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Health effects of internal alpha emitters, dosimetry

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Structure

- ICRP methodology for calculating doses from internal emitters

- Is ‘effective dose’ an adequate protection quantity for internal emitters?
    - Compare risks from alpha and external radiation

- Recent developments in ICRP methodology for internal dosimetry

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Differences between internal and external dosimetry

- The source of irradiation is the decay of radionuclides in one or more of the organs of the body
- Internal doses can’t be measured directly (and so models have to be used extensively)
- Internal doses are protracted over time
- Short range (non-penetrating) radiation (α, β, etc.) make a significant contribution to internal dose
- The distribution of absorbed dose between organs is often very inhomogeneous

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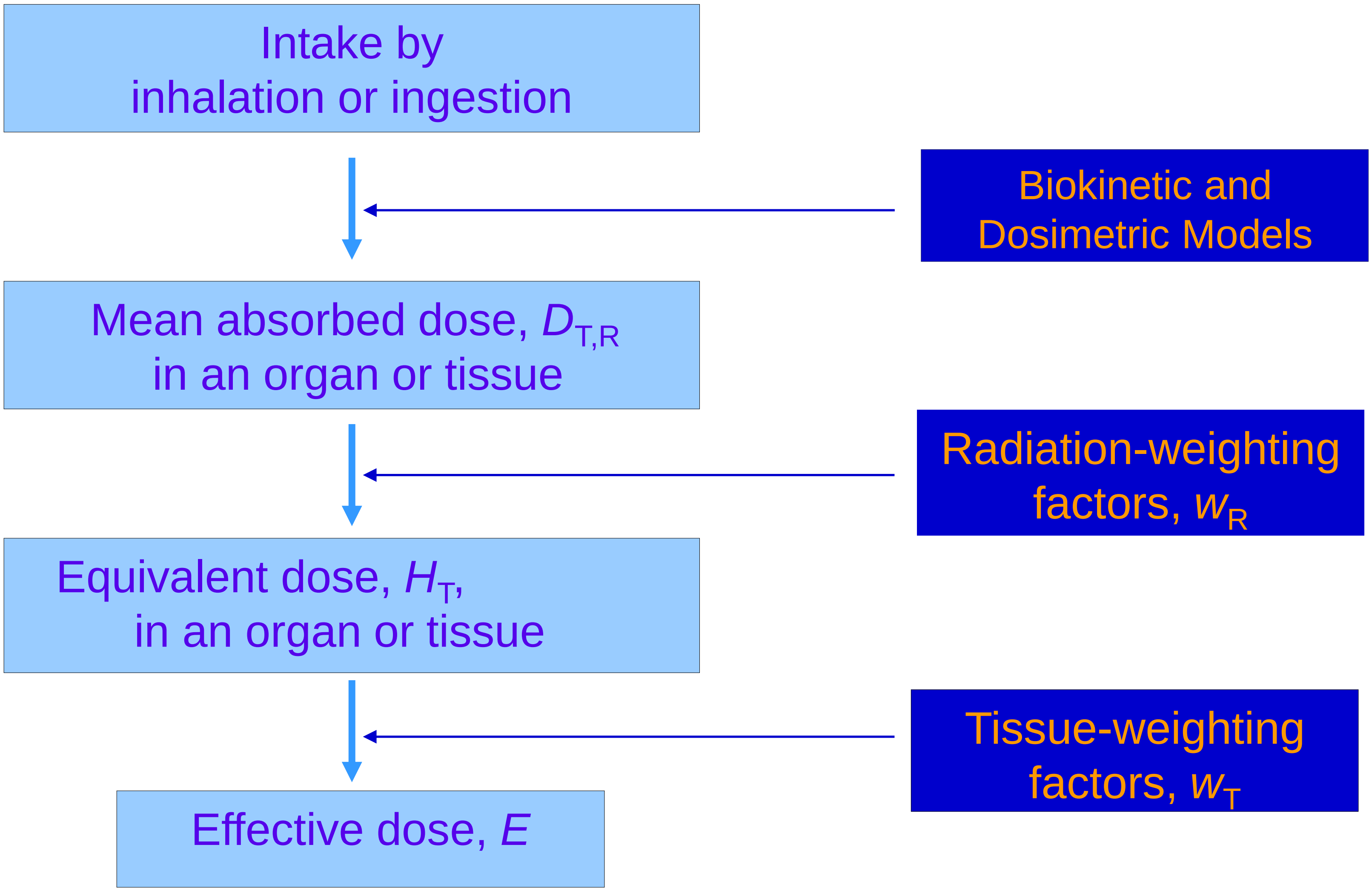
Effective dose

