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Internal dosimetry: ICRP models and data

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Two systems for internal dosimetry

Common scientific base

MIRD	ICRP
Biological endpoints	Risk estimations
Time of intake and intake usually known	Time of intake and intake can be unknown

Medical Internal Radiation Dose

ICRP-MIRD

- Calculation of absorbed dose is fundamentally similar in both systems
- Harmonization of concepts proposed in MURD Pamphlet No. 21, 2009.

(The Journal of Nuclear Medicine, 50(3), 2009.)

Pathways

Ingestion

Inhalation

Injection/Wounds

Absorption (intact skin)

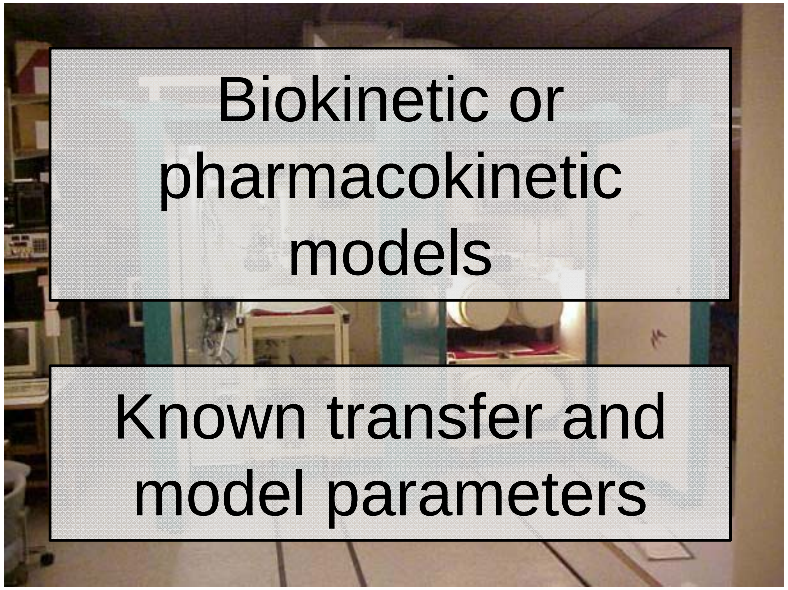
Difficulties in internal dosimetry compared to external dosimetry

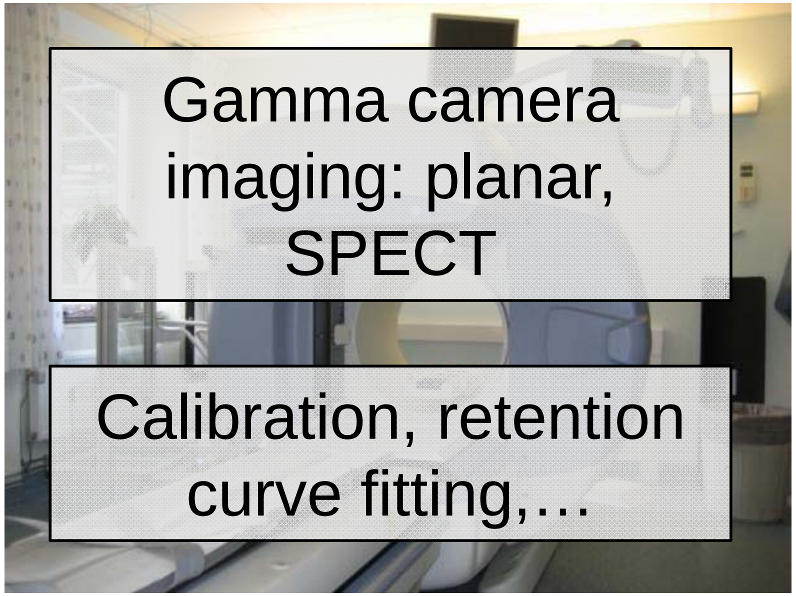
- You cannot measure internal dose
- Inhomogeneous distribution of the radionuclide within the body (and even within organs)
- Internal doses are protracted
- Different behaviour between elements

→ Models and calculations

Two types of dose estimations

Dynamic modelling	Direct measurements
Biokinetic or pharmacokinetic models	Gamma camera imaging: planar, SPECT
Known transfer and model parameters	Calibration, retention curve fitting,…
Input data from e.g. whole body counting	Calculations using the MIRD formalism
E.g. IMBA	E.g. OLINDA-EXM





Basic quantities

Equivalent dose (Sv) $$H_T = \sum_R w_R \cdot D_{T,R}$$

- To organ or tissue *T*
- Radiation weighting factors from ICRP 60 (ICRP 103) – stochastic effects

Effective dose (Sv) $$E = \sum_T w_T \cdot H_T$$

- Dose to the whole body that causes the same detriment
- Tissue wighting factors from ICRP 60 (ICRP 103) – stochastic effects

Basic quantities - internal

Committed equivalent dose (Sv)

$$H_T(\tau) = \int_{t_o}^{t_0+\tau} \dot{H}_T(t)dt$$

– Integration time usually 50 y for adults & 70 y for children

Committed effective dose (Sv)

$$E(\tau) = \sum_T w_T \cdot H_T(\tau)$$

– Calculated with dose coefficients $e(\tau)$ (Sv Bq^{-1}) from e.g. ICRP 72

Dose coefficients (ICRP 72)

