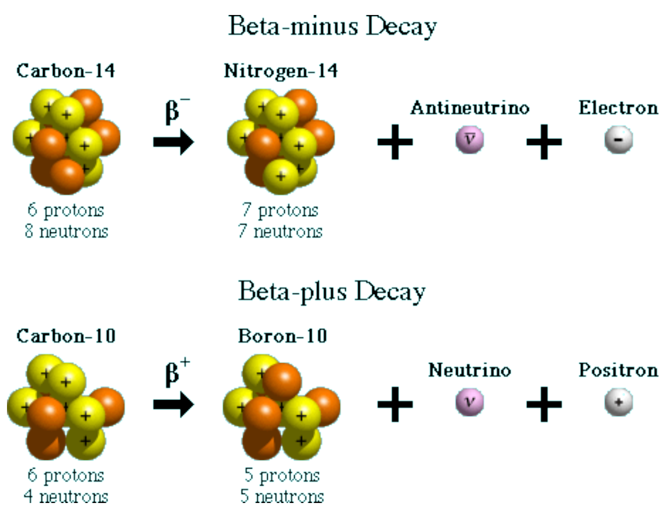
Answer is a.
The 9 MeV electron more probable…

Isotopes that emit higher energy alpha particles, have shorter lifetimes!!!

Alpha decay

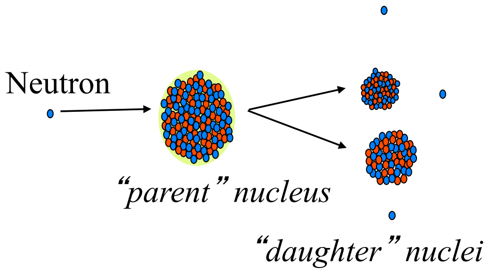


Other forms of decay: β-decay



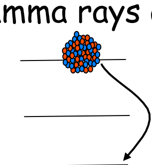
B. Radioactive decay-fission

Neutron Induced fission- key to atomic bombs



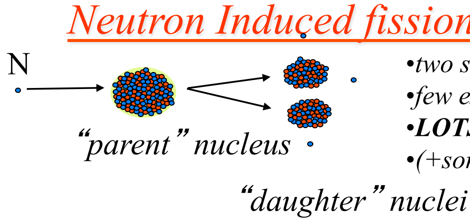
- *two smaller nuclei*
- *few extra free neutrons*
- ***LOTS OF ENERGY!!***
- *(+sometimes other bad stuff)*

"daughter" nuclei – come out in *excited* nuclear energy state
…. Give off gamma rays as drop to lower energy.



Jumps down in energy …
Gives off gamma ray…
VERY HIGH ENERGY PHOTON

Neutron Induced fission- key to atomic bombs



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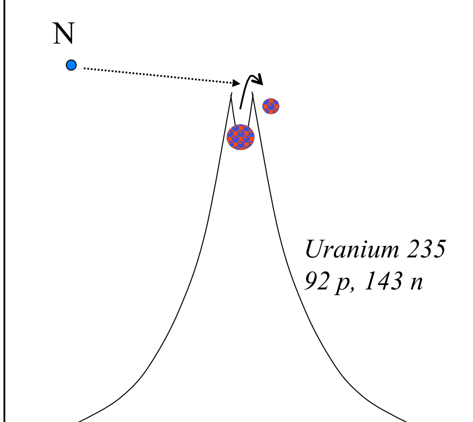
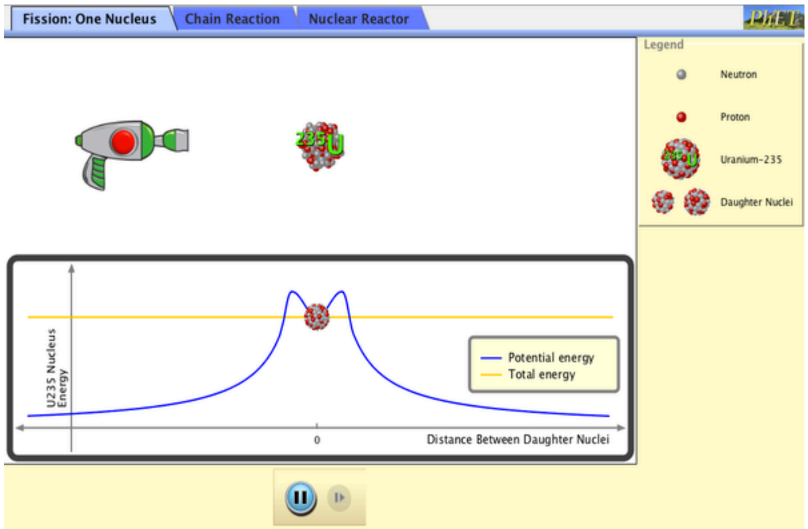


