

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

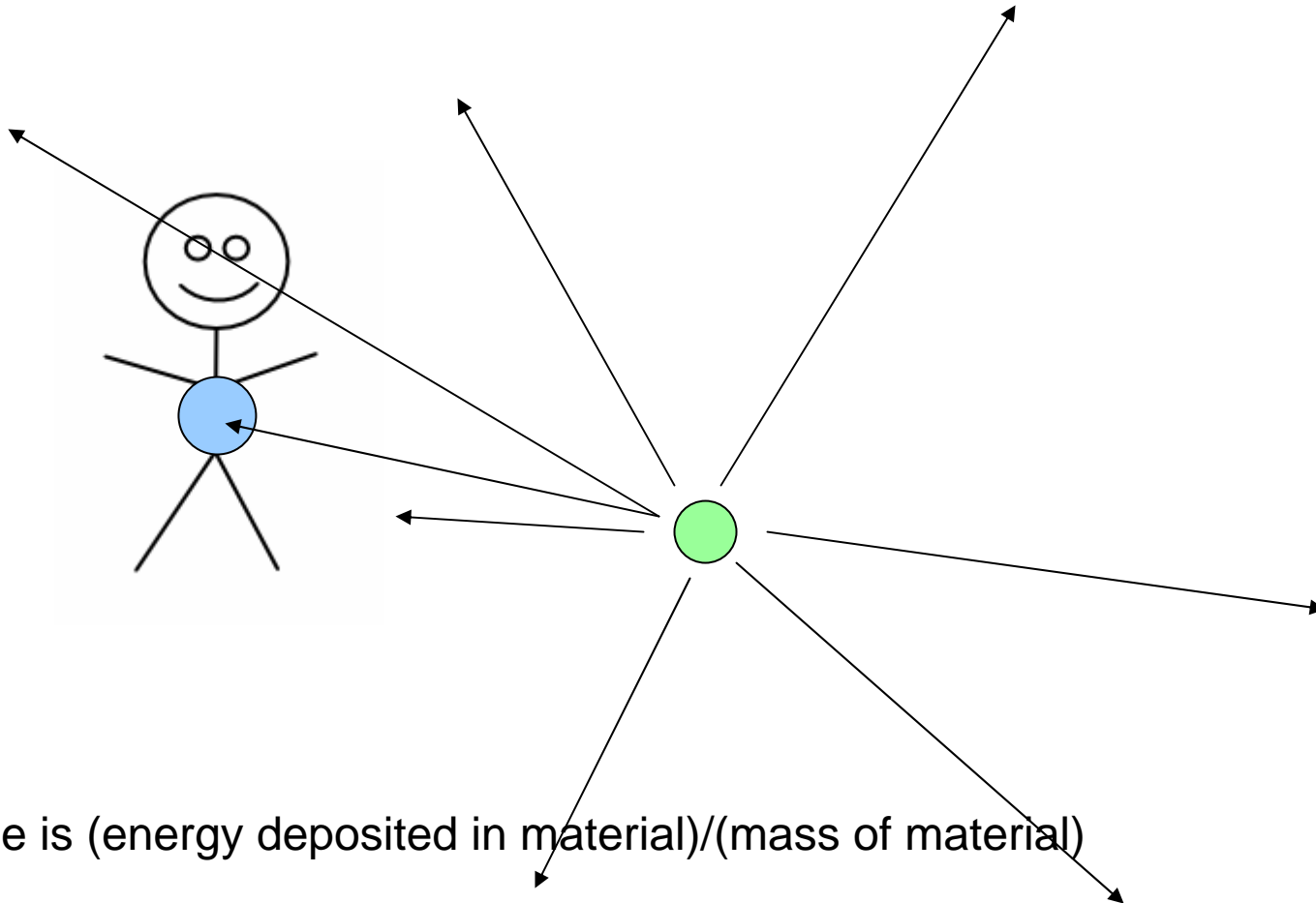
The dispassionate intellect, the open mind, the unprejudiced observer, exist in an exact sense only in a sort of intellectualist folklore; states even approaching them cannot be reached without a moral and emotional effort most of us cannot or will not make.

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

Impact of radiation:

Activity *by itself* doesn't hurt you.

