CALCULATING
RADIATION EXPOSURE

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But it matters what the isotopes decay *into*!

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Natural uranium is roughly 99% ^{238}U, with a half-life of 4.468 billion years, and 1% ^{235}U with a half-life of 0.7 billion years. Both decay by α-emission. From this and their masses we can calculate the number N of both isotopes in 1 g of natural uranium and the activity of same, namely $A \approx$ 13,000 Bq.

That sounds like a lot, but if you had a 1 gram block of U metal (a 3.74 mm cube) none of the short-ranged α-particles would make it out of the block unless they were within a few μm of the surface, and those would stop in a few cm of air.

On the other hand, if you ground it to a fine powder and dispersed it so that people could *inhale* the particles, those alphas might do some lung damage! *How much*, exactly?

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- X-rays, γ-rays & β-rays (fast electrons): *RBE* = 1 (by definition)
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REM (***R***, *R*oentgen *E*quivalent to *M*an):

R ≡ *RBE* × **rad**.

(1 mR ≡ 1 *milliREM* ≡ 10^{-3} R.)

sievert (***Sv***, standard international unit):

Sv ≡ *RBE* × ***Gy*** = 100 ***R***

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As mentioned earlier, the dose from 1 gram of natural uranium held at arm's length with tongs is exactly *zero*, because none of the alphas make it to you. So let's suppose you ground it up into a fine dust and breathed it *all* into your lungs, where the kinetic energy of the alphas would all get deposited in your lung tissue.

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How much energy is that? Alphas from ^{238}U decay have an energy of 4.267 MeV or 0.684×10^{-12} J; those from ^{235}U have about the same, 4.679 MeV. So the 13,000 alphas produced per second from your gram of natural uranium deposit 0.897×10^{-8} J/s in your lungs. In one *year* that would add up to 0.283 J deposited fairly uniformly in your lungs, which have a mass of about 1 kg. So that's 0.283 Gray per year. Alphas have an RBE of over 10, so we finally arrive at a meaningful **dose**: **3 Sieverts per year**, 30 Sv per decade or 300 Sv per century. After a few millennia it would get to be a *huge* dose! In a few billion years it would taper off, though.