Table A.1. Ingestion dose coefficients, $e(\tau)$, to age 70 y (Sv Bq^{-1})

Nuclide	Physical half-life	f_1	$e(\tau)$	f_1	$e(\tau)$				
		<1y	3 months	≥1y	1 Year	5 Years	10 Years	15 Years	Adult
Hydrogen[a]									
Tritiated Water	12.3 y	1.000	6.4E-11	1.000	4.8E-11	3.1E-11	2.3E-11	1.8E-11	1.8E-11
OBT	12.3 y	1.000	1.2E-10	1.000	1.2E-10	7.3E-11	5.7E-11	4.2E-11	4.2E-11
Beryllium									

Table 2. Biokinetic data and models used to calculate committed effective dose per unit intake via inhalation for exposure to particulate aerosols or to gases and vapours for members of the public

Element	Lung absorption Type(s)[a]	Classes for gases/vapours[c]	ICRP for details of biokinetic model[d] and absorption Type(s)
Hydrogen	F, M[b], S	SR-1, SR-2[d]	*56*, *67* and *71*
Beryllium	M, S		*30, Part 3*
Carbon	F, M[b], S	SR-1, SR-2[e]	*56*, *67* and *71*
Fluorine	F, M, S		*30, Part 2*

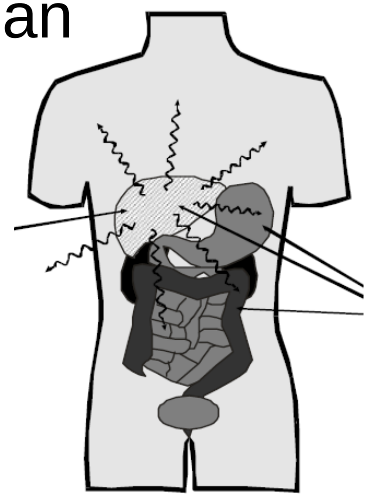
What´s behind the dose coefficients?

- Anatomy and physiology – reference man (ICRP 23)

- Source and target organs (ICRP 30)

- Absorbed fraction
  - Specific Absorbed Fraction SAF(T←S)

- Number of decays in source organ, in 50 y
  - Biokinetic models



Specific Effective Energy, SEE(T←S)

Y_R: yield per disintegration (radiation R)

E_R: energy

w_R: radiation weighting factor

$AF_R(T \leftarrow S)$: absorbed fraction

M_T: mass of target tissue

$$SEE(T \leftarrow S) = \sum_R \frac{Y_R \cdot E_R \cdot w_R \cdot AF_R(T \leftarrow S)}{M_T}$$

How to calculate the committed effective dose

- Number of decays, U_s
  - Activity in source organ, s
  - Biokinetic models
- Specific Effective Energy, SEE(T←S)
- Committed equivalent dose $$H_T(50) = \sum_s U_S \cdot SEE(T \leftarrow S)$$
- Committed effective dose $$E(50) = \sum_T w_T \cdot H_T(50)$$

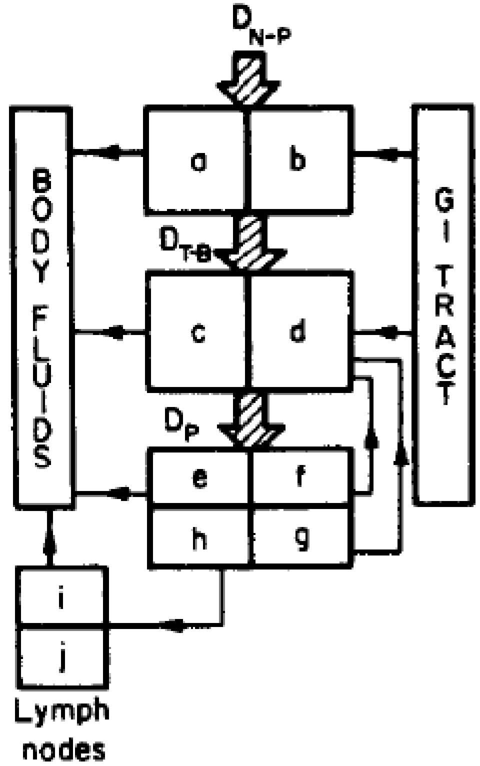
How to determine U_s – ICRP 30-models

To some extent replaced by refined models, but still in use

- Lung model
  - Retention of inhaled activity – calculation of lung dose
  - Transfer to blood through absorption
  - Transfer to GI tract through mechanical transport of particles
- GI tract model
  - Retention of ingested activity – dose to GI tract
  - Fraction absorbed to blood (f_1)
- Systemic models, metabolic – element specific

Lung model (ICRP 30)