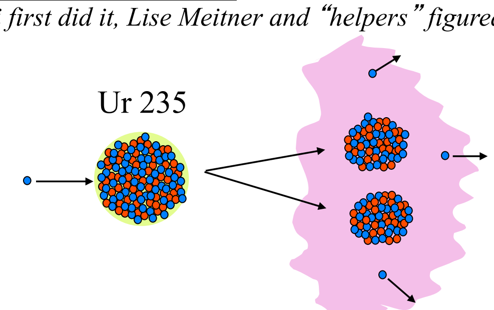
Neutron absorbed →
Excites U235 nucleus up above potential barrier →
Splits into two smaller nuclei…
which zoom apart due to electrostatic repulsion!

simulation



neutron induced fission

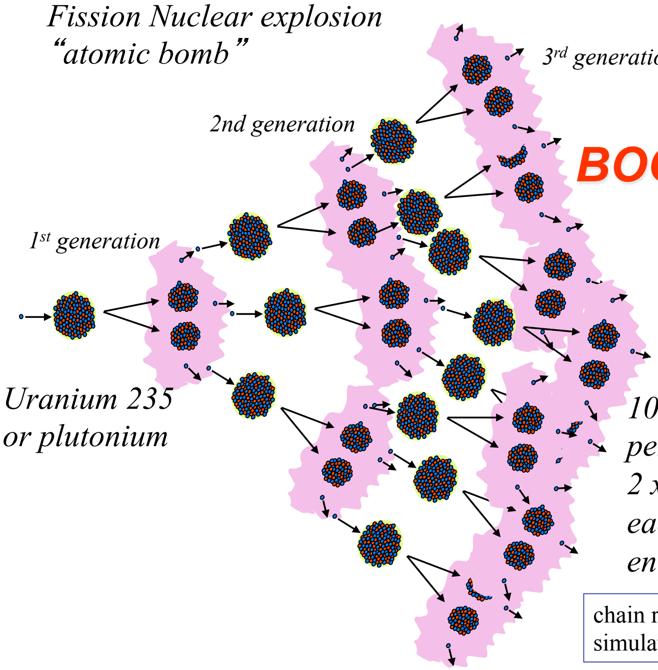
Fermi first did it, Lise Meitner and "helpers" figured out what was happening.



If don't get swallowed the 3 free neutrons can go induce more fission.

Chain reaction: neutrons making fission that makes more neutrons, that makes more fission that makes more neutrons, that makes more fission that makes more neutrons, that makes more fission that makes more neutrons, that makes more fission that makes more neutrons, that makes more fission that makes more neutrons, that makes more

Fission Nuclear explosion
"atomic bomb"

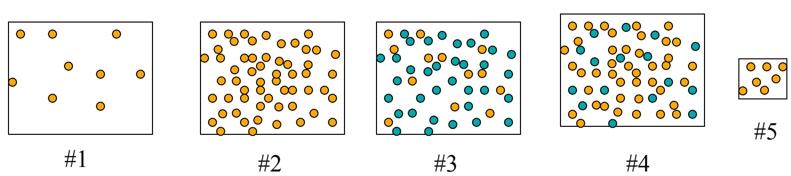


Uranium 235
or plutonium

100 generations
per microsecond!
2 x 2 x 2 ….x2 fissions
each with ***LOTS*** *of*
energy.