- Applies to stochastic effects only
- Assumes no threshold
- Allows summation of doses from different radionuclides, and with external dose
- Allows comparison with dose limits / constraints

Calculation of equivalent and effective dose for internal emitters

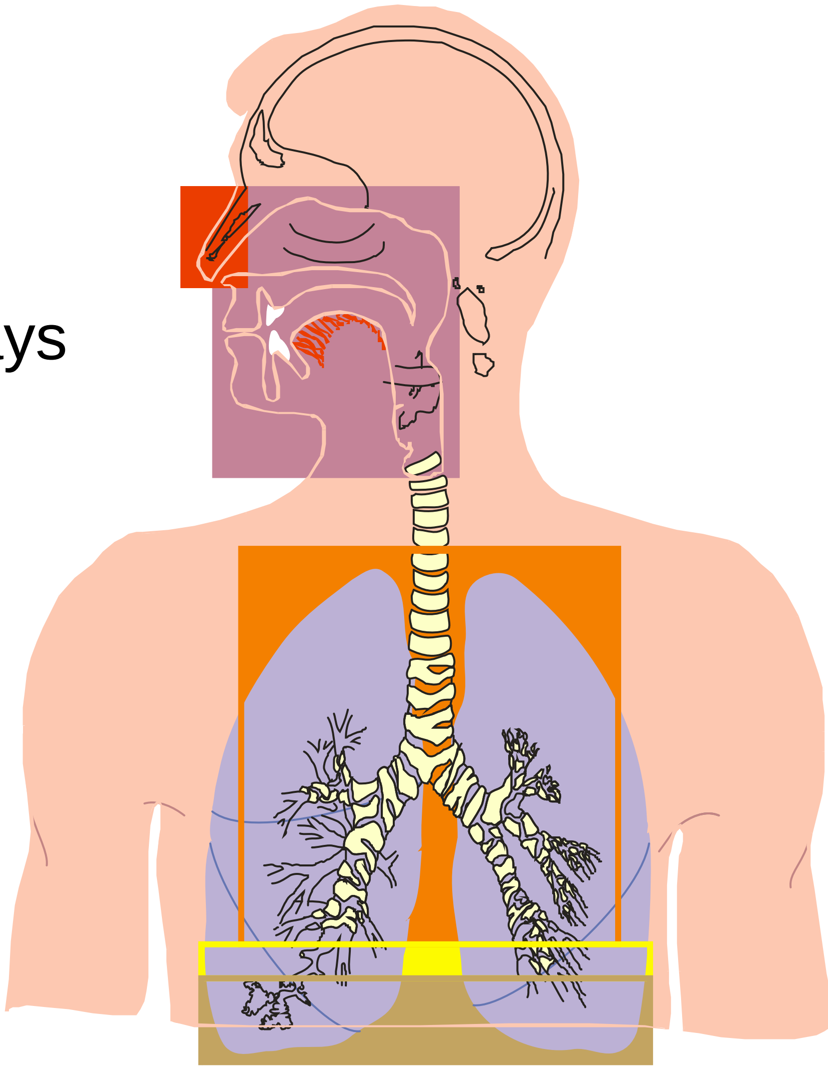


Human Respiratory Tract Model (HRTM); ICRP 1994

Extrathoracic airways

Bronchial

Bronchiolar
