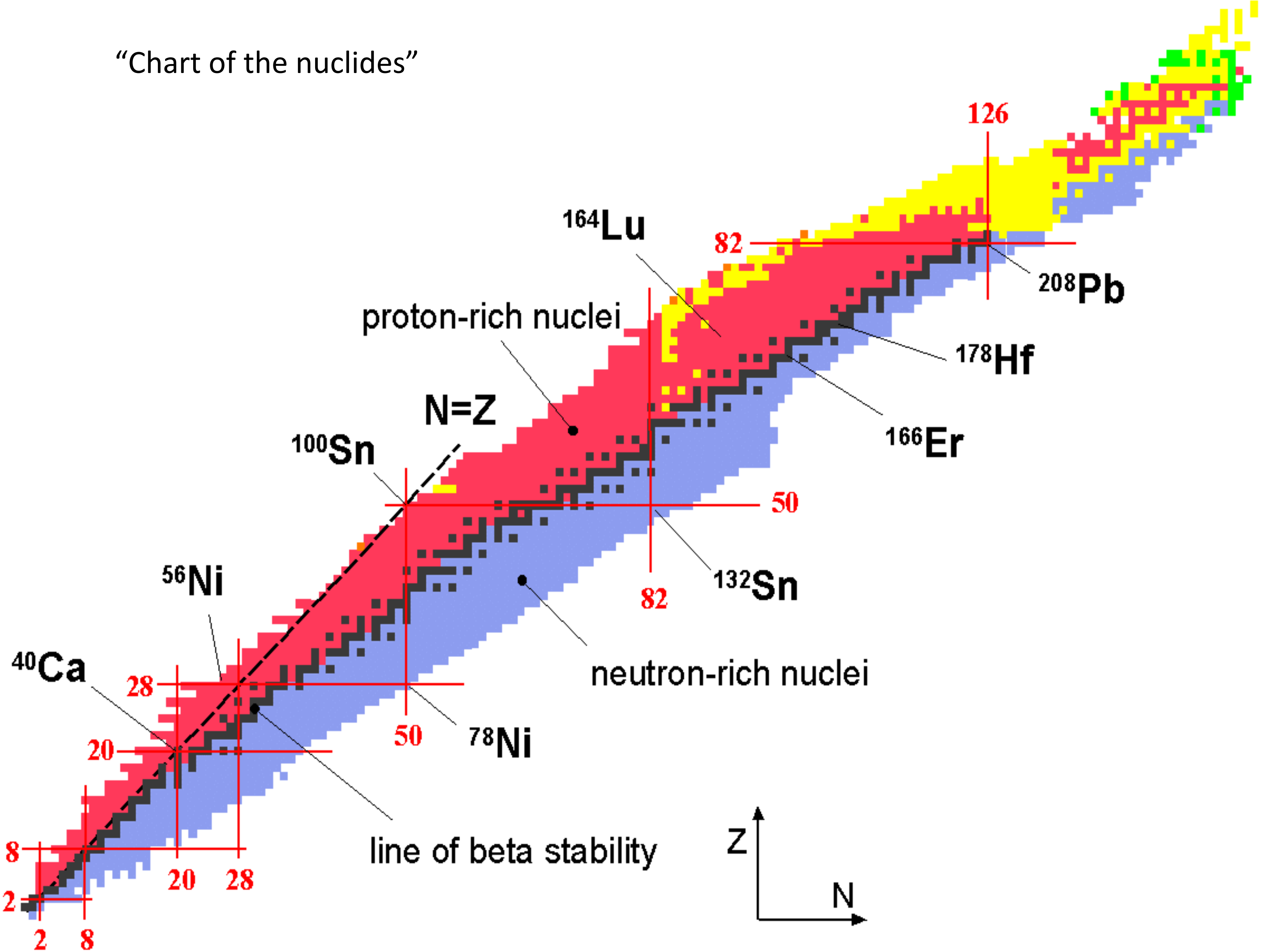
Science can only ascertain what *is,* but not what *should be,* and outside of its domain value judgments of all kinds remain necessary.