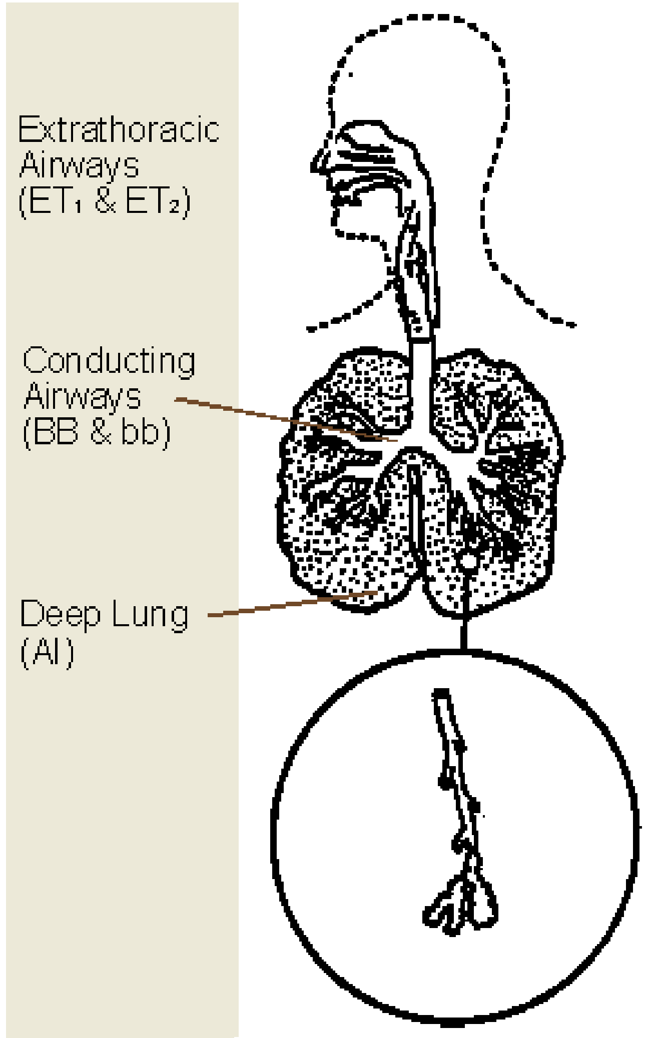
- Was not designed to model biokinetic behaviour
- Conservative estimation of doses
- Calculates the number of decays in different regions



N-P: Nasal Passage; T-B: Tracheo-Bronchial region; P: Pulmonary region; Distribution determined by chemical solubility

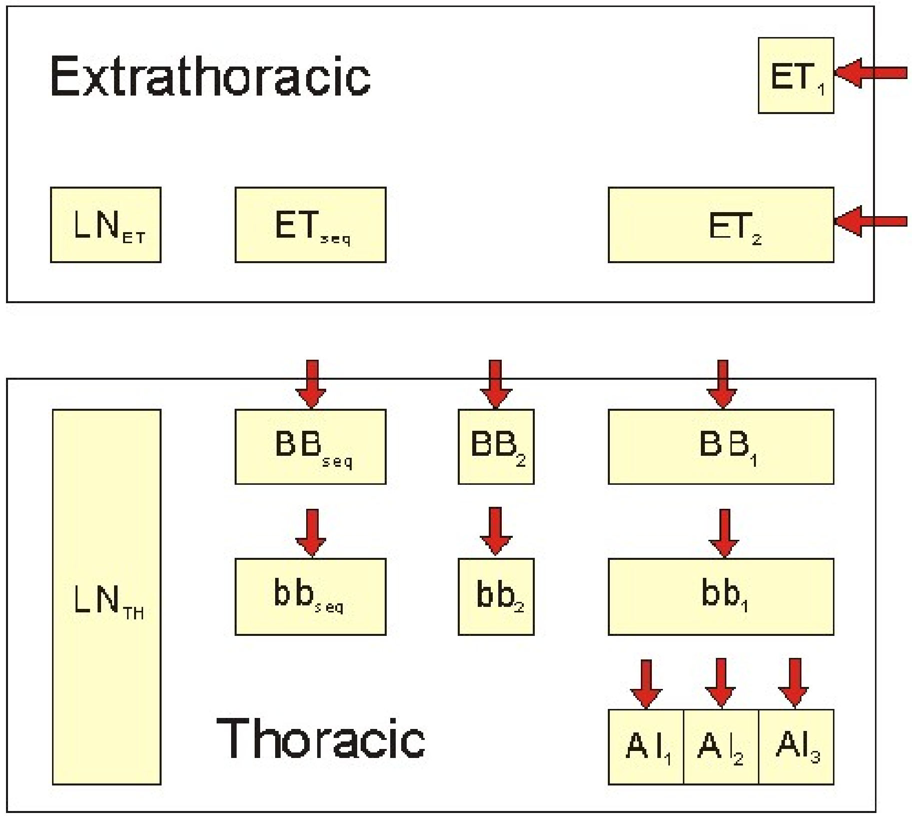
Lung model (ICRP 66) - regions

- Can be applied for workers and the public for inhalation of particles, gases and vapours
- ”Reference worker” = a male breathing normally through the nose while performing light work