Alveolar interstitial



ET_1

ET_2

BB

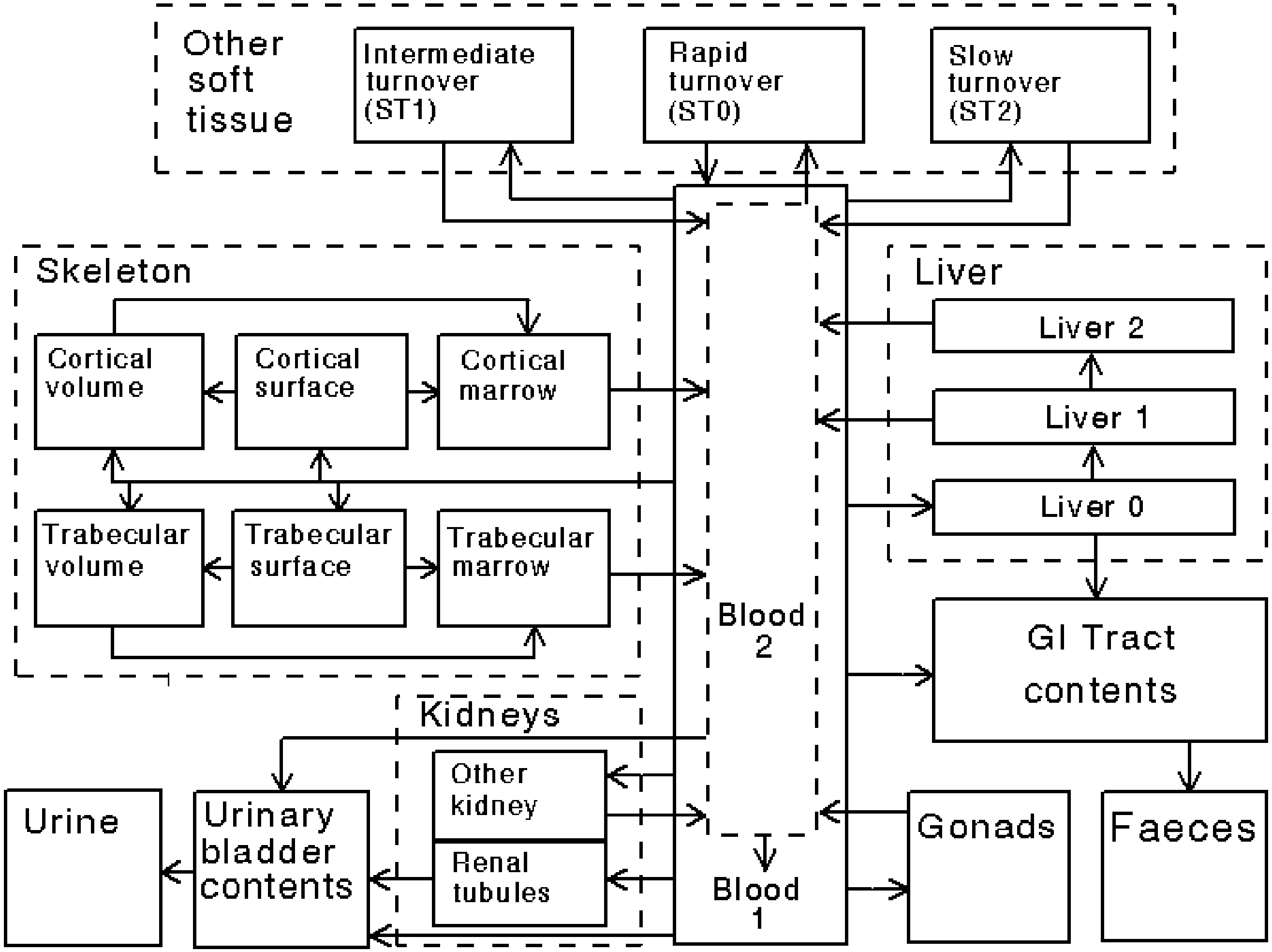
bb
AI

airway generations

0 - 8

9 -15

ICRP systemic biokinetic model for plutonium



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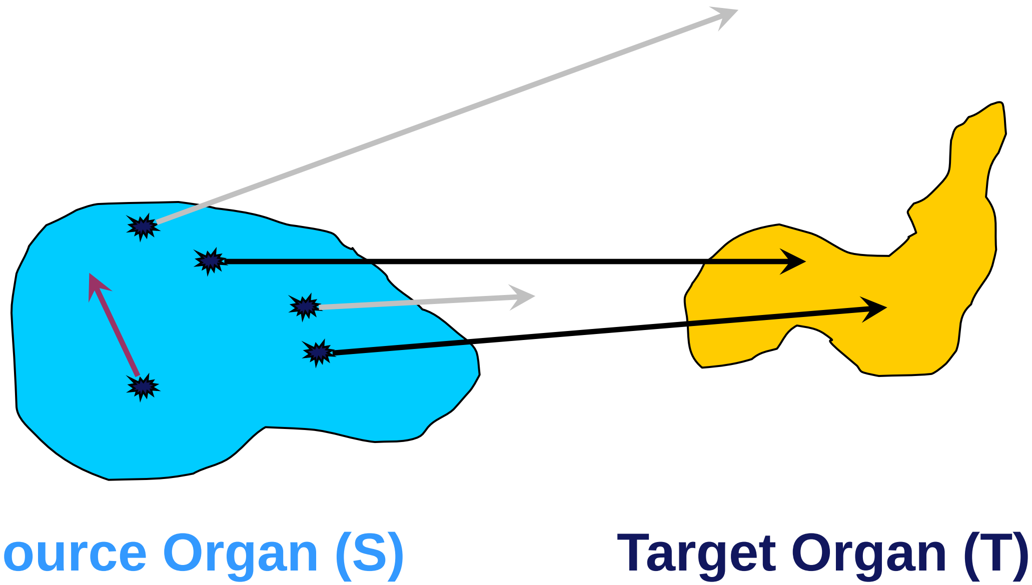
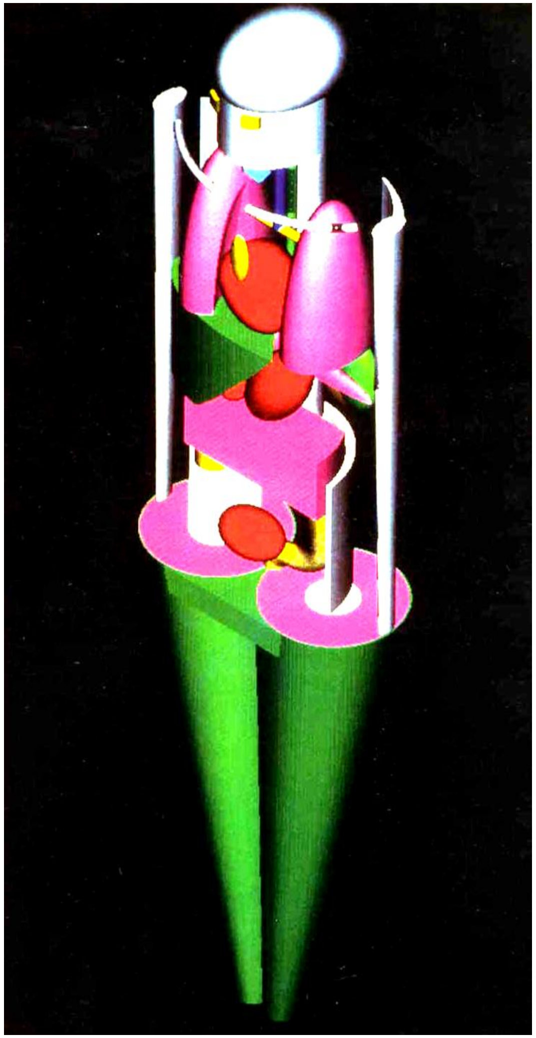
Dosimetry models

MIRD phantom





Effective dose applies to a reference person

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Weighting factors – simple risk adjustments

Radiation weighting factors, W_R

W_R = 1 for all low-LET radiation (e.g. gamma)

W_R = 20 for alpha particles for all types of cancer.

- Based on relative biological effectiveness (RBE) of alpha particles compared to gamma

Tissue weighting factors, W_T

Simple set of fractions which apply to all ages and both sexes.