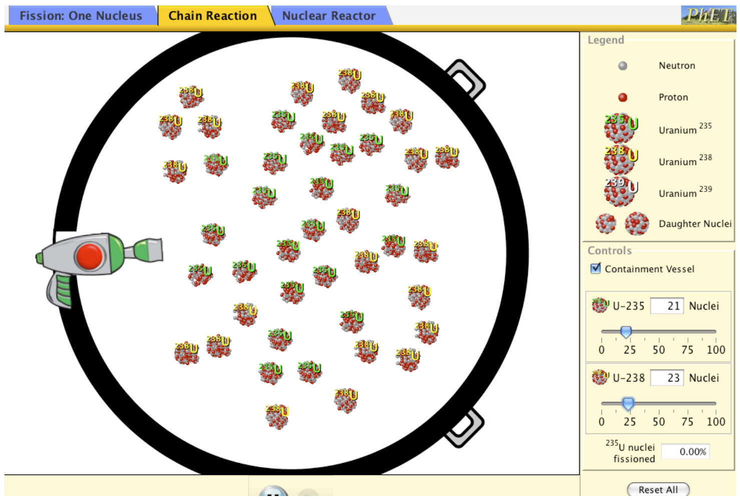
chain reaction
simulation

U235 and U238 atoms are placed into a container, which are likely to result in a chain reaction (resulting in explosion) when a free neutron triggers fission of one of the U235:



a. #2 only
b. #1, #2, and #5
c. #2 and #4
d. #2, #3, and #4
e. #2, #4, and #5.

A useful simulation



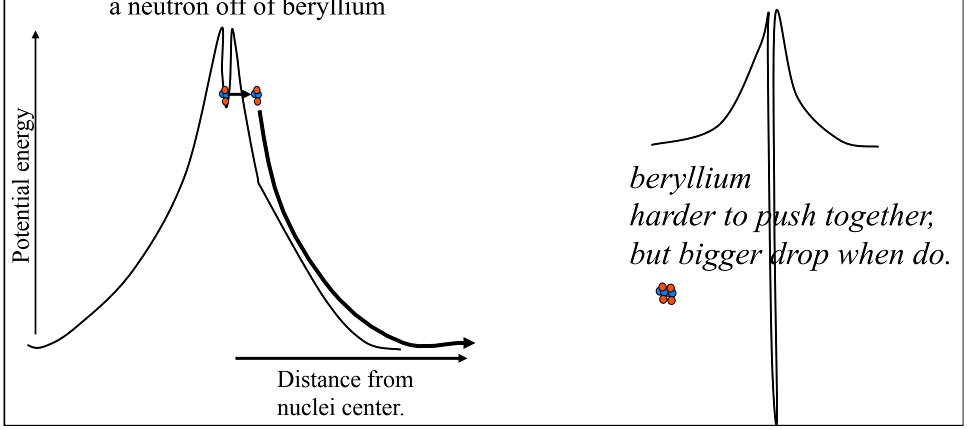
http://phet.colorado.edu/en/simulation/nuclear-fission

How to get ^{235}U?

The isotope ^{235}U (0.7%) may be separated from $^{natural}U$ by gaseous diffusion or centrifuges in large plants. The chemical compound used is UF_6, a corrosive gas.

Why use Beryllium as a neutron source for triggering fission bomb if so stable?
answer: good that stable… doesn't give off a neutron until you do something
What do you need to do to make it give off a neutron? …
Bombard with alpha particles from Polonium decay…

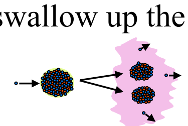
Polonium (84 p's, 125 n's):
Alpha particle (2 protons, 2 neutrons) tunnels out of well…. Zooms off and knocks a neutron off of beryllium



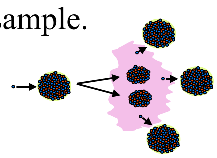
Recipe for fission bomb.