- Albert Einstein

The dispassionate intellect, the open mind, the unprejudiced observer, exist in an exact sense only in a sort of intellectualist folklore; states even approaching them cannot be reached without a moral and emotional effort most of us cannot or will not make.

- Wilfred Batten Lewis Trotter (1872-1939), English surgeon

"Chart of the nuclides"



Three primary modes of radioactive decay:

- alpha (α) decay:
  - -- ejection of $^{4}_{2}\mathrm{He}$ nucleus
  - -- $Z \to Z-2, \quad A \to A-4$
  - -- Ex: $^{241}_{95}\mathrm{Am} \to ^{237}_{93}\mathrm{Np}+\alpha$

- beta (β-) decay / inverse (β+) beta decay:
  - -- $n^0 \to p^+ + e^- + \bar{\nu}_e^0$ / $p^+ \to n^0 + e^+ + \nu_e^0$
  - -- ejection of electron (e^-) / positron (e^+)
  - -- $Z \to Z+1$ / $Z \to Z-1$
  - -- Ex: $^{137}_{55}\mathrm{Cs} \to ^{137}_{56}\mathrm{Ba} + e^- + \bar{\nu}_e^0$ / $^{22}_{11}\mathrm{Na} \to ^{22}_{10}\mathrm{Ne} + e^+ + \nu_e^0$

- gamma (γ) decay
  - -- nucleus does not change identity
  - -- often consequence of other kind of decay
  - -- always consequence of matter/anti-matter annihilation
  - -- Ex:

$$^{22}_{11}\mathrm{Na} \to ^{22}_{10}\mathrm{Ne}^* + \mathrm{e}^+ + \nu_e^0$$

$$^{22}_{10}\mathrm{Ne}^* \to ^{22}_{10}\mathrm{Ne} + \gamma^0$$

$$\mathrm{e}^- + \mathrm{e}^+ \to \gamma^0 + \gamma^0$$

All three forms of radiation are very energetic. Around 10^6 more energy than it takes to break chemical bonds or strip electrons from molecules. Hence, *ionizing radiation.*

Alpha particles are doubly positively charged and the highest mass. It turns out this means that it interacts the most strongly with materials. Can be stopped by a piece of paper.

Beta particles are singly charged and have small mass. This means it interacts fairly strongly with materials, but not as much as alpha particles. Can be stopped by metal foil or 1/8" thick piece of plastic.

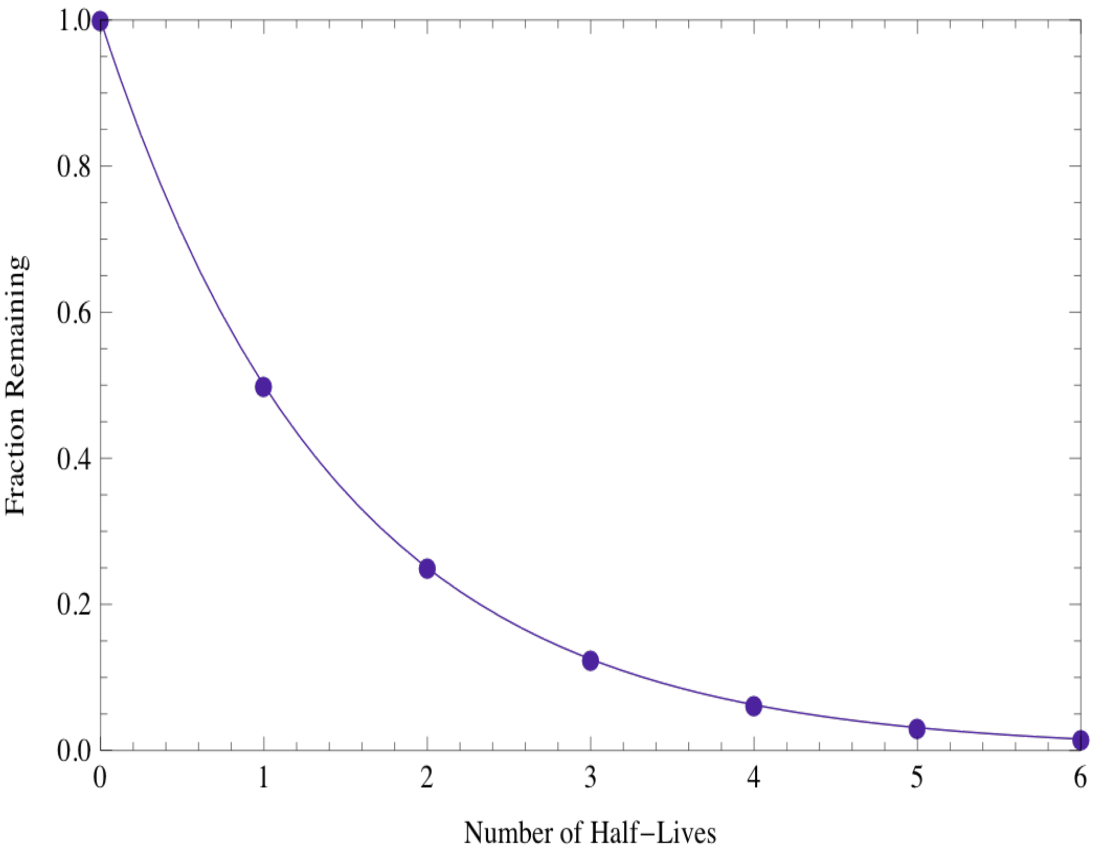
Gammas are not charged and so interact even less strongly with materials. So very penetrating radiation