- Based on relative detriment of individual organs from stochastic effects

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Detriment-adjusted nominal risk coefficients (10^{-2} Sv^{-1}) ICRP Publication 103, (2007)

	Cancer	Hereditary	Total
Worker	4.1	0.1	4.2
Public	5.5	0.2	5.7

- Based on cancer incidence weighted for lethality and life impairment
- Cancer incidence derived from epidemiological studies of Japanese atomic bomb survivors exposed largely to gamma rays

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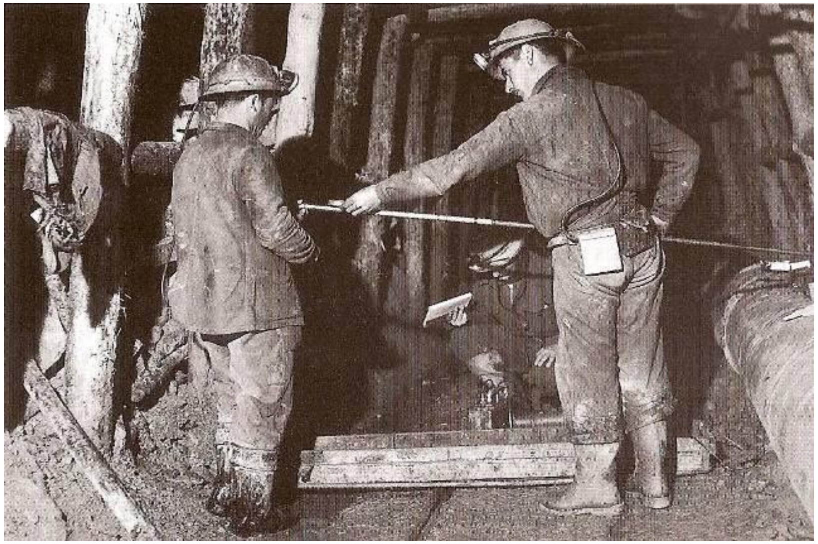
Lung cancer risks



- Radon progeny
  - Uranium miner, and
  - Residential studies

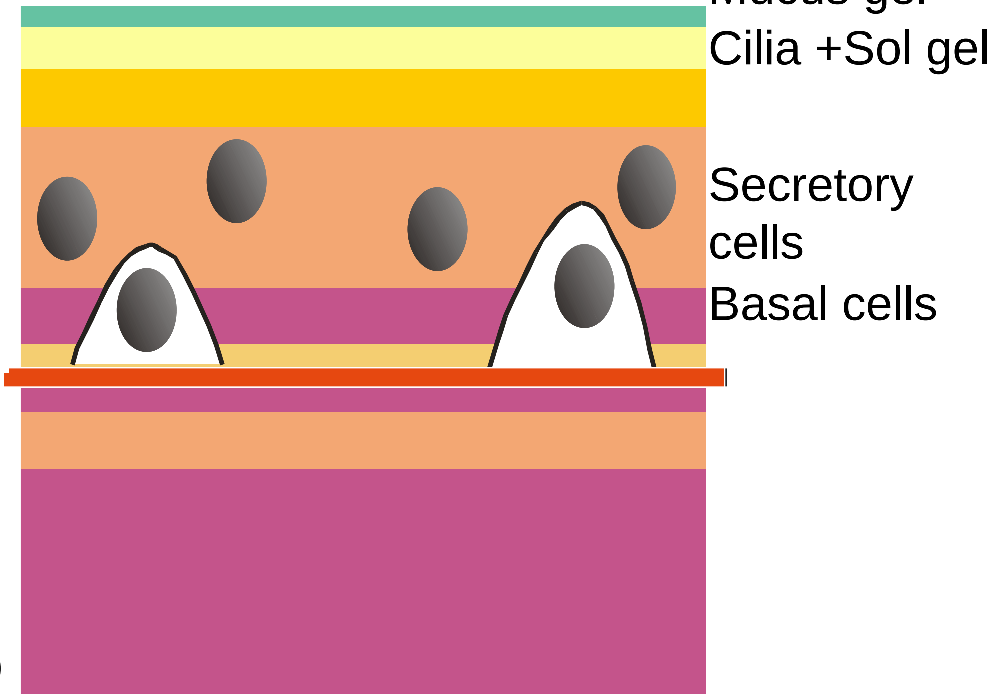
- Plutonium workers
  - Mayak nuclear facility, Russia
- Gamma radiation - Japanese atomic bomb survivors