1. Find neutron induced fissionable material that produces bunch of extra free neutrons when fissions.

*2. Sift it well to remove all the other material that will harmlessly swallow up the extra neutrons. (THE HARDEST STEP.)



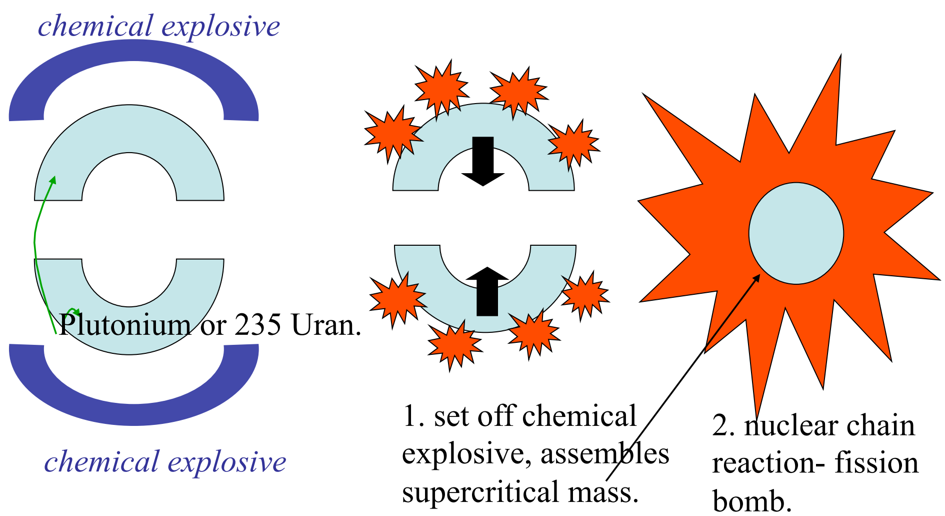
3. Assemble "supercritical mass", really fast!. Need enough stuff that the neutrons run into other nuclei rather than just harmlessly leaving sample.



If your mass tends to melt with a small fizzle you are not assembling fast enough to be supercritical. Put together faster.

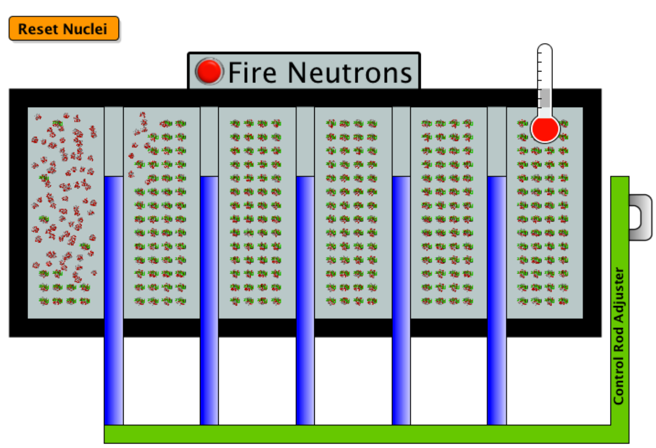
4. Let sit for 1 millionth of a second- will bake itself!