None of this radiation generates significant additional radioactivity.

Radioactive "decay"

Half-life form

t	N
0	N_0
$T_{1/2}$	$N_0/2$
$2T_{1/2}$	$N_0/4$
$3T_{1/2}$	$N_0/8$
$4T_{1/2}$	$N_0/16$
$\vdots$	$\vdots$
$nT_{1/2}$	$N_0/2^n$



Equation form:

$$N(t) = N_0 e^{-\left(\frac{0.6931}{T_{1/2}}\right)t}$$

where $N(t)$ is the remaining number of nuclei after time t,

N_0 is the original number of nuclei,

$T_{1/2}$ is the half-life, and

t is the time

Activity (rate of decay or decays per second)

This is what we can easily measure. Usually symbolized by *A.*

A is proportional to *N.*

So *A* and *N* follow the same laws:

$$A(t) = A_0 e^{-\left(\frac{0.6931}{T_{1/2}}\right)t}$$

t	$A(t)$
0	A_0
$T_{1/2}$	$A_0/2$
$2T_{1/2}$	$A_0/4$
$3T_{1/2}$	$A_0/8$
$4T_{1/2}$	$A_0/16$
$\vdots$	$\vdots$
$nT_{1/2}$	$A_0/2^n$

One decay each second is called a *becquerel (Bq)*.

3.7×10^{10} decays per second is called a *curie (Ci).*

1 μCi (10^{-6} Ci) generally unregulated

1 mCi (10^{-3} Ci) is generally regulated, needs to be handled cautiously

1 Ci generally requires government inspections, protocols

Half-life example:

One of the radioactive materials that leaked from Unit #1 at Fukushima Was cesium-137. Cesium-137 has a half-life of 30.17 years. Assuming that the cesium-137 is not removed by man, beast, or weather, about how long after the accident will the amount of cesium-137 be reduced by radioactive decay alone to $1/1000^{th}$ of its original amount?

Solution:

Note that $2^{10} = 1024$ which is about 1000. So the amount of cesium-137 will be reduced by radioactive decay to 1/1024 of its original amount in about 10 half-lives, or about 300 years.

Decay law example:

One of the radioactive materials that leaked from Unit #1 at Fukushima would be cesium-137. Cesium-137 has a half-life of 30.17 years. Assuming that the cesium-137 is not removed by man, beast, or weather, ~~about~~ how long after the accident will the amount of cesium-137 be reduced by radioactive decay alone to 1/1000th of its original amount?

