# RADIATION EXPOSURE

from

# FISSION PRODUCTS

We have seen how tedious it is to calculate radiation exposure from 1 g of uranium, but uranium *itself* is **not** what people worry about in nuclear reactor accidents.  Enriched uranium containing more $^{235}$U or plutonium ($^{239}$Pu) have a propensity to ***fission*** (split) into lighter nuclei and fast neutrons, and the neutrons (after moderation) can capture on a nearby $^{235}$U or $^{239}$Pu nucleus, causing it to promptly fission in its turn.  If this process is *unregulated*, the "**chain reaction**" can make a fission ***bomb***.  In a reactor it is kept under control.  But the fission products include many even more radioactive nuclides like ***iodine-131*** which don't fission but do *decay*, giving off penetrating radiation much more hazardous than the alpha particles of decaying uranium.

Shortly after the Fukushima disaster, milk in the USA was found to have 0.8 pCi/liter of $^{131}\mathrm{I}$ activity.  What does that mean?  It means that a *33 liter* tank of milk would produce ***one*** gamma ray per second, about the same as the number of cosmic ray muons piercing every 10 cm square area of your body every second.

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But it matters what the isotopes decay *into*!

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$^{131}$I, with a short half-life of ***8 days***, decays by β-emission (averaging190 keV) with an accompanying γ (mostly 364 keV). From this and the mass of $^{131}$I we can calculate the number $N$ of $^{131}$I nuclei and the mass $m$ of same needed to produce an activity of $A \approx 0.94 \times 10^{18}$ Bq. The answer? $N = 0.94 \times 10^{24}$ and $m = 0.204$ kg.

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Multiplying $A$ by the energy released per decay yields a ***power*** of about **81 kW**. That's just from the activity that ***escaped***. The ***entire*** content of the Fukushima cooling ponds generated enough heat to cause a *steam explosion*, which is *how the disaster happened*!

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Note: ***It's all gone now***.

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***REM*** (**R**, *R*oentgen *E*quivalent to *M*an):

**R** ≡ *RBE* × **rad**.

(1 mR ≡ *milliREM* ≡ $10^{-3}$ R.)

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

**Sv** ≡ *RBE* × ***Gy*** = 100 **R**

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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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The entire inventory of escaped activity from Fukushima generates 81 kW of heat and ionization. But where could that energy be ***deposited***? The gammas can go a long way without interacting; the betas are less penetrating — they probably stop in a few cm of water. So suppose (for a "worst case scenario") *all* the escaped activity from Fukushima were dissolved in an Olympic-sized swimming pool and *you went swimming in it*. You'd get gammas from all around, but betas only from the water right next to you. I estimate that about $0.25 \times 10^{-4}$ of that 81 kW would be deposited in your body, so that's 2 Watts per 80 kg (you) or, at an RBE of one, 0.025 Sv/s or 1.5 Sv/min. Yes, in that scenario you'd probably be dead within a few days, unless you scrambled out of that swimming pool in less than about 5 minutes. :-(

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Now *dilute* that 200 grams of $^{131}$I in the *entire Pacific ocean*… that's 710 million cubic kilometers, $0.28\times10^{15}$ times the volume of the Olympic swimming pool. So now your body immersed in the ocean would represent $8.7\times10^{-20}$ of the volume absorbing 81 kW of radiation from that $^{131}$I. That adds up to $7\times10^{-15}$ Watts of ionizing radiation deposited in 80 kg of you, for a grand total of $9\times10^{-17}$ Sv/s or $3\times10^{-9}$ Sv/year.

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How, then, can anyone ***detect*** the $^{131}$I from Fukushima in our seawater? The gammas from the "contaminated" seawater have a long range and a very specific characteristic energy, so patient physicists with a big gamma detector will see one occasionally; after a while, they will have enough statistics to make a positive identification.

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- **Cancer** [most unpleasant]

Runaway replicative zeal of a misguided cell…

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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.

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**https://xkcd.com/radiation/**