Fission bomb (basic picture)



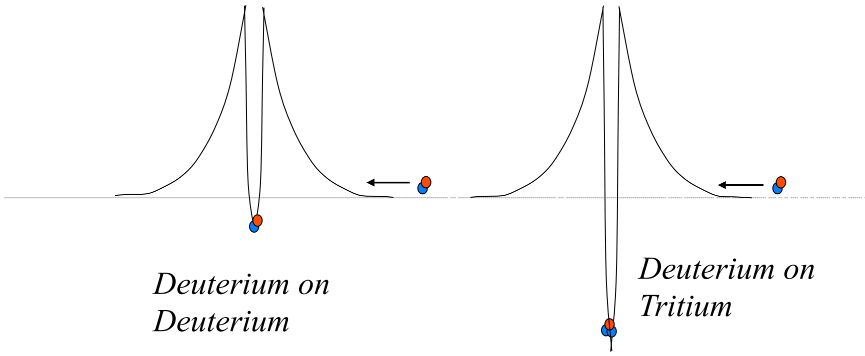
Nuclear Reactor Sim

http://phet.colorado.edu/en/simulation/nuclear-fission



Fusion bomb or "hydrogen bomb"

Basic process like in sun. Stick small nuclei together.



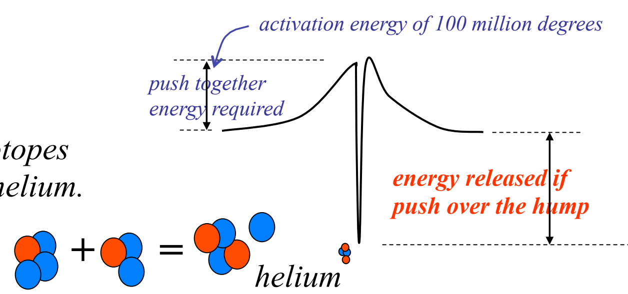
Which will release more energy during fusion?

a. Deuterium combining with deuterium
b. Deuterium combining with tritium

Fusion bomb or "hydrogen bomb"

Basic process like in sun. Stick small nuclei together.

Stick hydrogen isotopes together to make helium.

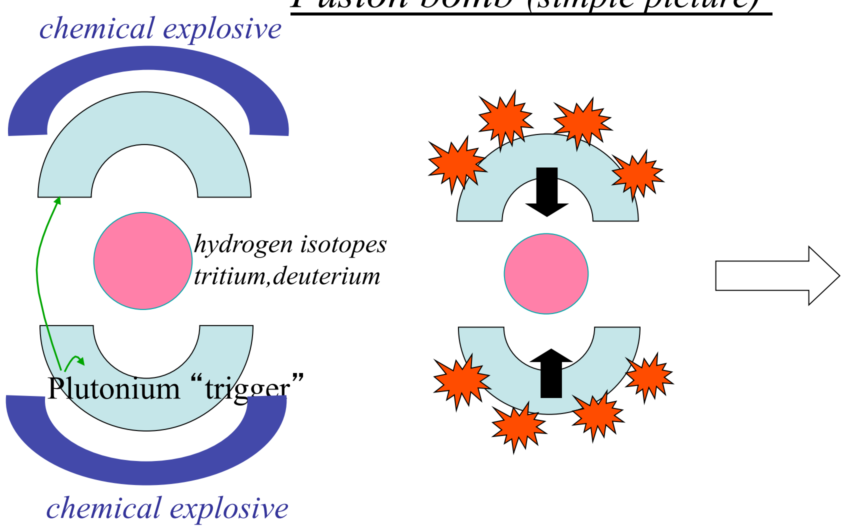


Simple if can push hard enough- just use sun or fission bomb.
More energy per atom than fission. Can use LOTS of hydrogen.

⇒End up with GIGANTIC bombs

1000 times bigger than first fission bombs

Fusion bomb (simple picture)



Shaped plutonium and assembled bombs at Rocky Flats.