Solution:

$$N(t) = N_0 e^{-\left(\frac{0.6931}{T_{1/2}}\right) t}$$

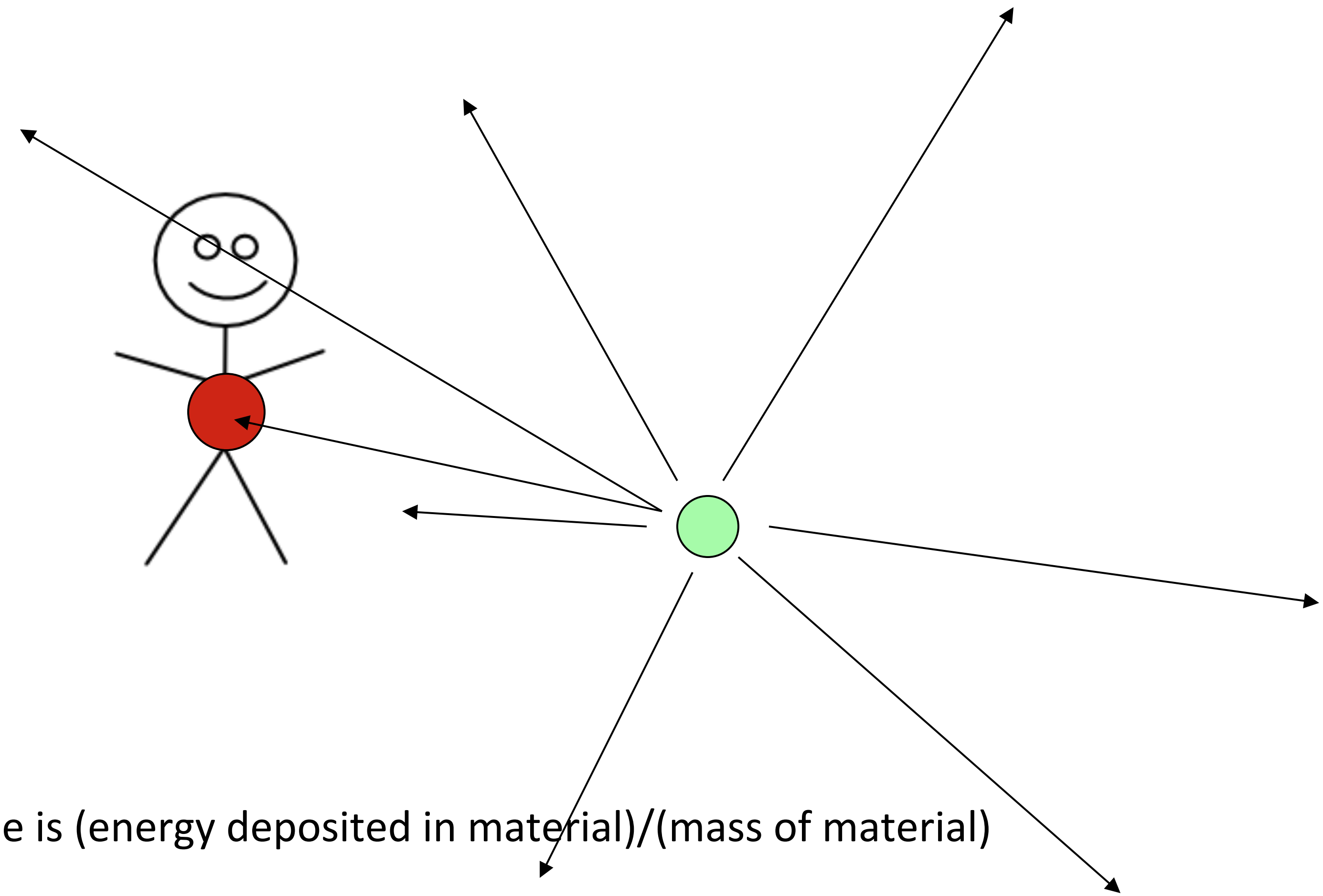
$$\frac{N(t)}{N_0} = \frac{1}{1000} = e^{-\left(\frac{0.6931}{T_{1/2}}\right) t}$$

$$\ln\left(\frac{1}{1000}\right) = -6.9078 = -\left(\frac{0.6931}{30.17 \text{ years}}\right) t$$

$$t = \frac{6.9078 \times 30.17 \text{ years}}{0.6931} = 301 \text{ years}$$

Impact of radiation:

Activity *by itself* doesn't hurt you. Only radiation that actually interacts in your body can do damage

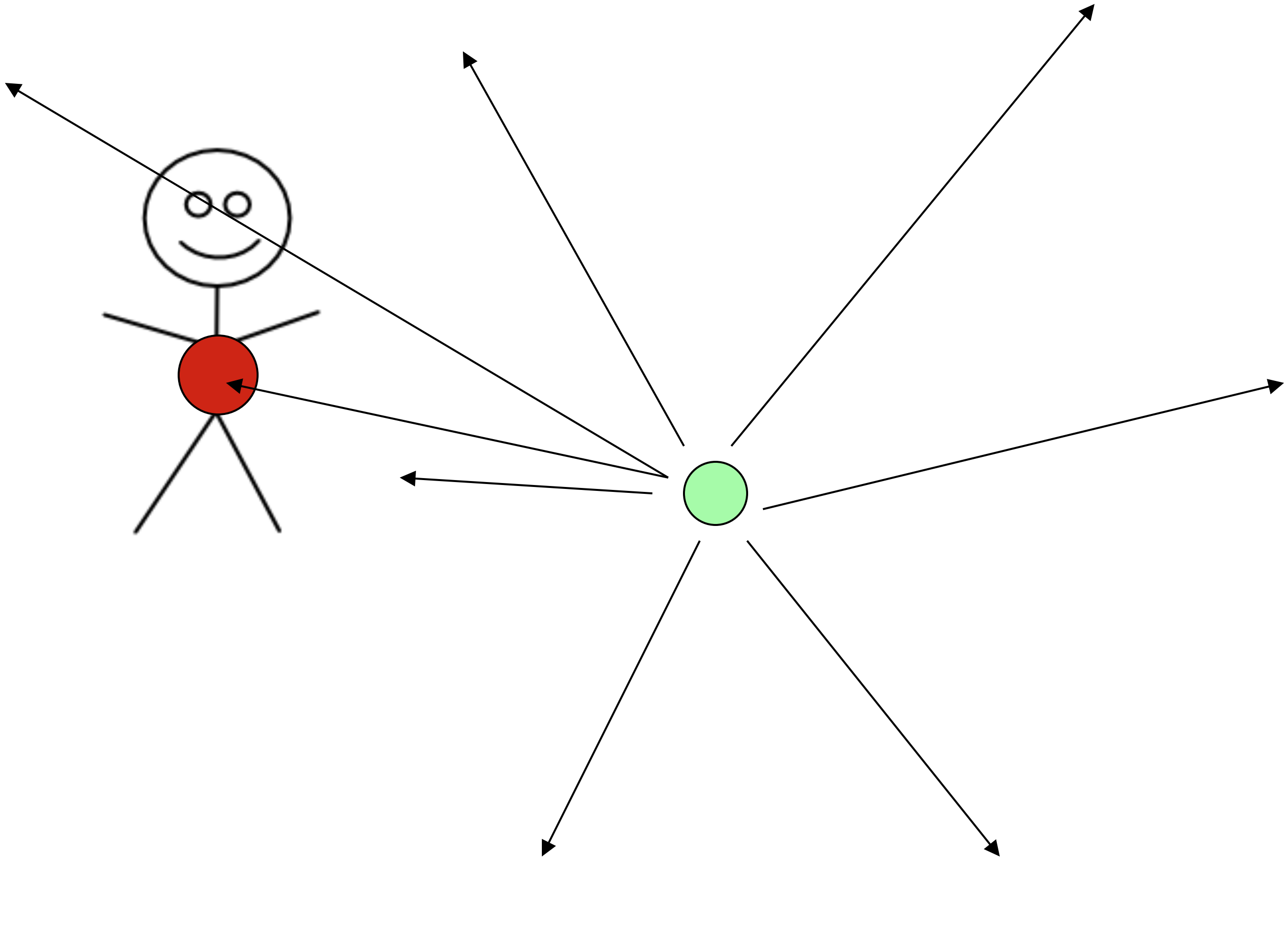


Dose is (energy deposited in material)/(mass of material)

