Illinois Institute of Technology

Physics 561
Radiation Biophysics

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Radiation Biophysics
Lecture 15:
Exposure from Natural and Man-Made Sources
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Week 15 Plans

- Radionuclides, concluded:
  - Uranium
  - Plutonium
- Exposure from natural & man-made sources
  - Population dosimetry
  - Natural sources
  - Man-made sources
- Outline of final

Uranium

- Plentiful in reactors and weapons
- Toxic to kidney independent of radioactivity
- Two plentiful isotopes: ^{235}U and ^{238}U
- ^{235}U
  - α emitter to ^{231}Th, $T_{1/2}=7*10^8$y
- ^{238}U
  - Much more common (99.3%)
  - α emitter to ^{234}Th, $T_{1/2}=4.5*10^9$y :
  - In 1 year, 1g of UO_2 produces $0.64*10^{-15}$ moles of ^{234}Th, i.e. $3.8*10^8$ depositions or 12 Bcq!

Plutonium

- Two common isotopes
  ^{238}Pu: $T_{1/2}$ = 86.4y and ^{239}Pu: $T_{1/2}$=24890 y
- Inhaled Pu in lung causes cancer and perhaps lymphatic-system damage
- Is it the most toxic substance in the world?
  - Available exposure routes limited
  - I wouldn't want to eat it, but there are worse toxins even among metals; biohazards are much worse per gram
  - Exposure through fallout:
    400 megacuries worldwide. That's a lot, but it still has to get inside of us.

What can and can't we control?

- Significant sources of risk from exposure to ionizing radiation to the population as a whole
  - Natural background
  - Diagnostic applications of ionizing radiation
- Anything else?
  - Therapeutic X-rays and isotopes:
    few people so population dose is tiny
  - Consumer applications (e.g. TV receivers):
    tiny per-person dose

Population Dosimetry

- Biologically effective dose:
  $H = \Sigma_{i=1}^{n} D_i Q_i N_i$
- This is an old way of doing things...
- Reference source of exposure:
  Whole-body exposure to γ rays
- Adjustments to dose depend on
  - Type of radiation
  - Portion of person irradiated

Why Consider Effective Dose?

- It enables us to compare radiation types & exposure modalities on a quasi-equal footing
- Unit of equivalent dose: *sievert* corresponds to the *Gray* for dose. *Rem* corresponds to *rad*.
- 1 Sv = 1 Gy if using reference exposure
- Equivalent dose $H_T = \Sigma_R w_R D_{T,R}$
- (Might underestimate health risks of the reference source!)
- High LET sources have high radiation weight factors, up to a point!

Radiation Weight Factors, w_R

Xrays, γ rays	1
e^-, e^+, μ	1
Neutrons	
– <10keV	5
– 10-100keV	10
– 100-2000 keV	20
– 2-20MeV	10
– > 20 MeV	5
Protons (non-recoil), > 2MeV	2
α particles, fission fragments	20
Relativistic heavy ions	20

Effective Dose

- Effective dose E is defined so that the probability of cancer and genetic effects is the same no matter where and how uniformly the deposition occurs:
  $E = \Sigma_T w_T H_T$
- Implicit here is the concept that w_R is independent of w_T, which isn't completely true; but it's close enough given how vague the values are!

Tissue Weight Factors, w_T

$w_T=0.01$	$w_T=0.05$	$w_T=0.12$	$w_T=0.20$
Bone surface	Bladder	Bone Marrow	Gonads
Skin	Breast	Colon	
	Liver	Lung	
	Esophagus	Stomach	
	Thyroid		
	Remainder		

Collective Dose

- Collective Dose *S*: the aggregate exposure received by a population of *N* individuals
- Thus if we know $<E>$ and *N* then (collective dose) $S = <E>N$ is proportional to expected number of cases of disease.
- Thus if at exposure level E P(cancer) = 10^{-5}, then in a population N = 10^6 we expect ~10 cancer cases
- This notion works well with stochastic endpoints

Risk Factors

- Weighting factor for any organ is the ratio of the risk for that organ to the total risk
- These estimates involve
  - Fatal cancers
  - Genetic risk
  - Life shortening
- Purpose:
  risk-weighted dose estimate for a mixture of types of radiation or for radiation of parts of the body

