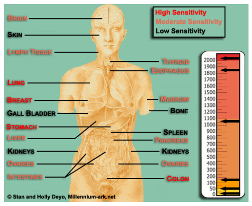
Class 14: Nuclear Weapons: fusion, radiation



Phys 1010, Day 14:
Questions?
Nuclear Reactors Blmfld 16.2

Reminders:
MidTerm next Thurs
HW Mon
HR Mon & Wed?

Some Admin.

- Midterm in 1 week
  - Info posted on web by Sat latest
  - Similar format /structure as previous
- Honor Code
  - HW should be your own
  - Collaboration is encouraged
  - HW should be your own

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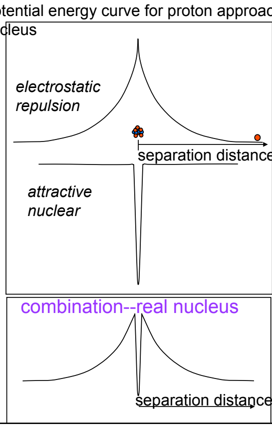
Potential energy curve for proton approaching nucleus



Energy scale gigantic compared to chemical energy.
Why? Simple coulomb's law.

$F = k \frac{(\text{charge of \#1})(\text{charge of \#2})}{r^2}$

Chemistry- forces between electrons and protons on distance scale of atomic size (> 10^{-10} m).

Nuclear forces- forces between protons on distance scale 10-100,000 times smaller. 10,000 times closer means forces **100,000,000 times bigger** because of $1/r^2$. Lots

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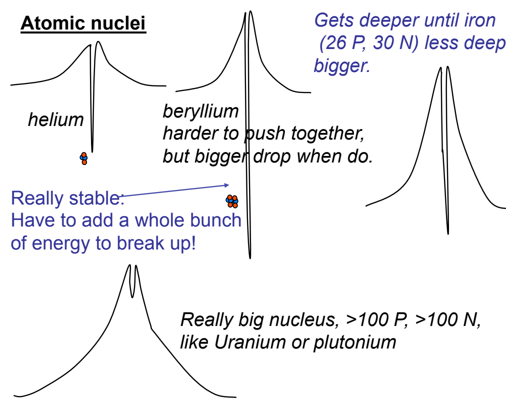
Atomic nuclei



Gets deeper until iron (26 P, 30 N) less deep if bigger.

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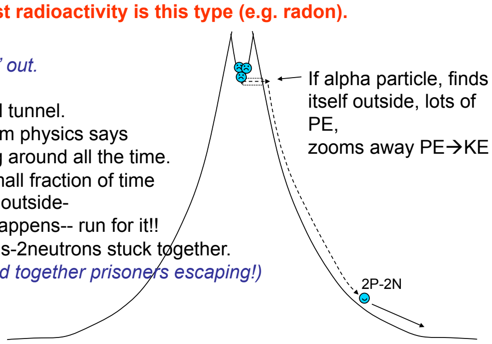
Nuclear decay- one kind of nucleus changes into another.
alpha decay, (beta decay), induced fission

A. alpha decay- alpha particle = 2p and 2n. They escape togeth
Most radioactivity is this type (e.g. radon).

"tunnel" out.

Not real tunnel.
Quantum physics says jumping around all the time.
Very small fraction of time appear outside-
when happens-- run for it!!
2protons-2neutrons stuck together.
(chained together prisoners escaping!)



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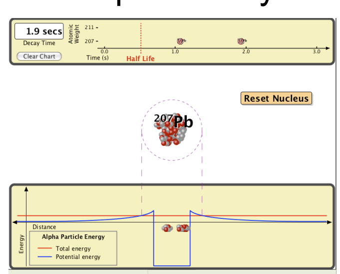
A useful simulation alpha decay



http://phet.colorado.edu/simulations/sims.php?sim=Alpha_Decay

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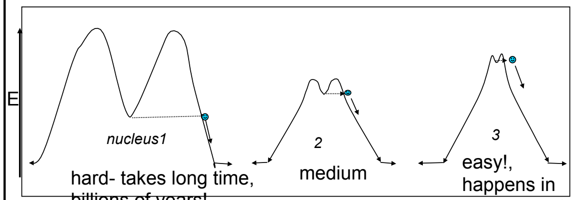
tunneling difficulty = width x depth of tunnel



hard- takes long time, billions of years!

medium

easy!, happens in millionths of a second!