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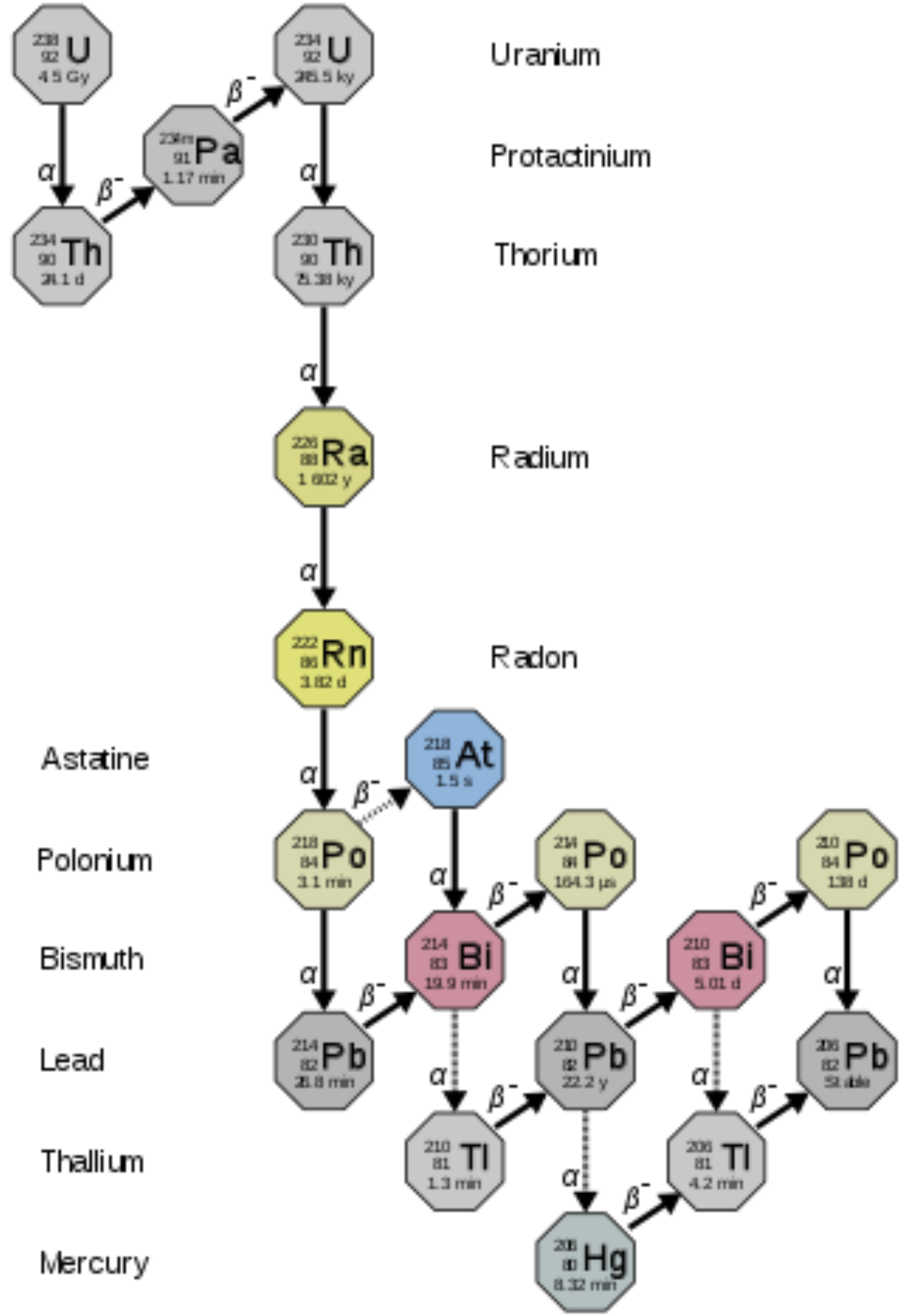
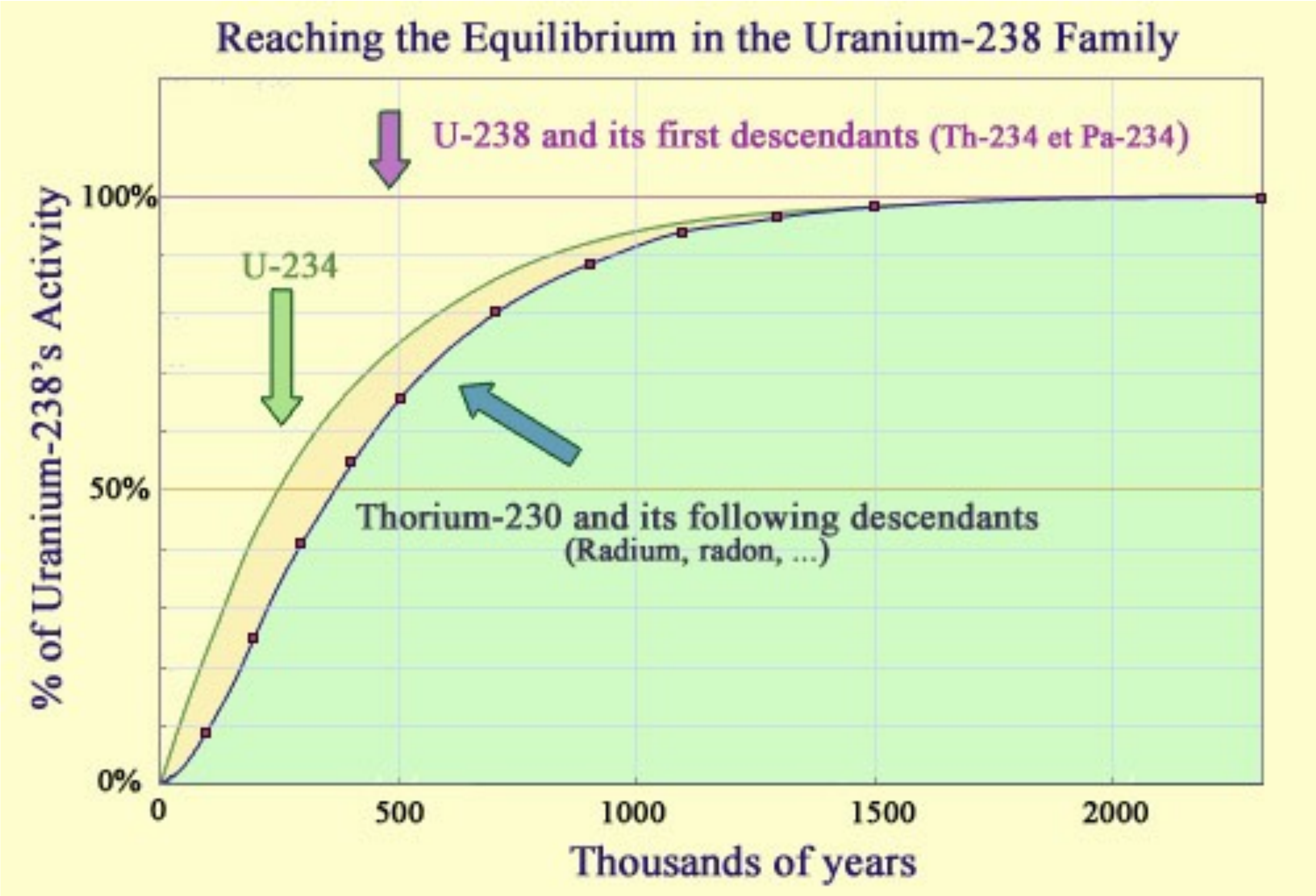
But wait… is that ***all*** the energy deposited?