Total Stochastic Detriment

Lifetime risk coefficients, 10^{-2} Sv^{-1}

Organ	Population	w_T	Rad workers	w_T
Bladder	0.29	0.040	0.23	0.042
Bone Marrow	1.04	0.143	0.83	0.150
Bone Surface	0.07	0.010	0.06	0.011
Breast	0.36	0.050	0.29	0.052
Esophagus	0.24	0.033	0.19	0.034
Colon	1.03	0.142	0.82	0.148
Liver	0.80	0.110	0.64	0.116
Ovary	0.15	0.021	0.12	0.022
Skin	0.04	0.006	0.03	0.005
Stomach	1.00	0.138	0.80	0.145
Thyroid	0.15	0.021	0.12	0.022
Remainder	0.59	0.081	0.47	0.085
Gonads (genetic)	1.33	0.183	0.80	0.145
Grand Total	7.25	1	5.53	1

Natural Sources

- A few natural sources matter:
  - Soil-borne radionuclides
  - Airborne radionuclides
  - Cosmic rays from deep space
- Total Exposure from these sources: around 0.7 - 1.1 millisieverts per year
- Substantial concern in recent years about radon such that w_R = 20 for Rn.
- n.b.: should we actually consider indoor radon a natural source?
- Pay attention to fig. 16.1!

What are the natural sources?

- Series Primordial radionuclides starting mostly from ^{238}U, ^{232}Th, and ^{235}U; especially ^{222}Rn from ^{226}Ra
- Nonseries primordial radionuclides: ^{40}K, ^{87}Rb
- Cosmogenic radionuclides:
- elements in earth's crust or in atmosphere interact with cosmic rays
- Mostly ^{14}C, ^{3}H, ^{22}Na (and ^{7}Be)

Outdoor, Extracorporeal Sources

- Mostly uranium-thorium series but also some ^{40}K
- Varies widely from place to place: 150-1400 µGy per year depending on where you are
- What matters is gamma emitters here: $w_R=1$ because nothing else gets into the skin
- Typical ^{222}Rn exposure is 232µGy per year; with $w_R=20$, that's almost 5 millisieverts

Indoor, Extracorporeal Sources

- Depend slightly on the method of construction
  - What is the source of the building material?
  - How leaky is the building (especially for ^{222}Rn); Well-insulated buildings deliver a high body burden because we're trying not to have to heat them so much--so the gas stays in the house
- Almost all uranium-thorium series stuff

Inhaled Radionuclides

- ^{222}Rn is the inhalation culprit
- Study in New York gave some big numbers for total body burdens received:
  1.9-3 mGy/year, I.e. around 38-60 millisieverts!
- This is actually equal to the occupational limit, so something is wrong: either we need to get radon out of our houses or we need to revise the occupational limits upward.

Nonseries Radionuclides

- ^{40}K and ^{87}Rb get into the body through ordinary metabolism. $w_R=1$.
- Typical doses for ^{40}K:
  - 180 µSieverts/year to gonads
  - 60 µSieverts/year to bone
  - 270 µSv per year to bone marrow
- Typical doses for ^{87}Rb:
  - 10 µSieverts/year to gonads
  - <10 µSieverts/year to bone
  - 10 µSv per year to bone marrow

Cosmic Rays and Cosmogenic Radionuclides

- Varies a lot by location
  - The higher in altitude you are, the more you get
  - Also, the portion contributed by neutrons goes up as you go higher in altitude
  - Some variation by latitude and longitude

Man-Made Sources

- Major contributors to population dose are:
  - Medical diagnostic procedures
  - Smoking (!) ^{210}Pb, ^{210}Po
- Individual burdens:
  - Diagnostic
  - Smoking
  - Therapeutic use of x-rays, γ
- Recall discussion of additive vs. multiplicative risk
- I encourage you to read the details about anthropogenic sources, but I won't test you on them.

Our very last homework assignment

- This one is due on the day you take the final!
- Okay, here goes:
- Using the radiation weighting factors and tissue weighting factors given in tables 16.1 and 16.2, calculate the effective dose E delivered to an individual if she receives a dose of 1 milligray of ^{222}Rn to her lung.

Final Exam

- 2:40 total time
- Open book, notes, no other books
- Vertical distribution
  - 40% final four chapters
  - 30% initial 12 chapters
  - 30% synthetic, i.e. incorporating old and new
- Horizontal distribution
  - 40% 2 or 3 essays (English!)
  - 40% 2 - 3 numerical problems
  - 20% 8 definitions & short answers
  - 5% extra credit