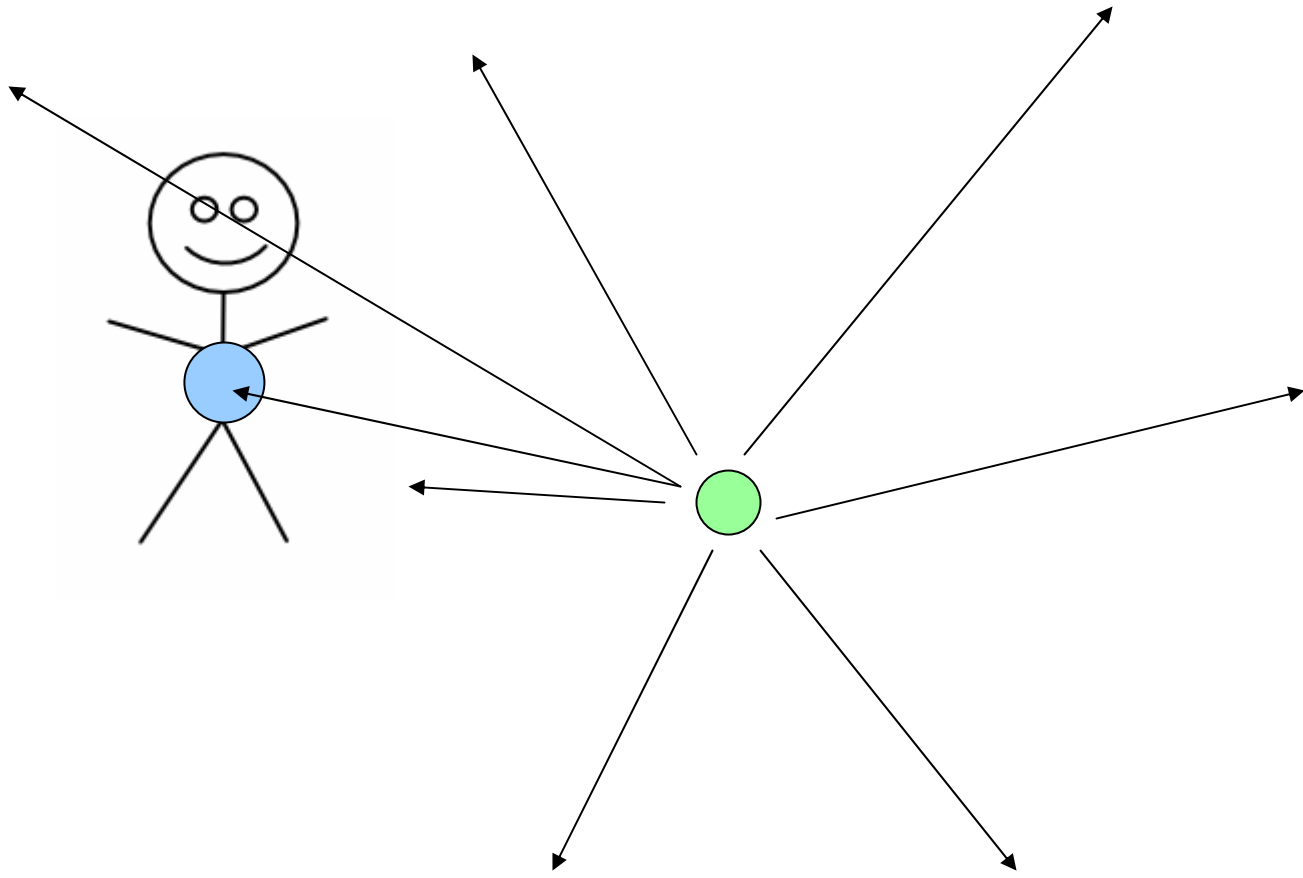
Only radiation that actually interacts in your body can do damage