^{238}U decay chain



CHANGING Dose from 1g of ^{238}U

The dose from the initial α-decay of 1 gram of pure ^{238}U is 3 Sv/year, or 50 mSv/week, but that's not the end of the story. The "daughter" nucleus, ^{234}Th, β-decays into ^{234}Pa in 24 days, and ^{234}Pa quickly β-decays into ^{234}U, which has a half-life of 0.245 million years, eventually α-decaying to ^{230}Th and on down to lead. During the first 100 years, the net dose would be increased by only those two βs, with RBEs of 1, so 3.2 Sv/y.



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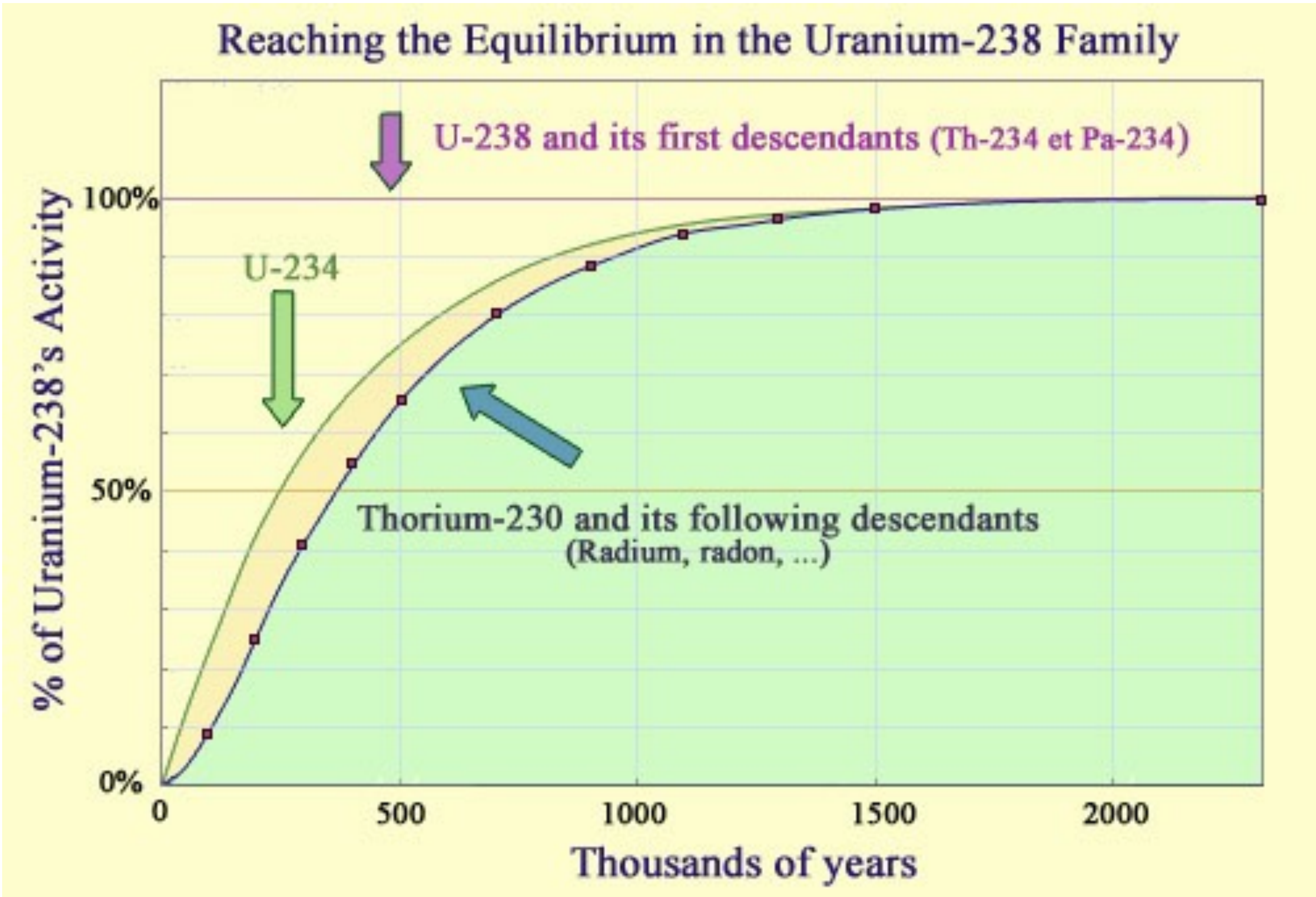