Energy:

1 fission of Uranium 235 releases:
$\sim 10^{-11}$ Joules of energy

1 fusion event of 2 hydrogen atoms:
$\sim 10^{-13}$ Joules of energy

Burning 1 molecule of TNT releases:
$\sim 10^{-18}$ Joules of energy

1 green photon:
$\sim 10^{-19}$ Joules of energy

Dropping 1 quart of water 4 inches ~ 1J of energy
Useful exercise… compare this volume of TNT, H2, and U235

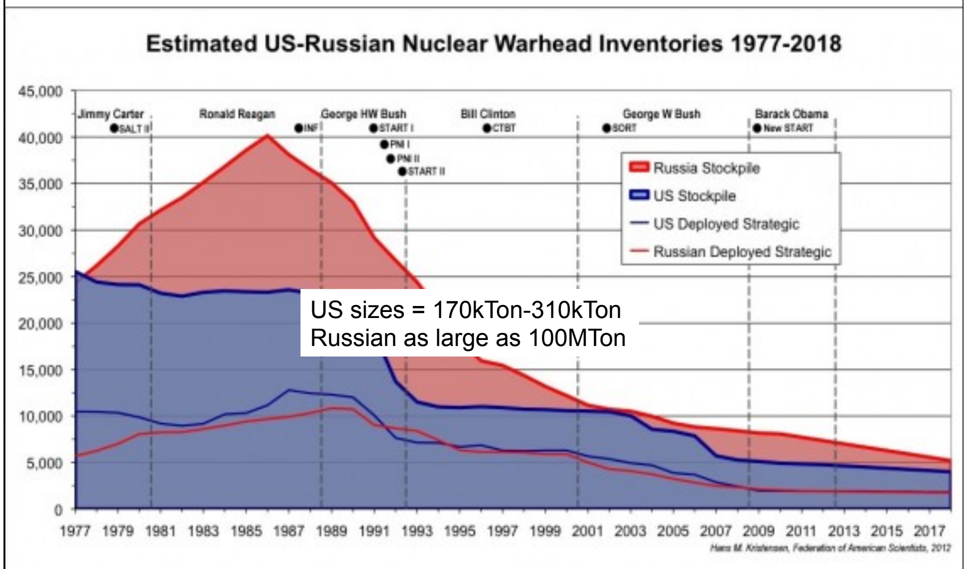
In the first plutonium bomb a 6.1 kg sphere of plutonium was used and the explosion produced the energy equivalent of 22 ktons of TNT = 8.8×10^{13} J.

17% of the plutonium atoms underwent fission.

How long would this power your house?

How much power (energy / sec) do you use?

US Nuclear weapons



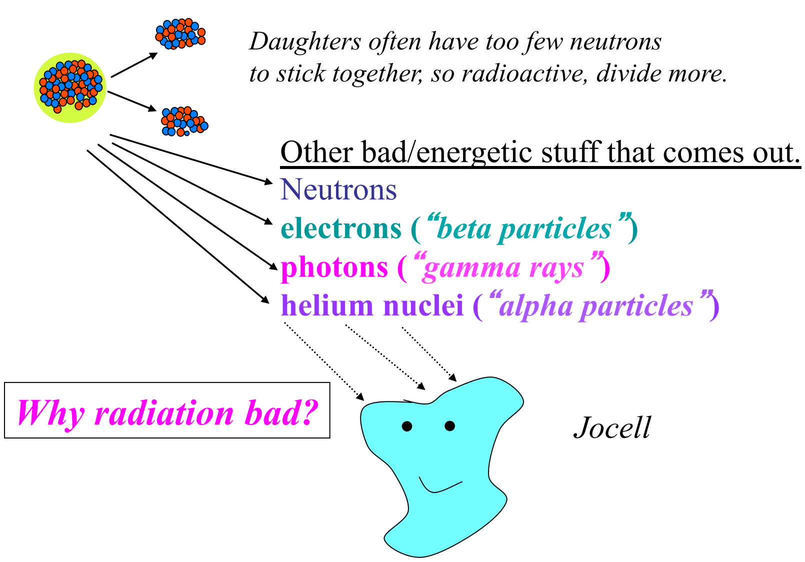
US sizes = 170kTon-310kTon
Russian as large as 100MTon

Fission bomb- ***chain reaction, hideous amounts of energy comes off as heat and high energy particles (electrons, neutrons, x-rays, gamma rays) "Radiation". Heats up air that blows things down.***

In atomic bomb, roughly 20% of Pl or Ur decays by induced fiss.
This means that after explosion there are

a. about 20% fewer atomic nuclei than before with correspondingly fewer total neutrons and protons,
b. 20% fewer at. nucl. but about same total neut. and protons.
c. about same total neutrons and protons and more atomic nuclei,
d. almost no atomic nuclei left, just whole bunch of isolated Neut.s and prot.s.,
e. almost nothing of Ur or Pl left, all went into energy.