Units are *rad (radiation absorbed dose)* (US), *Gray (Gy)* (everywhere else)

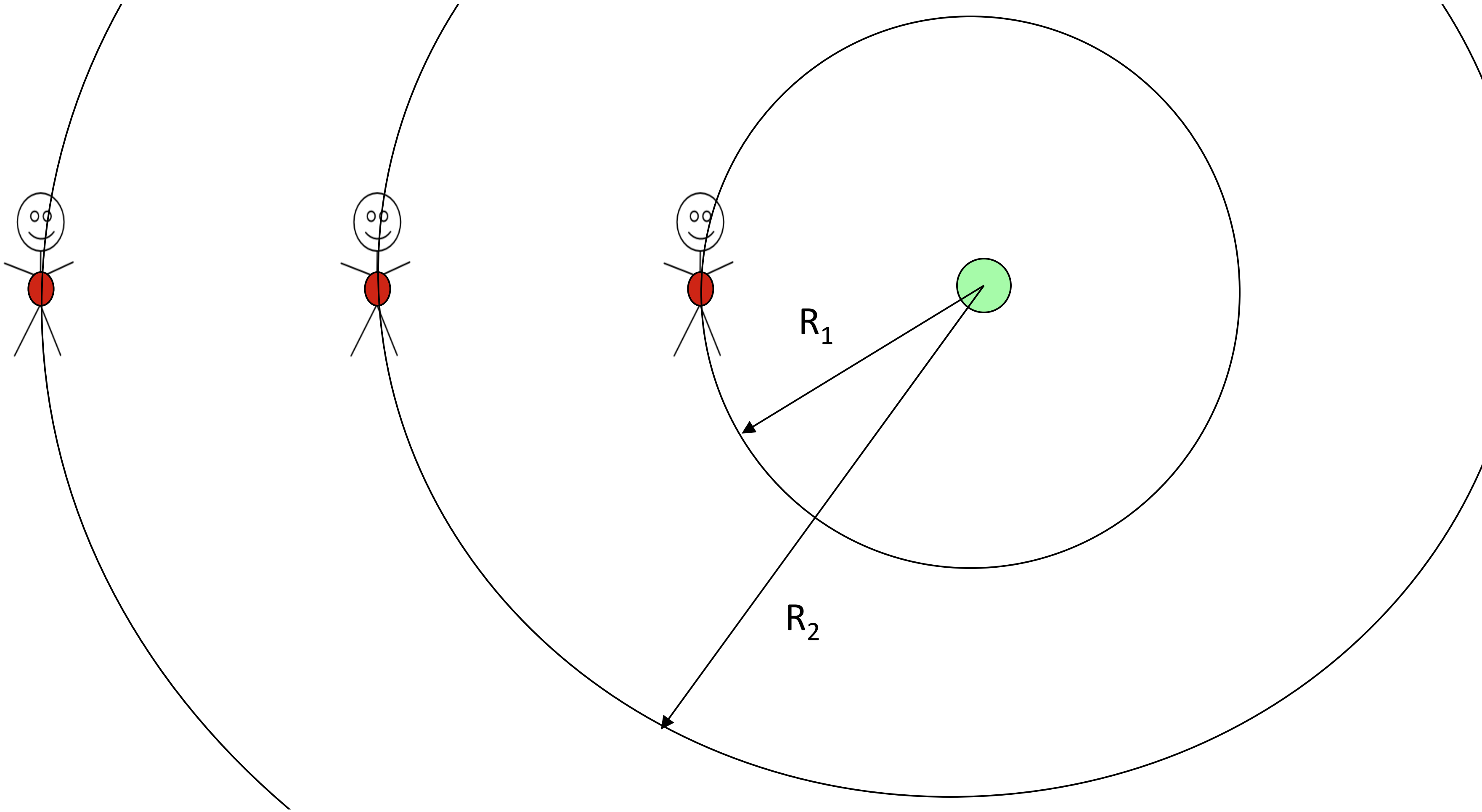
Dose proportional to time (if constant activity)