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

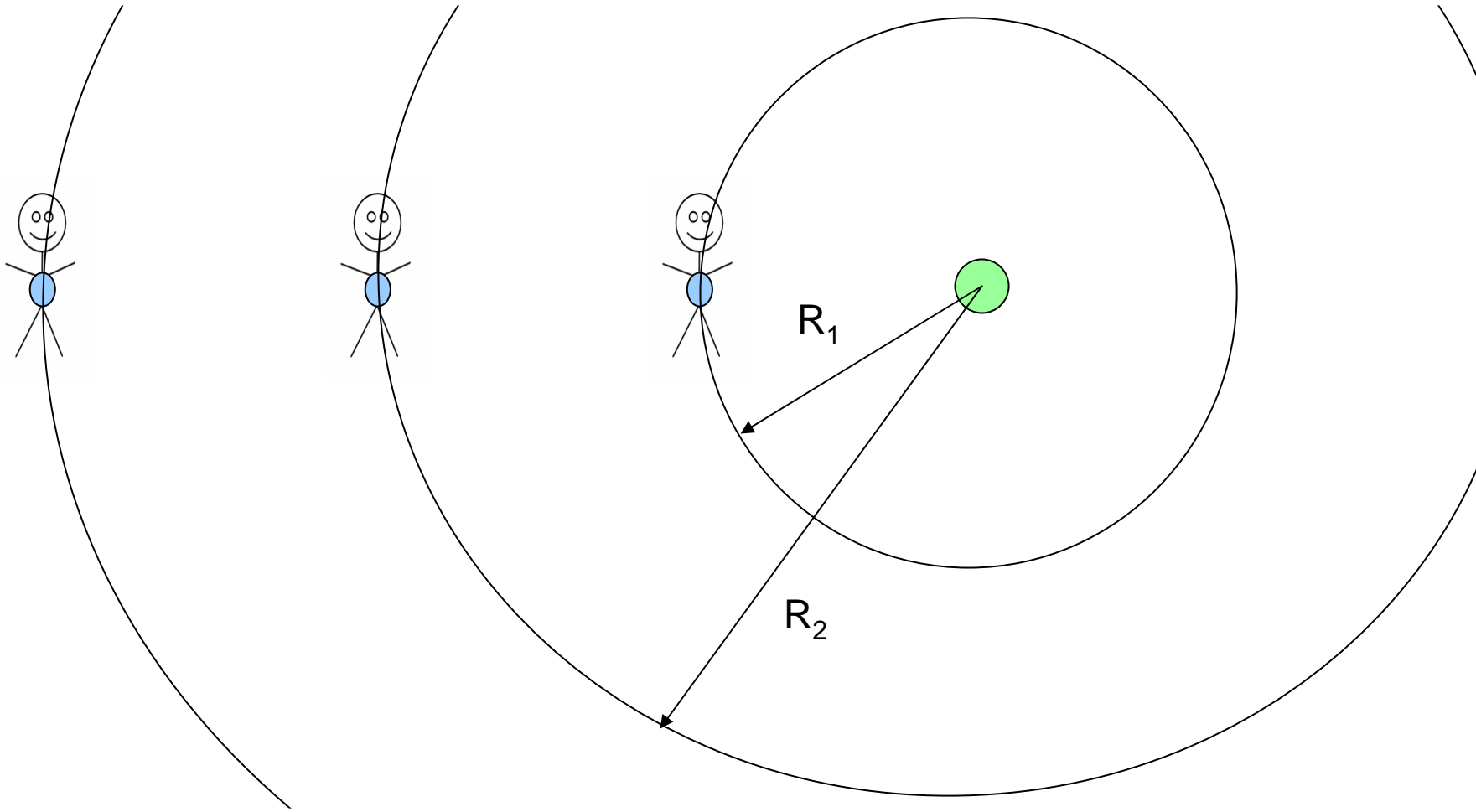
Units are *rad* (*radiation absorbed dose*) (US), *Gray (Gy)* (everywhere else)

Dose proportional to time (if constant activity)