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

energy is difference from bottom of crater to outside. 3 is most, 2 second, 1 is least

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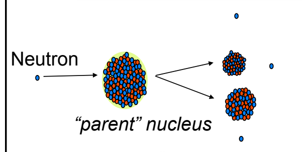
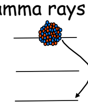
B. Radioactive decay-fission

Neutron Induced fission- key to atomic bomb



- •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

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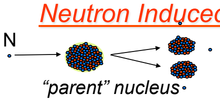
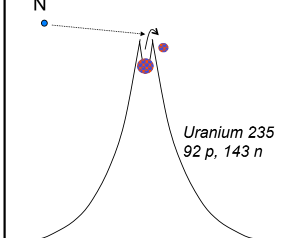
Neutron Induced fission- key to atomic bomb



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



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

simulation

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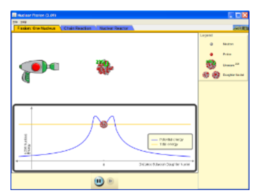
Another Sim

(because this is hard to do at home)



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

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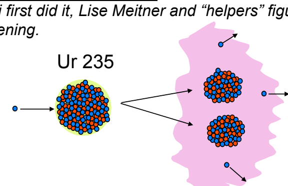
neutron induced fission

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



If don't get swallowed the 3 free neutrons can g 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 mo neutrons, that makes more fission that makes more neutrons, that makes mo

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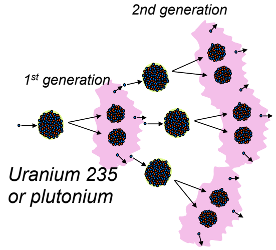
Fission Nuclear explosion
"atomic bomb"



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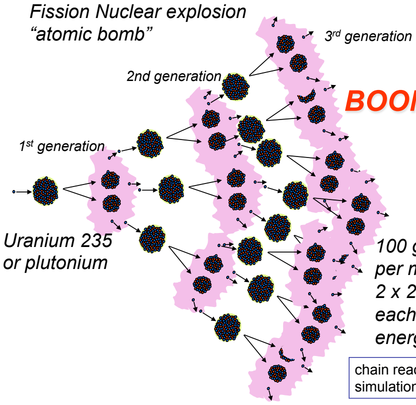
Fission Nuclear explosion
"atomic bomb"



Uranium 235
or plutonium

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

chain reaction simulation

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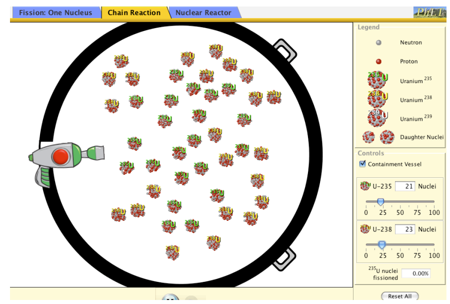
A useful simulation



http://phet.colorado.edu/simulations/sims.php?sim=Nuclear_Fission

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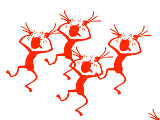
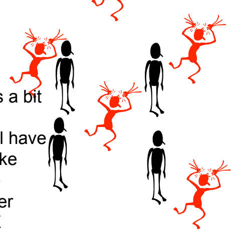
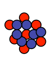
Stabilizing effect of neutrons in the nucleus …
why do you need them?

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

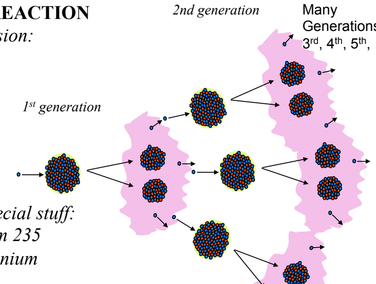






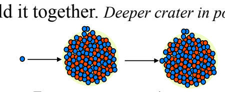
Add neutrons then space protons a bit away from each other, proton repulsion goes down a bit but still have strong nuclear binding forces. Like putting a bunch of neutral people between one's that find each other repulsive in same room… MORE STABLE SITUATION