Radon Dosimetry

The HRTM is used to calculate the absorbed dose to each of the 3 regions of the lung for a given exposure to radon progeny:

- bronchial region (BB)
  - $D_{BB} = ½ (D_{bas} + D_{sec})$
- bronchiolar region (bb)
- Alveolar-Interstitial region (AI)

Bronchial (BB) wall for dosimetry



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Detriment-weighted absorbed lung dose from inhalation of radon progeny for a miner

Region	Absorbed dose (mGy/WLM)
Bronchial ($D_{BB} = 0.5\ D_{sec} + 0.5\ D_{bas}$)	6.7
Bronchiolar (D_{bb})	7.0
Alveolar interstitial (D_{AI})	0.40

Detriment-weighted absorbed lung dose,

- $D_{lung} = ⅓D_{BB} + ⅓D_{bb} + ⅓D_{AI} = 4.7$ mGy per WLM
  - ➢ Assume risk is equally partitioned between the 3 regions of lung

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Plutonium dosimetry (MWDS-2008)

- Intakes and doses are assessed from urine data
- HRTM and systemic biokinetic model for plutonium model was implemented.

- Absorbed dose to lung calculated as:

$$= \frac{\text{Energy deposited in whole lung}}{\text{Mass of lung (1.1 kg)}} \approx \text{Dose to AI region}$$

The dose to BB and bb regions were effectively ignored.

➢ However, most of dose is to AI region

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Comparison of lung cancer risk estimates from alpha radiation for males

French uranium miner cohort (Rage et al. 2012)
Detriment-weighted absorbed lung dose

ERR per Gy: 4.5 (95% CI: 1.3 – 11)

Mayak Workers (MWDS-2008) (Gilbert et al. 2013)
Average absorbed lung dose
(i.e. mass-weighted absorbed lung dose)

ERR per Gy at age 60: 7.4 (95% CI: 5.0 – 11)

Risks are consistent but the doses were calculated differently.

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Estimation of RBE values of alpha particles for induction lung cancer

Comparison with risk estimates from life span study (LSS) of Japanese A-bomb survivors.

French uranium miner cohort (Rage et al. 2012)

Alpha: ERR per Gy: 4.5 (95% CI: 1.3 – 11)

LSS mortality data

Gamma: ERR per Sv: 0.48 (0.23-0.78)

Inferred RBE: 9

Mayak Workers (MWDS-2008) (Gilbert et al. 2013)

Alpha: ERR per Gy at age 60*: 7.0 (95% CI: 4.8 – 10)

LSS mortality data

Gamma: ERR per Sv: 0.36 (0.04-0.78)

Inferred RBE: 19

*Based on analyses with common attained age parameter for Mayak and LSS

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Comparison of lifetime excess absolute risk (LEAR) estimates

Risk model	Exposed population (ICRP, 2007)	Lifetime lung cancer risk (WLM^{-1})	Lifetime lung cancer risk (Gy^{-1})	Lung detriment[(a)] (Sv^{-1})	Inferred RBE
Miner studies ICRP, 2010	Sex-averaged	5.0×10^{-4}	0.12 [(b)]	1.21×10^{-2}	10
	Males	7.0×10^{-4}	0.16[(b)]	8.00×10^{-3}	21
Mayak workers Gilbert, et al., 2013	Males		0.15	8.00×10^{-3}	19

a) Values taken from ICRP Publication 103, (ICRP, 2007).

b) A detriment-weighted absorbed lung dose of 4.3 mGy WLM^{-1} was calculated with the revised HRTM for a miner.

Mayak calculations (ICRP Task Group, Tirmarche et al.)