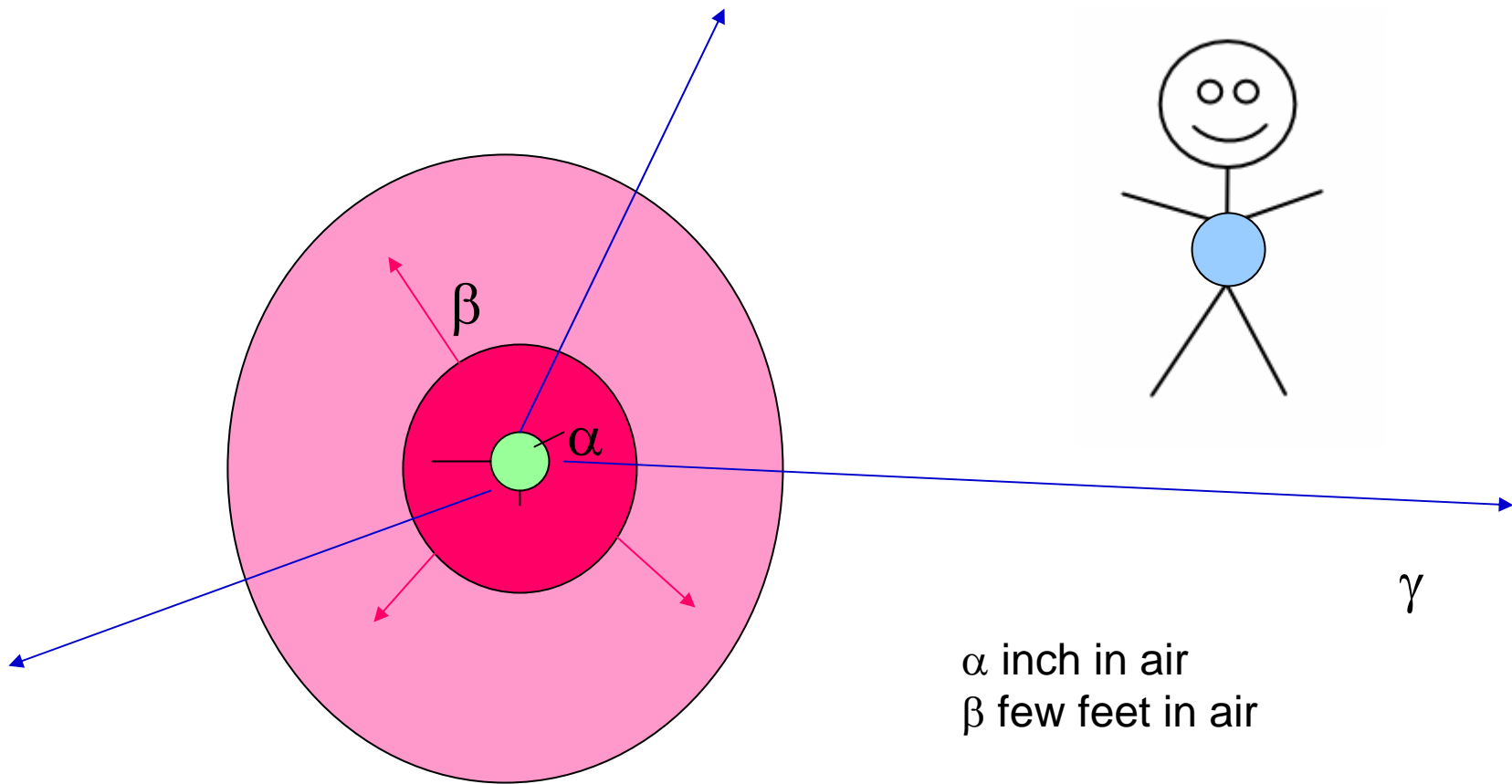


If simple, can quantify “misses”: Dose inversely proportional to distance squared