BACK TO CHAIN REACTION
Fission Nuclear explosion:
"atomic bomb"

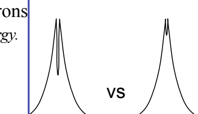


Very special stuff:
Uranium 235
or plutonium

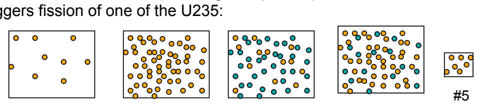
Why Ur 235 not 238? U 238 has 3 extra neutrons help hold it together. *Deeper crater in potential energy.*



Eats extra neutrons!



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.

Lots of uranium in the ground… why not just blow up?

Correct answer is c. (#2 and #4) Analysis:
#1 is too sparse .. most neutrons will leave box before hitting another U235.
#2 is good.. Pure U235, densely packed, large package
#3 has too many U238's… more U238's than 235's. Free neutrons more likely to be absorbed by 238's than to hit and fission another 235.
#4 is OK … More U235's than 238's, still densely packed, large package
#5 is too small of package … neutrons likely to escape package before hitting another U235.

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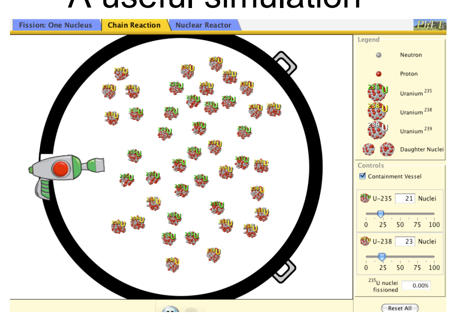
A useful simulation



http://phet.colorado.edu/simulations/sims.php?sim=Nuclear_Fission

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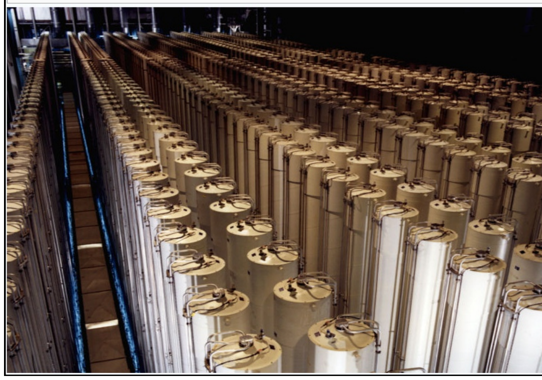
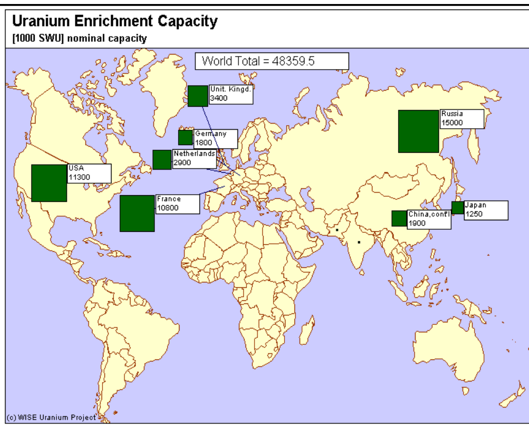
The hardest part of getting a nuclear bomb is the material
"Front End"
- obtain ^{235}U (HEU=at least 80%) by exactly the same methods used to make Low Enriched Uranium (LEU), typically 3-4%.

"Back End"
- obtain ^{239}Pu from Spent Nuclear Fuel by chemical reprocessing

Image:Gas centrifuge cascade.jpg

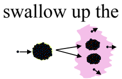




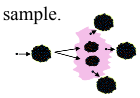
Recipe for fission bomb.

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.)



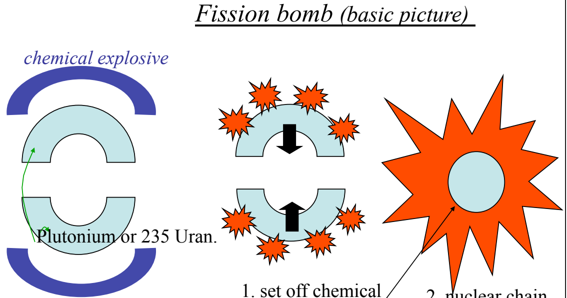
3. Assemble "supercritical mass", really fast!. Need enough stuff that the neutrons run into other nuclei rather than just harmlessly leaving sample.