LEAR up to age 90 y following a constant chronic intake of ^{239}Pu oxide between the ages 18 y- 64 y.

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ICRP developments in internal dosimetry

ICRP will provide new dose coefficients and bioassay quantities for inhalation and ingestion following the 2007 Recommendations (ICRP Publication 103)

- New human alimentary tract model (ICRP Publication 100)
- New systemic biokinetic models for some elements
- A revised human respiratory tract model
  - Longer retention in AI region for insoluble particles. → Greater lung dose
  - Review of lung-to-blood absorption characteristics of materials
- Adoption of male and female voxel phantoms
- Modification to the definition of effective dose
  - Sex-averaging in the calculation of effective dose

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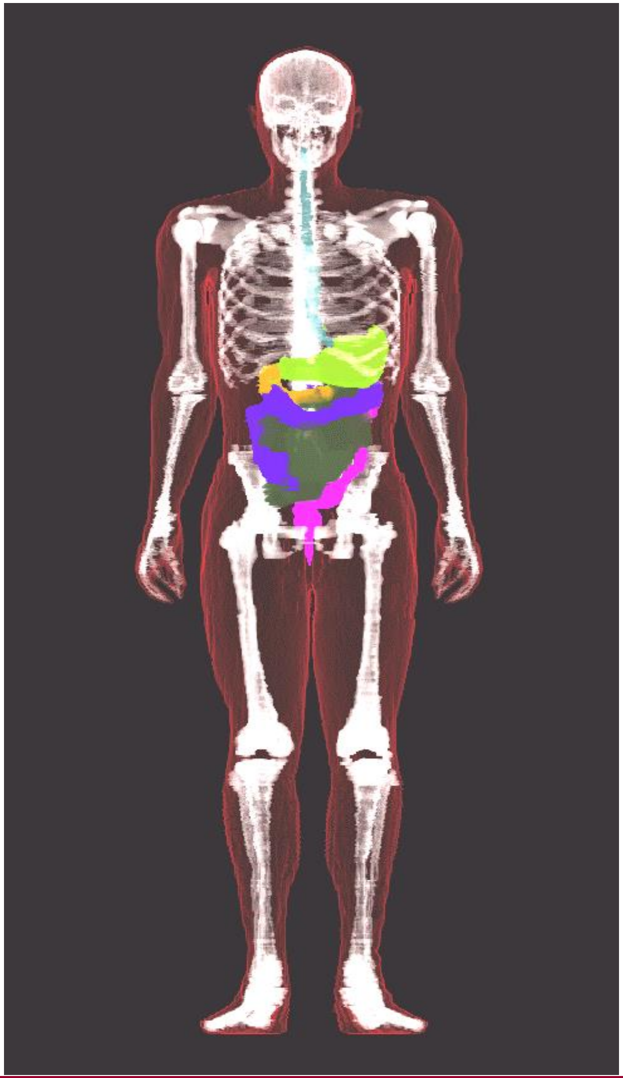
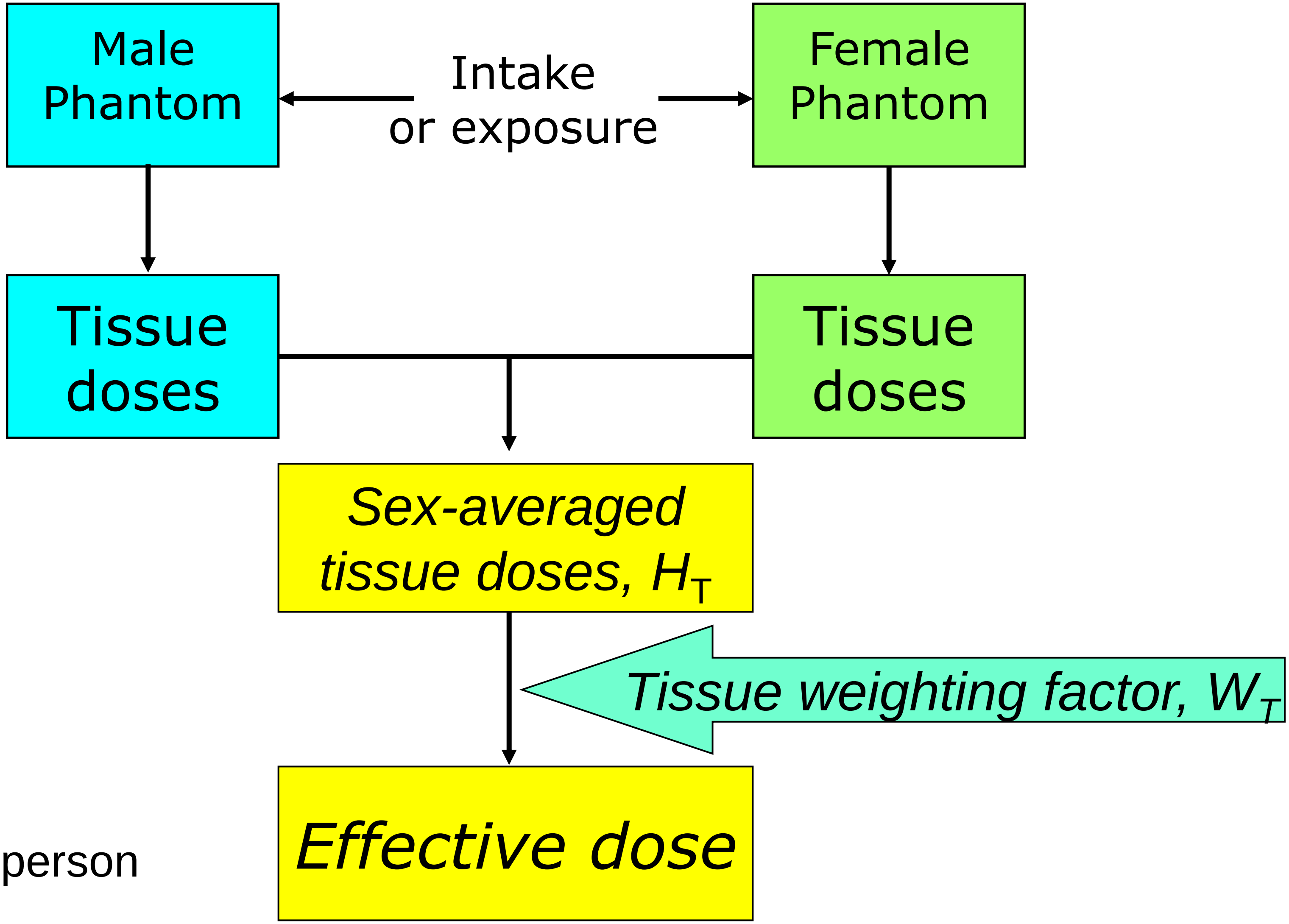
Voxel phantoms