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



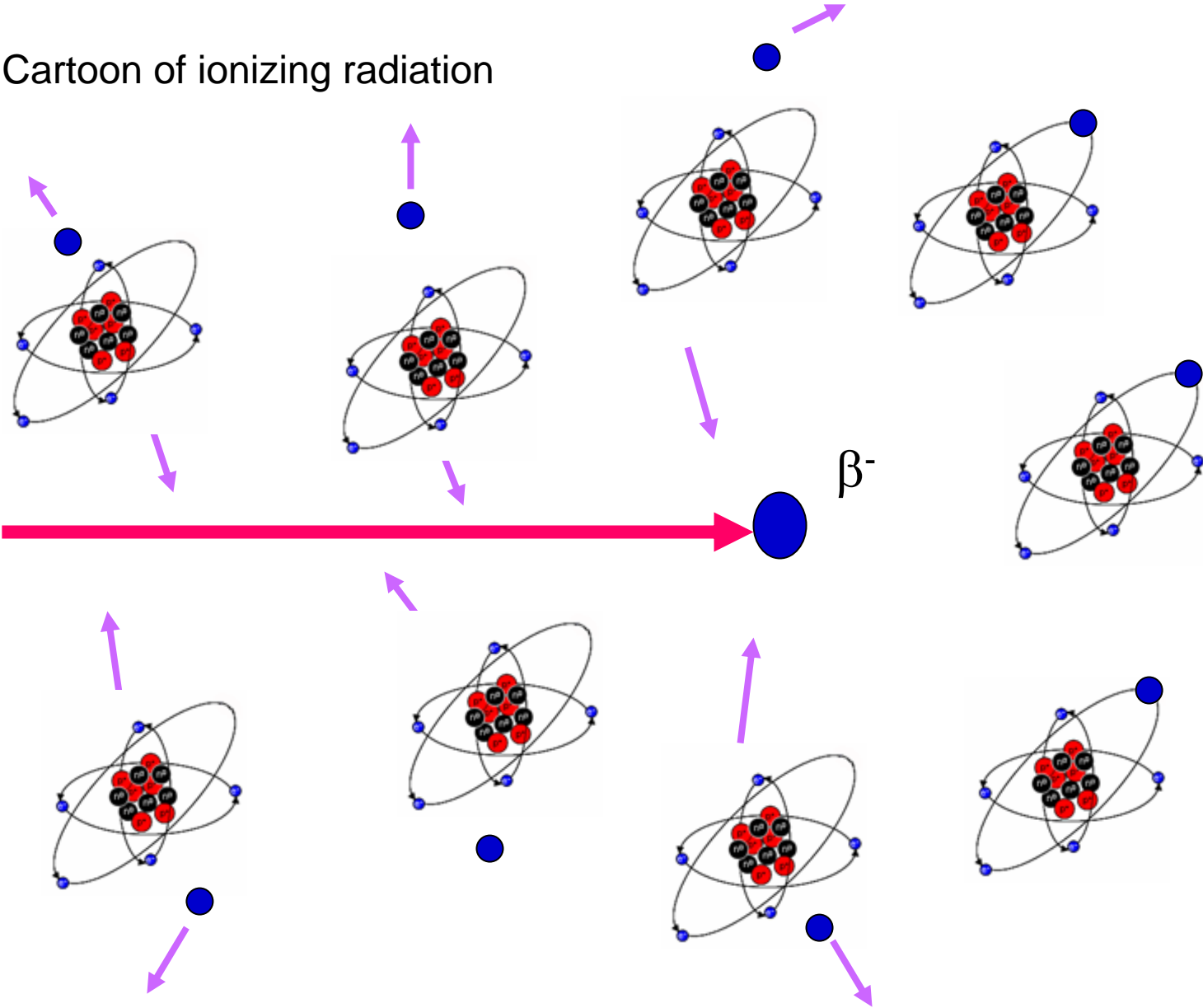
Air has different influence on α , β , and γ rays