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

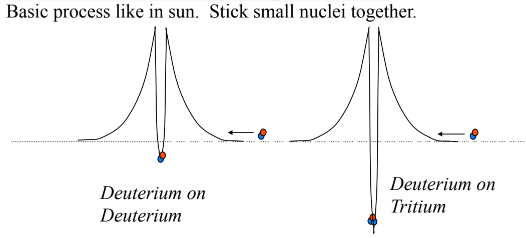
4. Let sit for 1 millionth of a second- will bake itself!

Fission bomb (basic picture)



Fusion bomb or "hydrogen bomb"

Basic process like in sun. Stick small nuclei together.



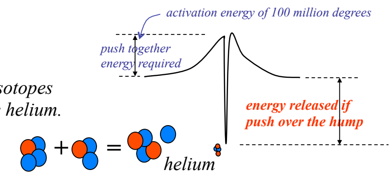
Which will release more energy during fusion?
a. Deuterium combining with deuterium
b. Deuterium combining with tritium

Answer is b. Incoming deuterium particle has comparatively more potential energy!

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

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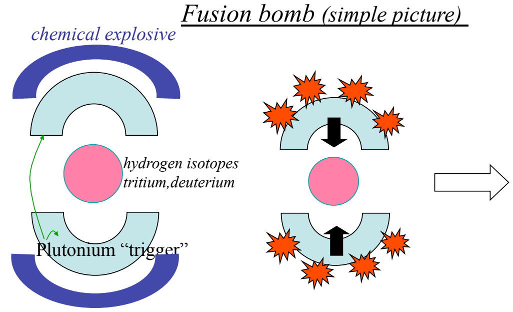
Fusion bomb (simple picture)



Shaped plutonium and assembled bombs at Rocky Flats.

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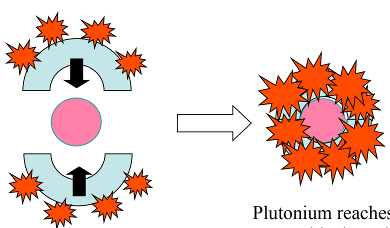

Plutonium reaches
supercritical, explodes.
(fission bomb)

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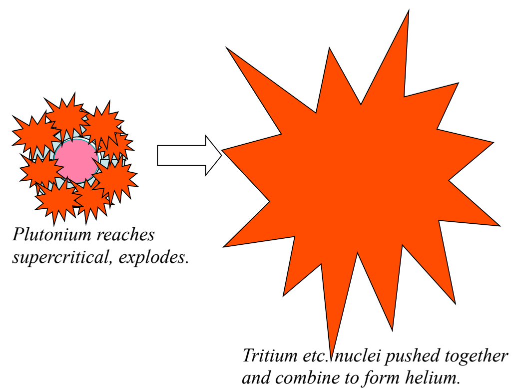

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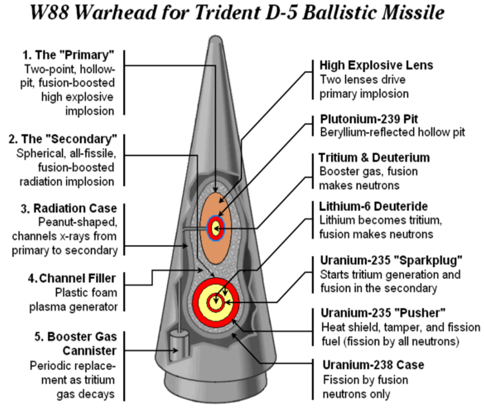
W88 Warhead for Trident D-5 Ballistic Missile



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

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

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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.

How does 6.1 kg relate to 22 ktons?

As the textbook says, 17% of the plutonium atoms underwent fission.

How long would this power your house?