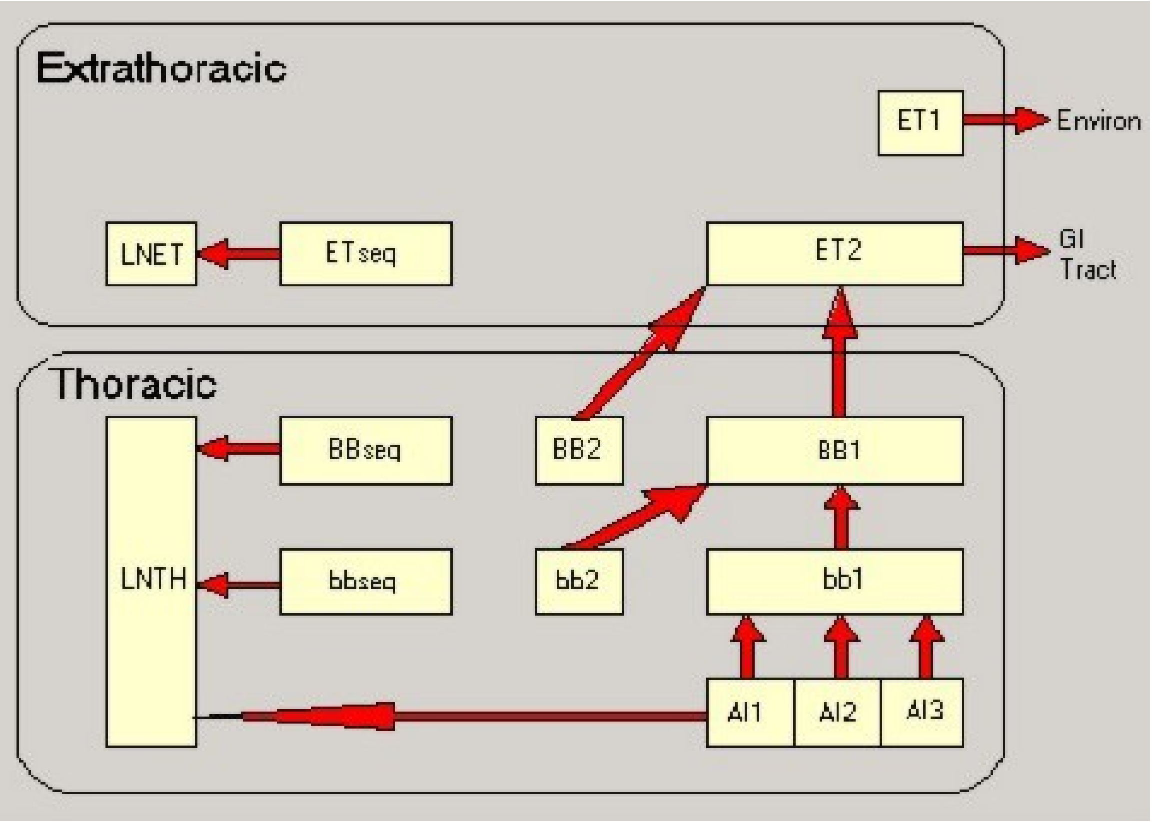


Lung model (ICRP 66) – particle deposition

- Regions divided into compartments
- Particle size given by the AMAD (Activity Median Aerodynamic Diameter), often 5 μm