- New male and female voxel phantoms
- New specific absorbed fractions (SAF)
- New nuclear data
- New S-coefficient (i.e. equivalent dose in target tissue per nuclear decay in source tissue

Sex averaging in the calculation of effective dose coefficient



Reference person

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Main points (1)

- Regional lung dose distribution differs
  - Radon progeny: most to BB and bb regions (97%)
  - Plutonium: most to AI region (55% nitrates; 80% oxides)

- ERR per unit ‘absorbed lung dose’ of alpha radiation is similar for French uranium miner and Mayak worker studies

- However, to compare risks from radon progeny and plutonium calculate detriment-weighted absorbed lung dose.

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Main points (2)

- New dosimetry system for Mayak workers give doses that are a factor of ~2.5 higher for plutonium nitrates.
  - ➢ this **may** lead to lower risks.
  - ➢ but still in agreement with risks estimates from radon progeny

- Comparison of lifetime risks from inhalation of radon progeny or plutonium with that from exposure to low-LET radiation indicate RBE values of 10 or 20

- A radiation factor, w_R of 20 for alpha particles seems reasonable for radiation protection purposes.

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Thank you for your attention

Acknowledgements

ICRP C1-task group 64 ; Headed by Margot Tirmarche

calculated the lifetime risk estimates for alpha emitters