α inch in air
 β few feet in air

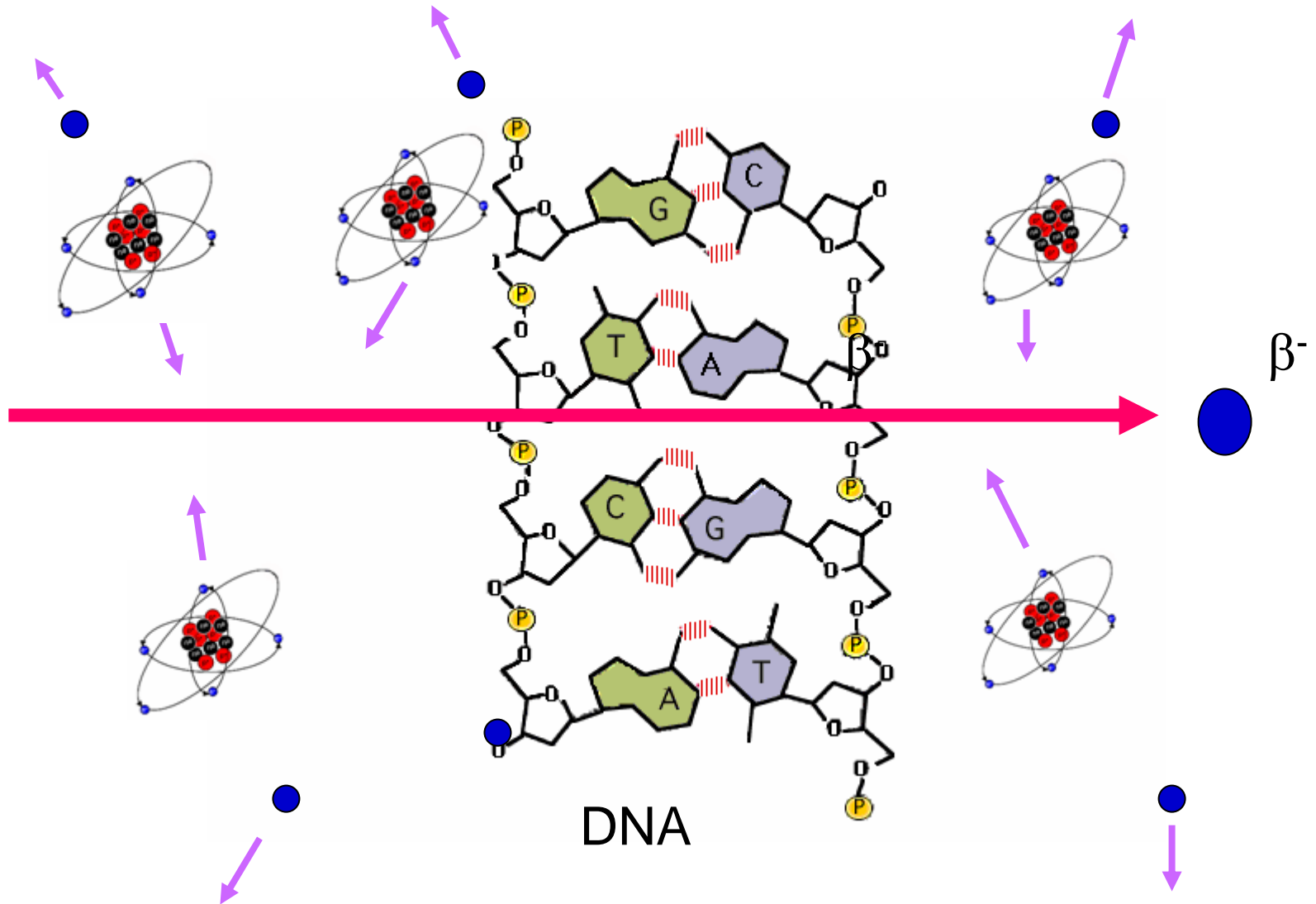
So, $1/R^2$ usually only works well for γ rays.

Cartoon of ionizing radiation



Operation of Geiger counter

Not all radiation equal in causing damage



Quality factor or Radiation Weighting Factor or Relative Biological Effectiveness:

| | |
|---------------------------------|--------------------------|
| X, γ , β radiation | 1 |
| α radiation | 20 |
| protons | 5 |
| neutrons | 5-20 (depends on energy) |

Equivalent dose is (dose)x(quality factor)

Units are *rem* (radiation equivalent man) (US) or
Sievert (Sv) (everywhere else)

$$1 \text{ rem} = 0.01 \text{ Sv}$$

Example: A dose of 1 rad of gamma radiation gives an equivalent dose of 1 rem, but a dose of 1 rad of alpha radiation gives an equivalent dose of 20 rem.

Sources of radiation exposure:

Natural (2.4 mSv/year = 240 mrem/year)

| | |
|----------------------|-----|
| inhalation of radon | 52% |
| radiation from earth | 20% |
| cosmic rays | 16% |
| things we eat | 12% |

Man-made (0.5 mSv/year = 50 mrem/year)

| | |
|--------------------|-----|
| medical X-rays | 58% |
| nuclear medicine | 21% |
| consumer products | 16% |
| occupational | 2% |
| fallout | 2% |
| nuclear fuel cycle | 1% |

Total 2.9 mSv/year = 290 mrem/year

(Data taken from BEIR VII)

Breathing: radon, carbon-14, smoking

Eating, drinking: uranium decay products, potassium

Traveling by airplane: 0.1 mrem/1000 miles

Living near coal fired power plant: 0.03 mrem/year

Living within 50 miles of nuclear plant: 0.009 mrem/year

Whole body CT scan: 1200 mrem

Mammogram: 13 mrem

Chest X-ray: 8 mrem

Stress test: 1000 mrem

Worker limits:

adult: 5000 mrem/year

minor/pregnant woman: 500 mrem/year

Public limits:

100 mrem

2 mrem/hour in publicly accessible areas

Health effects of radiation exposure:

Acute or “non-stochastic”:

| | |
|----------------------------|--------------|
| changes in blood chemistry | 5000 mrem |
| nausea | 50000 mrem |
| vomiting | 70000 mrem |
| hair loss | 75000 mrem |
| diarrhea | 90000 mrem |
| hemorrhage | 100000 mrem |
| death in months | 400000 mrem |
| death in weeks | 1000000 mrem |
| death in hours | 2000000 mrem |

(Data from US EPA)

Health effects of radiation exposure:

“stochastic”:

Cancer:

If 10,000 people were each exposed to 1000 mrem of ionizing radiation, you would estimate that there would be 5-6 excess deaths from cancer. Of those 10,000 people, about 2000 would be expected to die of cancer even without this (above background) dose.

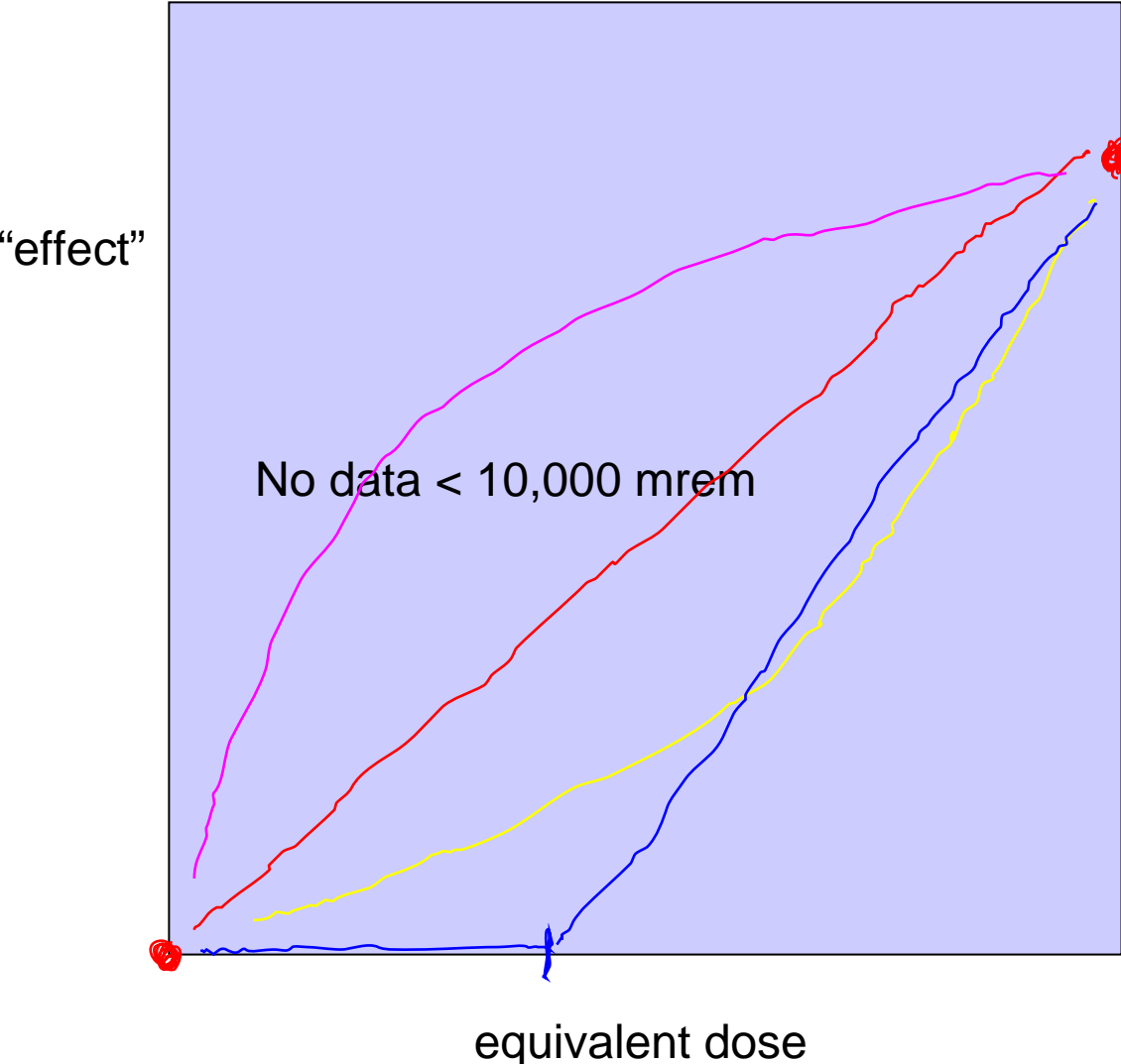
Genetic effects:

If both parents of 1,000,000 live born children are exposed to 1000 mrem of ionizing radiation, you would estimate that 50 more of those children would have severe hereditary effects. Without this (above background) dose, you would estimate that 100,000 of the children would have severe hereditary effects.

Teratogenic effects:

Four of 1000 fetuses in their 8th-15th week exposed to 1000 mrem of ionizing radiation are estimated to become mentally retarded. One of 1000 if later.

(Data from US EPA)



- Linear, no threshold —
- Supra-linear —
- Sub-linear —
- Linear with threshold —

Data from:

Hiroshima/Nagasaki survivors

Medical radiation studies (radiation given as treatment)

Occupational radiation studies (not enough data even for nuclear workers)

Nature can concentrate chemicals, including radioactive ones:

E.g., $^{131}_{53}\text{I}$ (iodine-131) is a common product of fission. In explosion or accident (see Chernobyl) iodine-131 is spread in fallout. Would be relatively harmless, except that it is eaten by cows and concentrates in the milk. When drunk, it is sent to the thyroid gland which needs iodine to work properly.

E.g., $^{90}_{38}\text{Sr}$ (strontium-90) is in the same column of the periodic table as calcium. It is also a common product of fission. If ingested, rather than being flushed out, it is deposited in the bones, so increasing its chances of causing damage.

| | 1 | 2 | | | | | | | | | | | 13 | 14 | 15 | 16 | 17 | 18 | |
|---|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|-------------------------|
| 1 | 1 H 1.008 | | | | | | | | | | | | | | | | | | 2 He 4.003 |
| 2 | 3 Li 6.941 | 4 Be 9.012 | | | | | | | | | | | | | | | | | |
| 3 | 11 Na 22.99 | 12 Mg 24.31 | | | | | | | | | | | 13 Al 26.98 | 14 Si 28.09 | 15 P 30.97 | 16 S 32.07 | 17 Cl 35.45 | 18 Ar 39.95 | |
| 4 | 19 K 39.10 | 20 Ca 40.08 | 21 Sc 44.96 | 22 Ti 47.88 | 23 V 50.94 | 24 Cr 52.00 | 25 Mn 54.94 | 26 Fe 55.85 | 27 Co 58.93 | 28 Ni 58.69 | 29 Cu 63.55 | 30 Zn 65.39 | 31 Ga 69.72 | 32 Ge 72.61 | 33 As 74.92 | 34 Se 78.96 | 35 Br 79.90 | 36 Kr 83.80 | |
| 5 | 37 Rb 85.47 | 38 Sr 87.62 | 39 Y 88.91 | 40 Zr 91.22 | 41 Nb 92.91 | 42 Mo 95.94 | 43 Tc 98.91 | 44 Ru 101.1 | 45 Rh 102.9 | 46 Pd 106.4 | 47 Ag 107.9 | 48 Cd 112.4 | 49 In 114.8 | 50 Sn 118.7 | 51 Sb 121.8 | 52 Te 127.6 | 53 I 126.9 | 54 Xe 131.3 | |
| 6 | 55 Cs | 56 Ba | 71 Lu | 72 Hf | 73 Ta | 74 W | 75 Re | 76 Os | 77 Ir | 78 Pt | 79 Au | 80 Hg | 81 Tl | 82 Pb | 83 Bi | 84 Po | 85 At | 86 Rn | |

| | | |
|--|----------|---------------|
| | 6 | Atomic number |
| | C | Symbol |
| | 12.01 | Atomic weight |

| |
|--|
| Metal |
| Semimetal |
| Nonmetal |