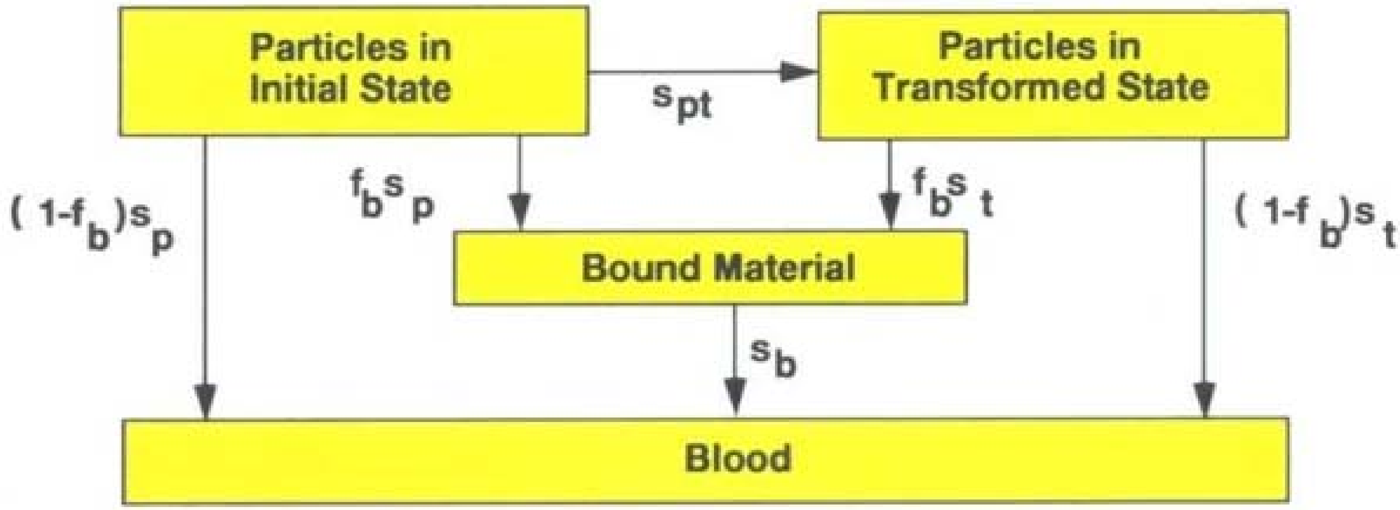


Lung model (ICRP 66) – particle transport

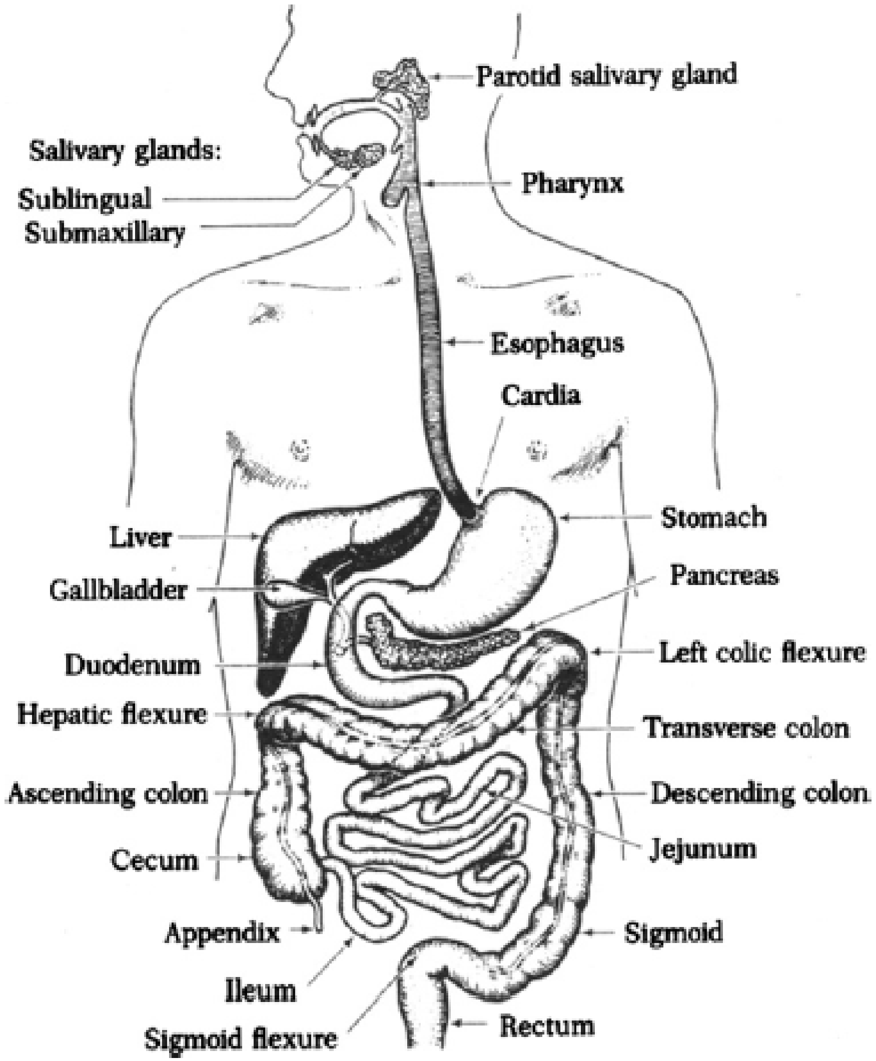


Lung model (ICRP 66) - absorption

- Compartment model for absorption to blood from all regions except ET_1
  - Three types of absorption: fast (F), moderate (M) and slow (S); determines the choice of parameter values