Radioactive materials and "radiation"



Measuring “Radioactivity” & the Discovery of Radium and Polonium

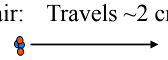
“One of our joys was to go into our workroom at night; we then perceived on all sides the feebly luminous silhouettes of the bottles or capsules containing our products. It was really a lovely sight and one always new to us. The glowing tubes looked like faint, fairy lights.”

-Marie Curie,
Nobel Prize Physics 1903,
Nobel Prize Chemistry 1911

Alpha particles: helium nuclei

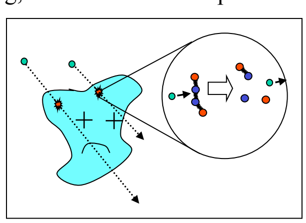
- most of radiation is this type
- common is Radon (comes from natural decay process of U^{238}), only really bad because Radon is a gas .. Gets into lungs, if decays there bad for cell.

In air: Travels ~2 cm ionizing air molecules and slowing down …



eventually turns into He atom with electrons

If decays in lung, hits cell and busts up DNA and other molecules:

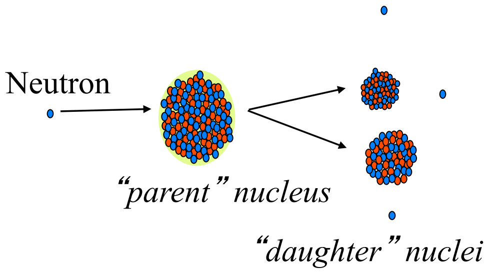


Usually doesn’t get far -- because it hits things

Beta particles:

energetic electrons … behavior similar to alpha particles, but smaller and higher energy

Sources of Gamma Radiation



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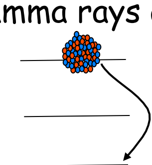
"daughter" nuclei – come out in *excited* nuclear energy state
…. Give off gamma rays as drop to lower energy.

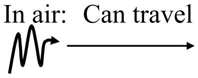


Jumps down in energy …
Gives off gamma ray…
VERY HIGH ENERGY PHOTON

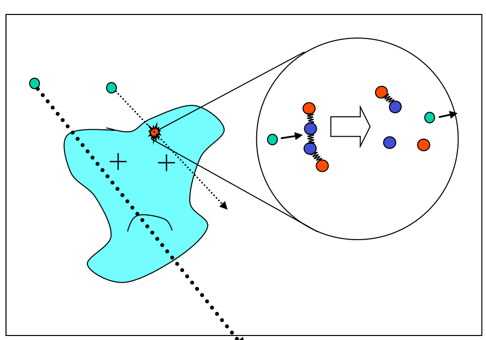
gamma rays: high-energy photons

- So high energy can pass through things (walls, your body) without being absorbed, but if absorbed really bad!

In air: Can travel long distances until absorbed



In body, *if* absorbed by DNA or other molecule in cell …
damages cell… can lead to cancer.



Most likely

If pass through without interacting with
anything in cell then no damage.

An odd world…

You find yourself in some diabolical plot where you are given an alpha (α) source, beta (β) source, and gamma (γ) source. You must eat one, put one in your pocket and hold one in your hand. You …

a) α hand, β pocket, γ eat
b) β hand, γ pocket, α eat
c) γ hand, α pocket, β eat
d) β hand, α pocket, γ eat
e) α hand, γ pocket, β eat