RADIATION HAZARDS

An Introduction

by

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Mortality

Paraphrased from memory: Front page of special *HEALTH* edition of *LA Free Press* (around 1970):

"No matter how much money you have, how good your health care provider or how healthy your diet and life style, ***you***, ***personally***, *are going to* ***die***."

This may no longer be certain for some of our children, but it still makes an excellent *starting point* for any discussion of ***hazards***.

We cannot (for now) avoid dying, but we can exercise *some* influence over *when* we will die and *from what causes*.

We also (for now) get to choose how much of our enjoyment of life and liberty we sacrifice to this effort.

What IS "Radiation"?

Electromagnetic Waves:

- AM Radio, FM Radio, Shortwave Radio, TV, Cell Phones, WiFi, Microwave, Visible Light — all ***harmless*** *at low intensity*.
- Near Ultraviolet (UV) — ***beneficial*** *at low doses* (Vitamin D)
- Far UV, X-rays, Gamma-rays — ***damaging*** *at all levels*

Fast Massive Particles:

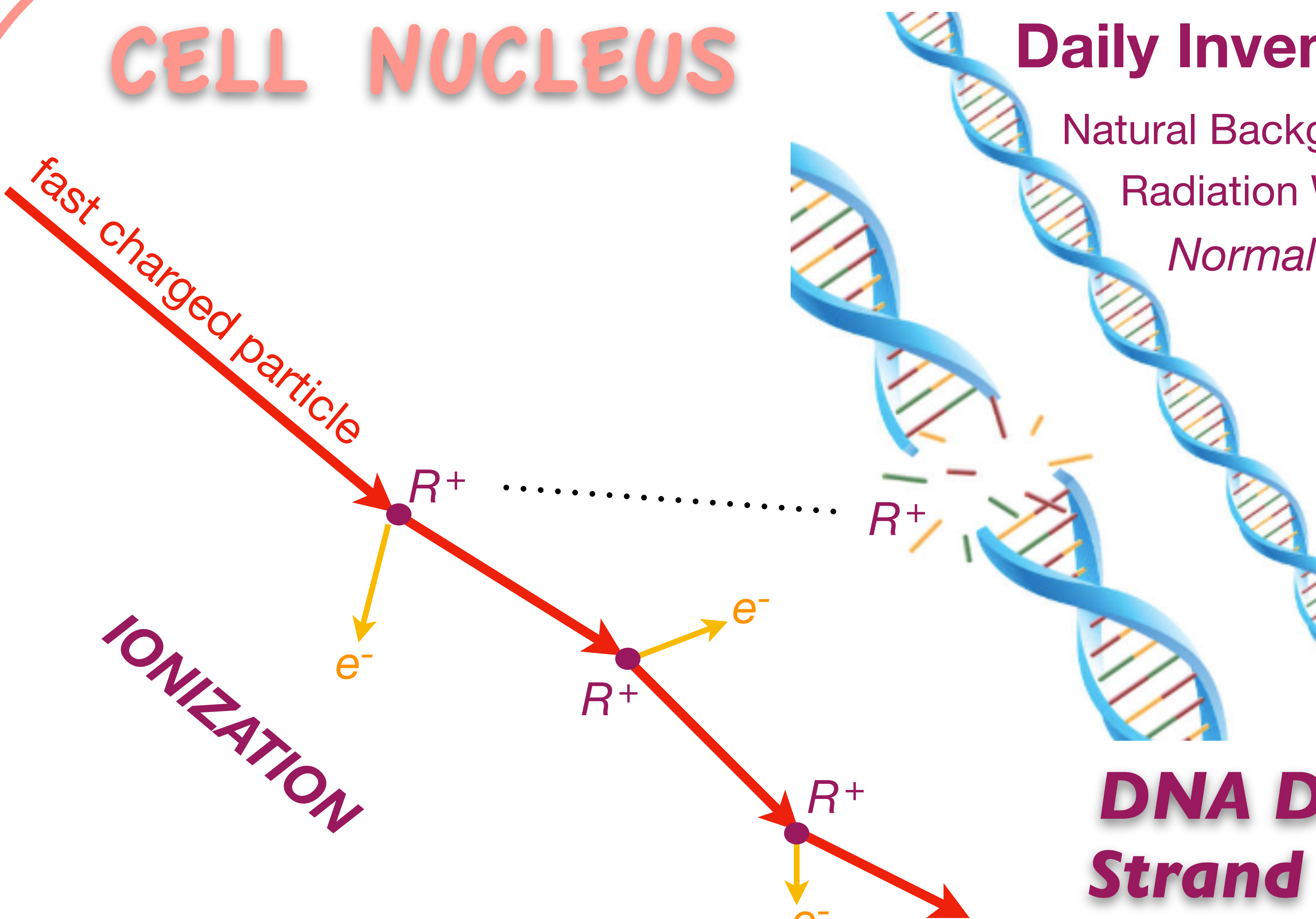
- Electrons (β-rays)
- Protons & Neutrons
- α-rays (^{4}He nuclei)
- Heavy Ion Beams