GI tract model (ICRP 30) - anatomy



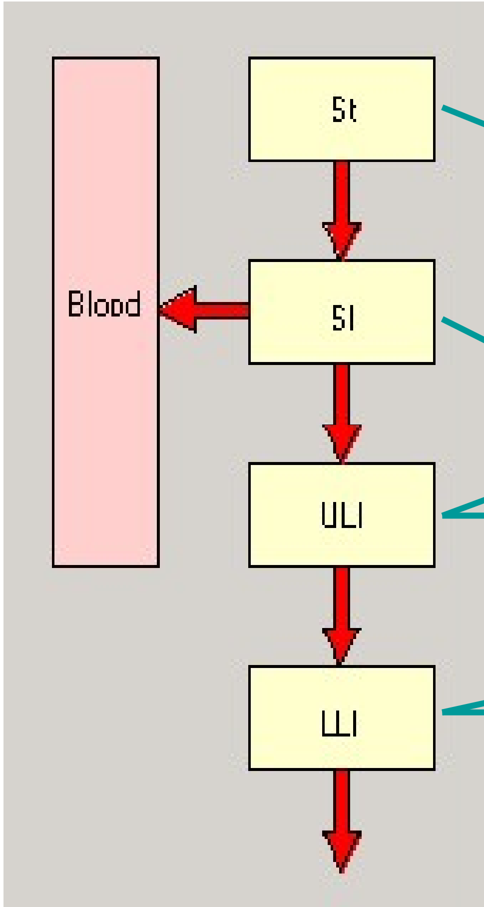
GI tract model (ICRP 30) - compartments

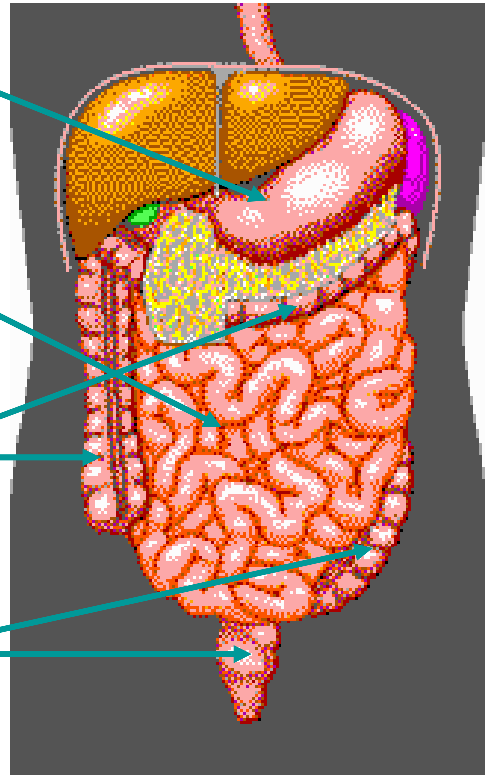
Stomach

Small intestine

Upper large intestine

Lower large intestine





www.innerbody.com

GI tract model (ICRP 30) – absorption to blood

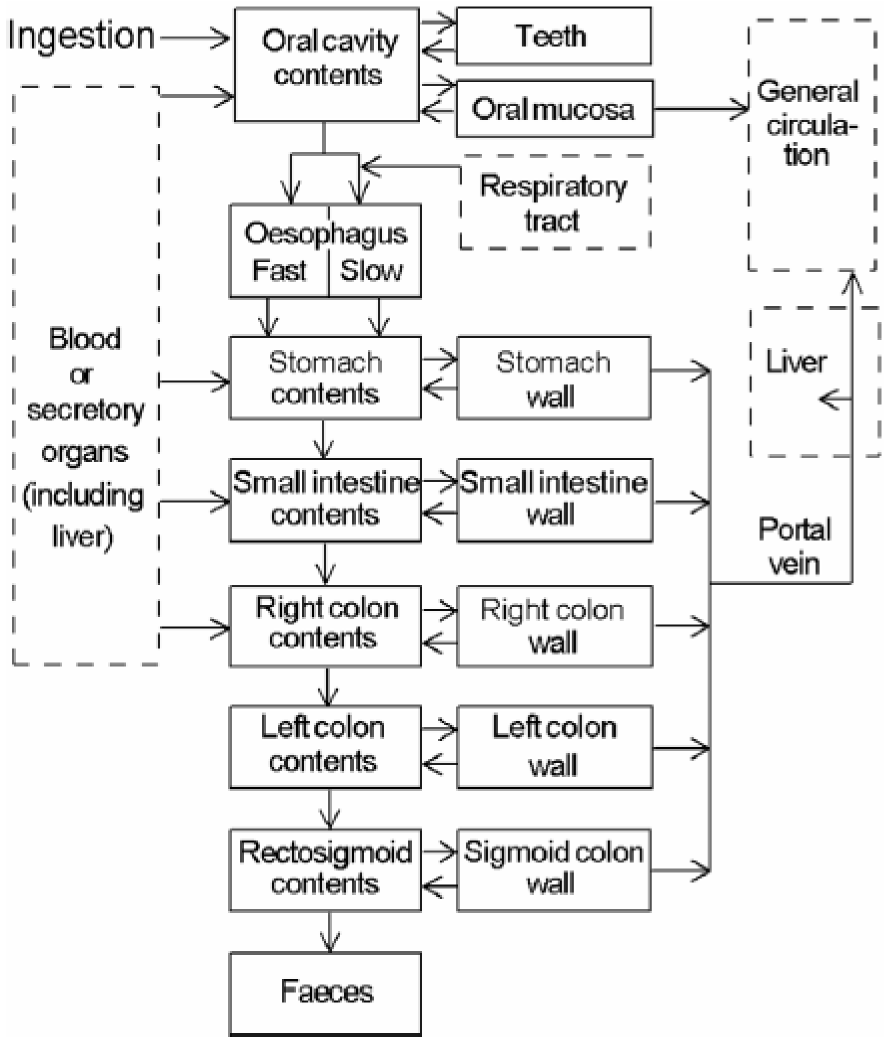
- Transfer to blood determined by f_1 (fraction of ingested activity that reaches the blood):

$$f_1 = \frac{\lambda_B}{\lambda_B + \lambda_{SI}}$$

- Transfer parameters, λ (d^{-1}), and mean residence time (h)

St $\rightarrow$ SI (λ_{St})	24 d^{-1}; 1 h
SI $\rightarrow$ blood (λ_B)	$6f_1/(1-f_1)$
SI $\rightarrow$ ULI (λ_{SI})	6 d^{-1}; 4 h
ULI $\rightarrow$ LLI (λ_{ULI})	1,8 d^{-1}; 13 h
LLI $\rightarrow$ outside (λ_{LLI})	1 d^{-1}; 24 h

GI tract model (ICRP 100)