How ***bad*** would ***this*** be for your lungs?

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- **Sub-Acute Exposures**: ~ **1** Sv whole-body delivered all at once → no immediate symptoms, but possible leukemia (rarely, years later).

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Okay you've ground it up and breathed it into your lungs, where it delivers a dose of **3.2 Sieverts per year**. If 3.2 Sv were delivered *all at once* (or in less than a week) you might get cancer in a decade or so. But you only get about 0.054 Sv (54 mSv) in any given week.

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Why does the ***rate*** of delivery matter?
Because of what ionizing radiation ***does***
and how your cells ***respond***.

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- **Cancer** [most unpleasant]

  Runaway replicative zeal of a misguided cell…

Revisiting our 1 g of Uranium

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A dose of 3.2 Sv/year is only about 54 mSv/week. While this is probably undesirable, you'd have a good chance of being basically unaffected… if it were not for the ***chemical*** toxicity of uranium — which depends critically on its oxidation state — and the fact that inhaling 1 g of ***any*** metal into your lungs is apt to produce nasty effects having little to do with either radiation or chemistry.

The *relative* toxicity of radioactivity, chemicals and irritants is frequently ignored.

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It is hard to calculate how much harm is done by a given amount of radioactivity. We can fairly easily calculate the ***activity*** of a certain amount of a given radioisotope, and then we can fairly easily find how much *energy* its ionizing radiation deposits *per kg* of flesh; but the same energy deposited by one type of particles can be an order of magnitude worse for you than the same amount of energy deposited by another type of particles; and it makes a *huge* difference whether that energy is deposited *all at once* or spread out over time, because *the damage* ***heals***. Moreover, many of these "fudge factors" are based on empirical observations that are not rigorously quantitative.

As a result, it's very tempting to make qualitative ***comparisons***, especially with "natural background radiation". But even then we have disagreements on how a *low* dose should be compared with a *high* dose….

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We have data on the survivors of *Hiroshima* and *Nagasaki*. We also have data on the people exposed to high radiation levels at *Chernobyl*. We know roughly how much their probability of (*e.g.*) thyroid cancer was heightened over time by exposure to Iodine-131, and we know how many suffered immediate effects of "radiation sickness". What we *don't* know so well is how people are affected by much *lower* levels of radiation exposure. One reason for this is that we don't have a "control group" of people who are not exposed to *any* radiation. There are no such people! Your *bones* are radioactive.

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The "***Threshold***" model assumes that the "normal background" radiation level is *harmless*, and may even be *beneficial* up to a point ("***hormesis***"). There is actually some evidence for the latter.