What *does* the Damage?

- *Enough intensity* of ***anything*** will "***cook***" you.
- *Highly reactive* ***free radicals*** produced by ***Ionizing Radiation***.

What does Radiation ***DO*** *to us?*

CELL NUCLEUS



Daily Inventory for 1 cell:

Natural Background Radiation:	**0.00005**
Radiation Worker (Max.):	**0.00137**
Normal Cell Metabolism:	**45**

Usual **healing** time: ***hours*** to ***days***

DNA Double *Strand Break* (DSB)

Ionizing Radiation → DNA Strand Breaks

Single strand breaks (SSBs) usually *heal* in *milliseconds*.

NIH: SSBs occur *naturally* more than 10,000 times a day in any single mammalian cell.

Double strand breaks (DSBs) can take longer to heal, and may even be *permanent*, causing…

- **Cell Reproductive Death** [most common]

Cells usually survive for their natural lifetimes — a few days for hair follicles, skin and mucous membrane cells; "forever" for brain cells and some muscle cells.

- **Genetic Mutation** [most subtle]

Damaged *gamete* cells → *mutations* (usually fatal to foetus; almost always detrimental to the individual offspring…)

- **Cancer** [most unpleasant]

Runaway replicative zeal of a misguided cell…

Cancer Therapy

Most cancer ***radiation therapies*** involve radiation insults that inflict DNA damage similar to that caused by “bad” radiation.

Strategy: to ***kill*** *every single cancer cell* (along with up to 90% of nearby normal cells).

Dose may be more than 10,000 times maximum legal limit for “accidental” radiation exposure… but not “whole body”.

Why Worry, and When?

Informed Consent *vs.* Public Policy

Cost/Benefit Analyses: *Every* public policy decision creates risks. Is this likely to do any good? How much good? Is it likely to do any harm? How much harm? What are the relative probabilities of good and harm? How many people are likely to suffer from the harm? How many people are likely to benefit from the good?

And of course the two questions most popular with politicians, "Which people?" and "When?"

Any sensible policy regarding radiation hazards, whether public or personal, must take into account that *each of us is going to die*, that our lifespan is frustratingly short no matter what we do, and that our chances of dying of cancer (radiation-induced or otherwise) are already rather high. (About 20%.)

Radiation Units

There is a big difference between a ***little*** and a ***lot***. To make rational distinctions requires *quantitative* measurements, which in turn require well defined and understood **units**.

ACTIVITY units

1 **Bequerel** (**Bq**) ≡ 1 radioactive decay per second.

1 **Curie** (**Ci**) ≡ 37 billion **Bq**

An isotope with a ***half-life*** of $T_{½}$ has a ***mean lifetime*** of

$$\tau = T_{½}/\ln 2 \approx 1.44\, T_{½}$$

and a ***decay rate*** of $\lambda = 1/\tau$

so a sample of N such nuclei will have an ***activity*** of

$$A = \lambda N = N \ln 2 / T_{½} \text{ Bq}$$

(if $T_{½}$ is measured in *seconds*)

Note: the *activity is higher* if the *lifetime is shorter*. (But not for long!)