Metabolic models

Describe the kinetics of a substance after it has entered the blood by

- absorption from lungs
- absorption from GI tract
- skin, wounds or injection

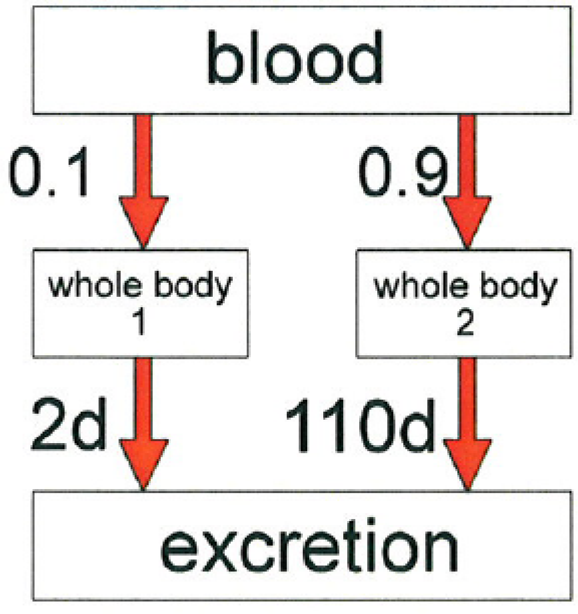
Metabolic models (ICRP 30)

- Rather simple models (except alkaline earth metals)
- For calculating the number of decays in each organ
- Not designed to model transfer rates lungs-blood or excretion rates

Metabolic models (ICRP 30)

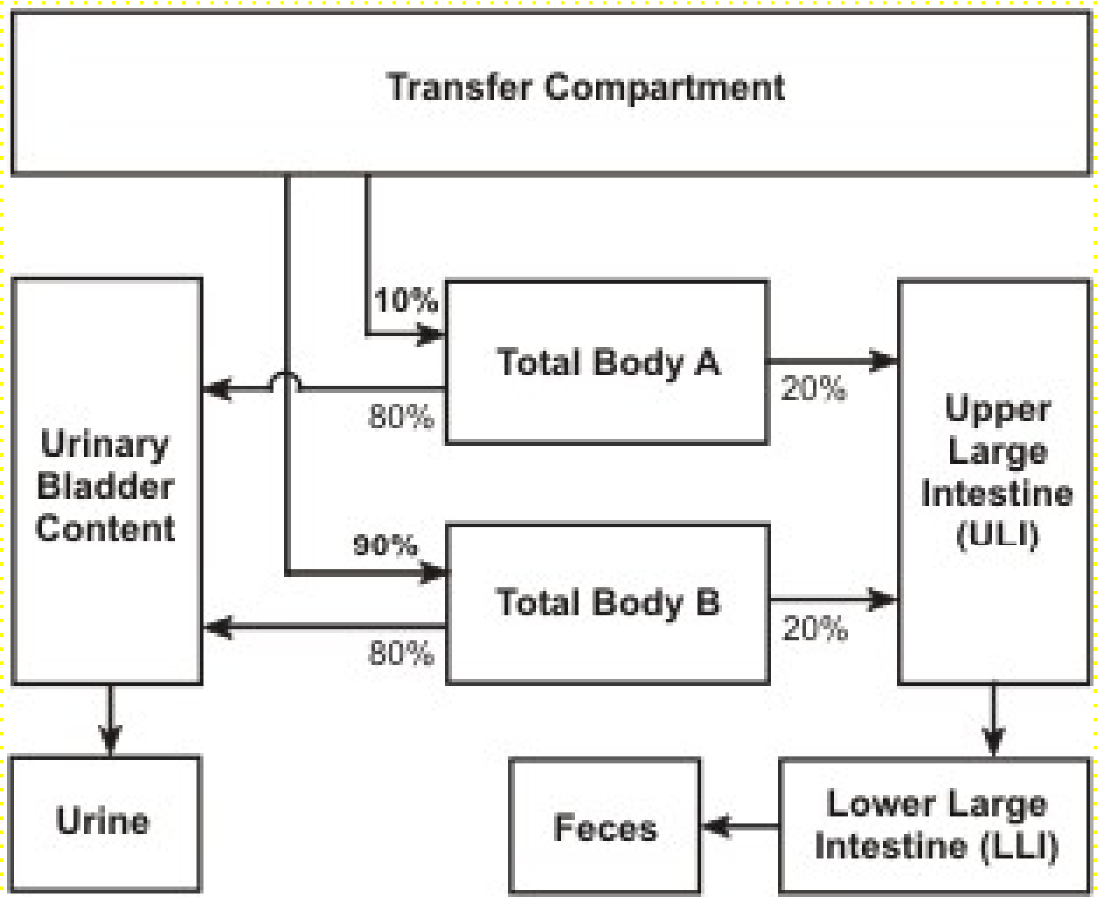
- Organs modelled by one or more compartments
- First order kinetics
- No recycling back to blood (except for iodine)
- Radioactive progeny behave as their parents (except iodine and radon daughters)