How much power (energy / sec) do you use?
e.g. 10 x 100W light bulbs? Or 100x 100W?
(use your energy bill)
1000W = 1000 J / sec.
8.8×10^{13} J / (1000 J /s) = ?? sec

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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 fission
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.

ans. c. Makes and spreads around lots of weird radioactive "daughter" nuclei (iodine etc.) that can be absorbed by people and plants and decay slowly giving off damaging radiation.
Lots of free neutrons directly from explosion can also induce radioactivity in some other nuclei.

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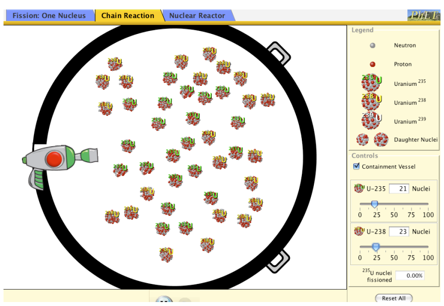
A useful simulation



http://phet.colorado.edu/simulations/sims.php?sim=Nuclear_Fission

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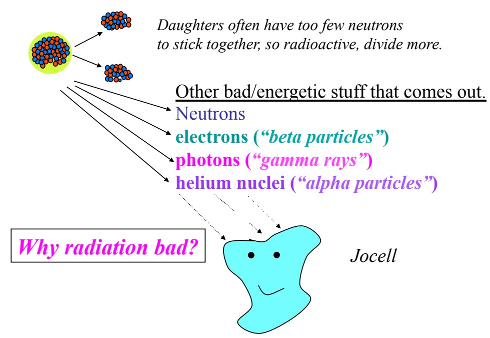
Radioactive materials and "radiation"



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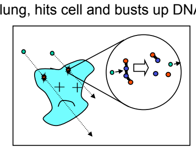
Alpha particles: helium nuclei
- most of radiation is this type
- common is Radon (comes from natural decay process of U^{238}), only really bad because Radon is a gas .. Gets into lungs, if decays there bad for cell.

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

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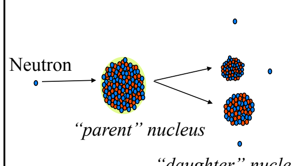
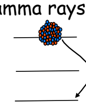
Sources of Gamma Radiation



- *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

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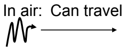
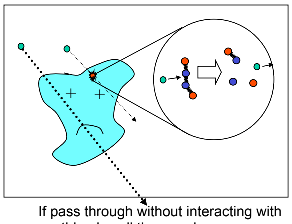
gamma rays: high-energy photons
- So high energy can pass through things (walls, your body) without being absorbed, but if absorbed really bad!

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.

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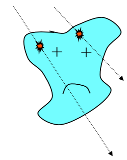

Also break DNA → cancer

But also can cure cancer- Concentrate radiation on cancer cells to kill them.

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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

α - very bad, but easy to stop -- your skin / clothes stop it
β - quite bad, hard to stop -- pass into your body -- keep far away
γ- bad, but really hard to stop--- rarely rarely gets absorbed
Me--- I pick (d)---

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Results of radiation

~4,000 counts/min = .002 Rem/hr

dose in rem = dose in rad x RBE factor (relative biological effectiveness)
RBE = 1 for γ , 1.6 for β, and 20 for α.
A rad is the amount of radiation which deposits 0.01 J of energy into 1 kg of absorbing material.

source/situation	dose	effect
neutron bomb blast	>100,000 rem	immediate death
Chernobyl firefighter	400 rem	50% probability of death within 30 days
space shuttle astronaut	25 rem	due to increased cosmic ray exposure
accidental exposure	10 rem	blood changes barely detectable
max. allowed exposure for radiation workers	5 rem over 1 year	no blood changes detectable, negligible increased risk of cancer.
radon exposure (avg. US)	200 mrem = 0.2 rem/yr	probably none
other terrestrial sources	40 mrem/year	probably none
cosmic radiation (sea level)	30 mrem/ year	probably none
single chest x-ray	20 mrem	probably none
nuclear fallout+	3 mrem/year	probably none
nuclear power plant leakage	0.01 mrem/year	probably none
total average dose (US citizens)	350 mrem/year	probably none

+ primarily due to atmospheric testing of nuclear weapons by US and USSR in the 50's and early 60's, prior to the nuclear test-ban treaty which forbid above-ground testing.

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