Radiation DOSE Units

Units: 1 **rad** ≡ 100 erg/g (*energy deposited per unit mass*)
1 ***Gray*** ≡ 100 **rad** ≡ 1 J/kg. [***SI*** units]

*R*elative *B*iological *E*ffectiveness (*RBE*) "**fudge factor**":

- X-rays, γ-rays & β-rays (fast electrons): *RBE* = 1 (by definition)
- Slow neutrons: average *RBE* ≈ 3. (Variable!)
- Fast neutrons, protons & α-rays: *RBE* = 10.
- Fast heavy ions: *RBE* = 20.

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

1 R ≡ *RBE* × **rad**.
(1 mR ≡ *milliREM*] ≡ 10^{-3} R.)

Sievert (Sv) [***S***tandard ***I***nternational unit]:

1 Sv ≡ 100 *REM*

Problems with **DOSE UNITS:**

No mention of ***over what time*** the dose is *delivered*.

∴ Implicitly *assumed* that DNA damage is ***accumulative***.

Safety standards usually limit mSv *per* ***year***.

But normal cell oxygen metabolism also causes DNA DSB…

…and most DNA DSB ***heal*** within ***hours***.

Meanwhile, a healthy ***immune*** system is constantly eliminating lone cancer cells.

Still, the rare ***permanent*** DSB may occur, and under constant irradiation the number of such defects ***does*** accumulate.

How Bad is How Much of What?
EFFECTS of Penetrating Radiation

- **Instant Death**: ~ **50** Sieverts [Sv] "*whole-body*" can wipe out the central nervous system (CNS) *when delivered all at once*.
- **Overnight Death**: ~ **9** Sv whole-body may accomplish the same thing in about a day.
- **Ugly Death**: ~ **5** Sv → severe *radiation sickness* (nausea, hair loss, skin lesions, *etc*.) as short-lived cells fail to provide new generations to replace their normal mortality. Complications (infection) often kill. Some recover completely but may develop leukemia years later; offspring (if any) may have genetic mutations.
- **Sub-Acute Exposures**: ~ **1** Sv whole-body delivered all at once → no immediate symptoms, but possible leukemia (rarely, years later).

EFFECTS, cont'd

- **Marginal Exposures**: average exposure from *natural* sources in Canada ~ 180 mR (1.8 mSv) per year. (Nearly *twice* the Canadian legal limit for public exposure from *artificial* sources!)

Different body parts have dramatically different resistance to radiation.

Hands can withstand radiation doses that would *kill* if delivered to the whole body.

The ***lens of the eye*** and the ***gonads*** are considered to be the *most vulnerable*.

There is some evidence (*e.g.* from `Ramsar` and `Kerala`) for ***radiation hormesis*** (marginal exposures may actually *promote better health*).

Maximum Permissable *Occupational* Doses

USA & **Canada**

- Non-Radiation Worker: **1** mSv/year *vs*. **1** mSv/year
- Radiation Workers: **50** mSv/year *vs*. **50** mSv/year

- Natural Background (at sea level): **1.8** mSv/year
- Cosmic Ray Muons *alone*: **0.3** mSv/year (at sea level)

- Kerala Coast, India: **3.3** to **60** mSv/year
- Guarapari beach, Brazil: **175** to **482** mSv/year
- Ramsar region, Iran: up to **260** mSv/year

- Abdominal/Pelvic CT scan: **20-30** mSv (*all at once*)

Maximum Permissable Occupational Doses

USA & Canada converted to *μSv per day*

- Non-Radiation Worker: **3** μSv/day *vs*. **3** μSv/day
- Radiation Workers: **137** μSv/day *vs*. **137** μSv/day

- Natural Background (at sea level): **5** μSv/day
- Cosmic Ray Muons *alone*: **1** μSv/day (at sea level)

- Kerala Coast, India: **9 to164** μSv/day
- Guarapari beach, Brazil: **480** to **1320** μSv/day
- Ramsar region, Iran: up to **712** μSv/day

- Abdominal/Pelvic CT scan: **20,000-30,000** μSv (*all at once*)

Sources of Radiation

1972 survey of *average* doses to USA population:

Occupational and miscellaneous artificial exposures: ~ 1-2 mR/y.