Metabolic models (ICRP 30) – Example: Cs



$$R(t) = 0.1 \cdot e^{-0.693 \cdot t/2} + 0.9 \cdot e^{-0.693 \cdot t/110}$$

Metabolic models (ICRP 67) – Example: Cs



History

Dose coefficients	ICRP 30
Revised dose limits and tissue weighting factors (ICRP 60)	Revised dose coefficients, ALI (ICRP 61)
Revised lung model and metabolic models (ICRP 66, 67)	Revised dose coefficients (ICRP 68)
Age dependent dose coefficients for ingestion (ICRP 56, 67, 69) and inhalation (ICRP 71)	Summary, ICRP 72

Relevant publications 1

110: Adult Reference Computational Phantoms 2009

107: Nuclear Decay Data for Dosimetric Calculations 2008

100: Human Alimentary Tract Model for Radiological Protection 2006

89: Basic Anatomical and Physiological Data for Use in Radiological Protection: Reference Values 2002

ICRP Supporting Guidance 3: Guide for the Practical Application of the ICRP Human Respiratory Tract Model 2002

72: Age-dependent Doses to the Members of the Public from Intake of Radionuclides Part 5, Compilation of Ingestion and Inhalation Coefficients 1996

Relevant publications 2

71: Age-dependent Doses to Members of the Public from Intake of Radionuclides: Part 4 Inhalation Dose Coefficients 1995

70: Basic Anatomical & Physiological Data for use in Radiological Protection: The Skeleton 1995

69: Age-dependent Doses to Members of the Public from Intake of Radionuclides: Part 3 Ingestion Dose Coefficients 1995

68: Dose Coefficients for Intakes of Radionuclides by Workers 1994

67: Age-dependent Doses to Members of the Public from Intake of Radionuclides - Part 2 Ingestion Dose Coefficients 1993

66: Human Respiratory Tract Model for Radiological Protection 1994

Relevant publications 3

56: Age-dependent Doses to Members of the Public from Intake of Radionuclides: Part 1 1989

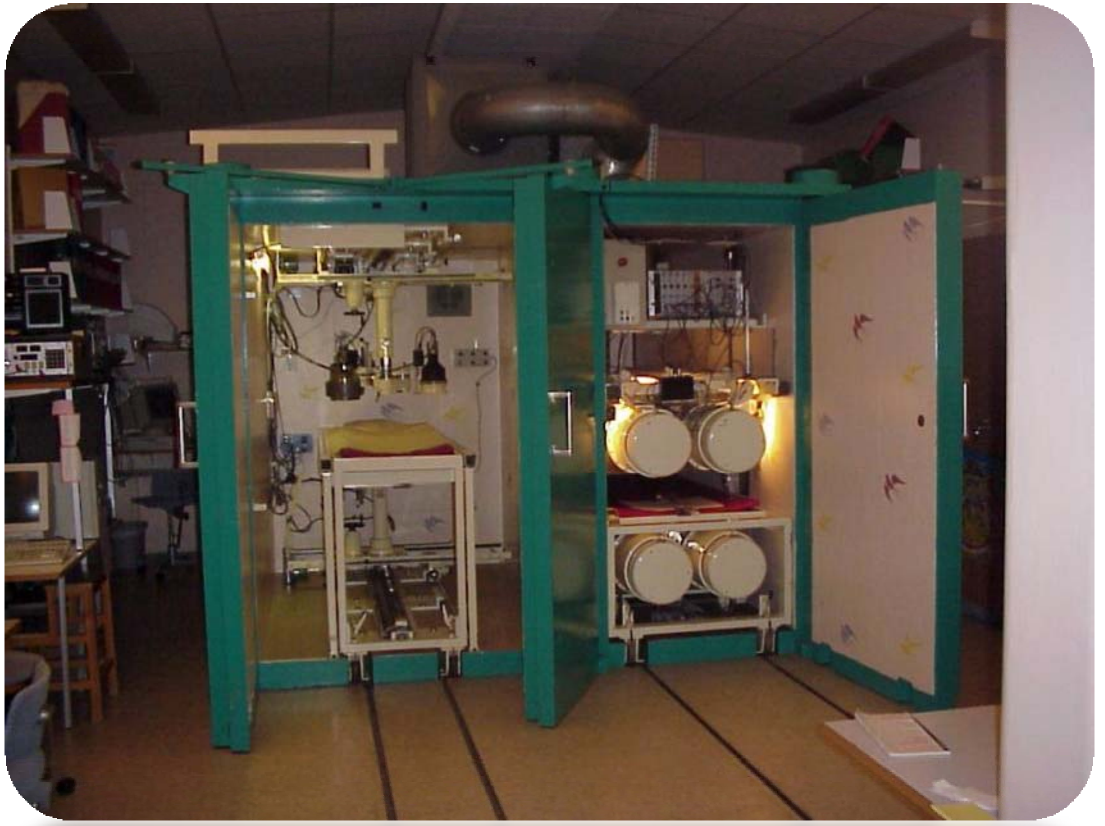
48: The Metabolism of Plutonium and Related Elements 1986

30: Limits for Intakes of Radionuclides by Workers, Part 3 1981 (with supplement)

30: Limits for Intakes of Radionuclides by Workers, Part 2 1980 (with supplement)

30: Limits for the Intake of Radionuclides by Workers, Part 1 1979 (with supplement)

23: Reference Man: Anatomical, Physiological and Metabolic Characteristics 1975



THANK YOU!