$D(t_2)/D(t_1) = t_2/t_1$

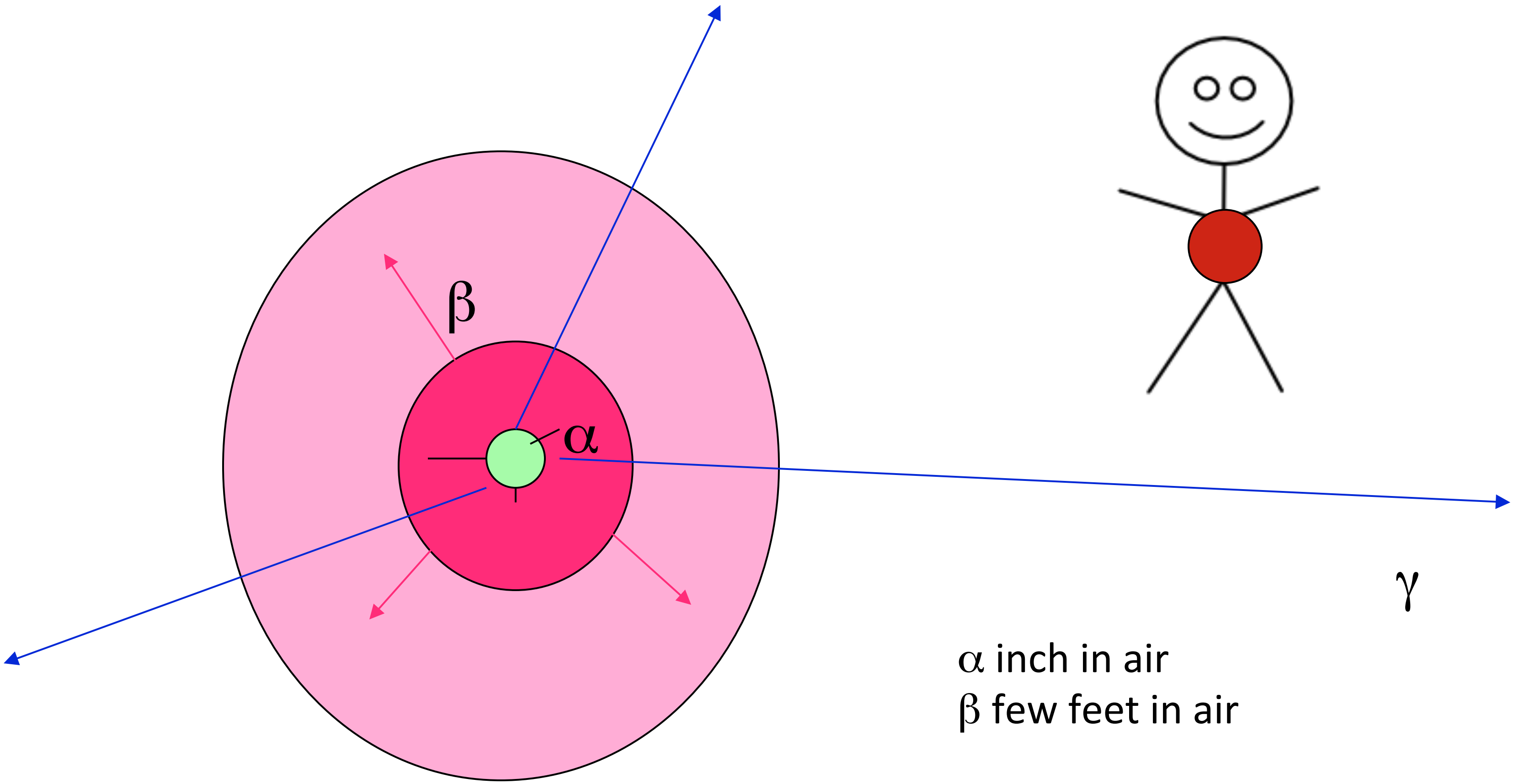


Dose inversely proportional to distance squared

$$D(R_2)/D(R_1) = (R_1/R_2)^2$$



Air has different influence on α, β, and γ rays



α inch in air
β few feet in air

So, $1/R^2$ usually only works well for γ rays.