Global fallout from nuclear testing: ~ 6 mR/y

Medical exposures (see below): ~ 100 mR/y

Natural background: ~ 120 mR/y. [*Extremely* variable!]

- **Medical X-rays**:

  Chest, radiographic: 45 mR per exposure
  Chest, photofluorographic: 504 mR per exposure
  Spinal (per film): 1265 mR per exposure
  Dental (average): 1138 mR per exposure, *localized*.

- **Cosmic Rays**:

  Sea level: 30-40 mR/y
  Colorado: 120 mR/y
  At 40,000 ft: 0.7 mR/*hour*.
  (One average round-trip transcontinental flight gives 6-8 mR)

Sources of Radiation, cont'd

- **Natural Terrestrial Radionuclides**:

  γ-radiation is fairly uniform in the U.S.A., ranging from 30 mR/y in Texas to 115 mR/y in South Dakota. (Guess where the uranium deposits are!)

  I don't have the numbers for the Okanagan, but I believe they are even higher than for South Dakota.

See also **xkcd chart**

The Really Bad Stuff: Ingested Radionuclides

Many radionuclides (radioactive isotopes) emit fast α particles (^{4}He nuclei). The range of most α "rays" is only ~ cm in air and ~ mm in tissue. ***Good*** if they are at arm's length; ***bad*** if you swallow them or breathe them! A wide variety of radioactive elements have assorted chemical properties, each with a specific hazard.

- **Radon**: All rock contains some *radium* which decays, releasing the chemically inert noble gas *radon*, itself a radioactive element which emits a low energy α (difficult to detect). Radon probably killed Madame Curie. Widespread and dangerous because it accumulates in the air of any building made of rock, brick or concrete (especially those with closed air circulation) and thence in the lungs of the people breathing that air, who become radioactive (easy to detect).

Different regions have a huge range of radium content, so a stone house may be perfectly safe in one place and hazardous in another.

Ingested Radionuclides, cont'd

- **Potassium & Carbon**: Radioisotopes of K and C are continually created in the atmosphere by cosmic ray bombardment and build up to a constant level in all living tissues, only to decay away in a few thousand years after death. *You are radioactive!* Potassium-Argon and ^{14}C dating provides handy means of estimating how long ago biological matter was alive.

- **Man-Made Radionuclides**: Formerly most famous: *plutonium*, ^{239}Pu, of which fission bombs are made. A deadly chemical poison as well as a nasty radioisotope, a miniscule grain caught in your lungs or other tissues exposes (only) nearby tissue to a huge dose. Newly famous: *polonium*, ^{210}Po, is made in reactors by adding neutrons to bismuth. It is an even deadlier poison.

Ingested Radionuclides, cont'd

The food chain concentrates "harmless" levels to dangerous ones; fission waste products include many radionuclides with chemical properties not seen in naturally occurring isotopes.

Otherwise it might be marginally sensible to dispose of radioactive waste by diluting it in the oceans.

Although radioisotopes from the Fukushima meltdown are easily `detected` in BC, the levels are utterly harmless.

In the 1960s we could detect parts per million (ppm) of Selenium (Se), a heavy metal which is *poisonous* at that concentration. The US Congress then passed a law making it illegal for any foodstuffs to contain a ***detectable*** amount of Se. A few years later we were able to detect parts per billion (ppb). That's when we discovered that Se is an ***essential mineral***. This illustrates the foolishness of any policy of "**zero tolerance**".

Protection Against Radiation

Best shielding is ***Gauss' Law***: intensity $\propto 1/r^2$.

Localized sources are labelled with their activity *at a given distance*, for instance "10 mr/h at 1 m".

Never *touch* a source! ($1/r^2 \to \infty$ as $r \to 0$).

Lead aprons are effective *only* for X-rays, γ-rays and low energy β-rays.

Thick concrete shielding is needed for neutrons and high-energy charged particles. (Visit TRIUMF sometime!)

For *ingested radionuclides*, ***chelation*** can sometimes help. In the case of *tritium* (^3H), one should drink lots of ***beer****!*