20 Years of ICRP work in Internal Dosimetry: An overview of challenges overcome and major successes

ICRP Madan Rehani Award Lecture

Virtual event

3 June 2025

François Paquet
ASNR, France
C2 Vice-Chair
IDC Chair

ICRP

The work of an entire team (TG 95, with TG36,96,103)

K. Eckerman (former TG 96 Chair)
W. Bolch (former TG 96 Chair)
Derek Jokisch (TG96 Chair)

John Harrison (former TG95 Chair)

Chan Hyeong Kim (TG103 Chair)

Augusto Giussani (TG 36 Chair)

Rich Leggett

Michael Bailey

Tracy Smith

Eric Blanchardon

Gennadii Ratia

Volodymyr Berkovskyy

Demetrio Gregoratto

Caleigh Samuels

Estelle Davesne

Maria Antonia Lopez

Ämilie Degenhardt

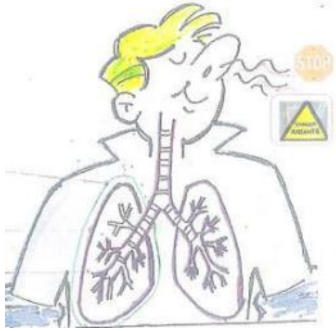
Stephanie Lamart

Internal dosimetry is the discipline used to determine the committed effective dose

$$E = \Sigma w_T \, \Sigma w_R \, D_{T,R}$$

The data required to calculate a dose after internal contamination

Intake
(Bq)



Depends on:

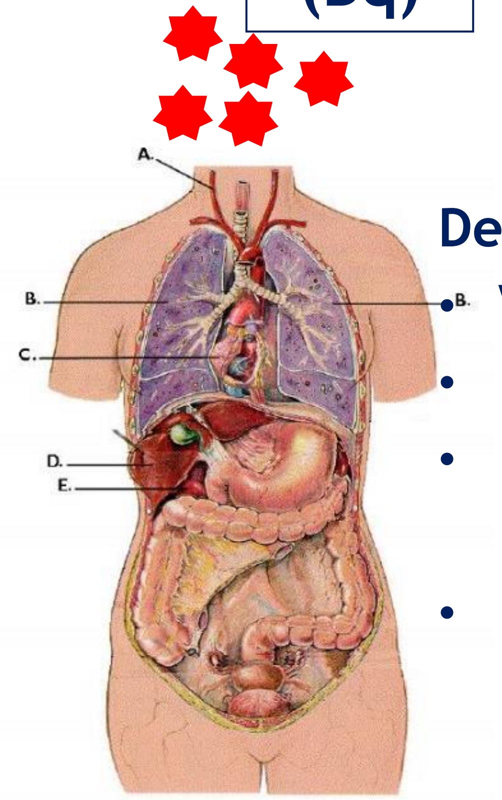
For inhalation : Aerosol concentration and breathing rate

For ingestion : Radionuclide concentration in foodstuffs and food consumed

These data are provided by exposure monitoring

The data required to calculate a dose after internal contamination

Intake (Bq) → Deposition in tissues

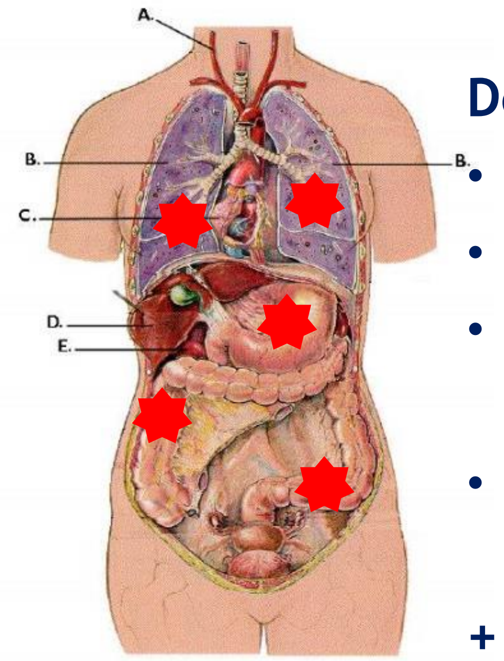


Depends on:

- Way of entry (inhalation, ingestion, wound)
- Physico-chemical parameters (part. size, chemical form,..)
- Biological parameters (age, sex, morphometry, physiology (e.g. breathing rate,..)
- Influencing factors : e.g.smoking for inhalation or diet for ingestion..

The data required to calculate a dose after internal contamination

Intake (Bq) → Deposition in tissues



Depends on:

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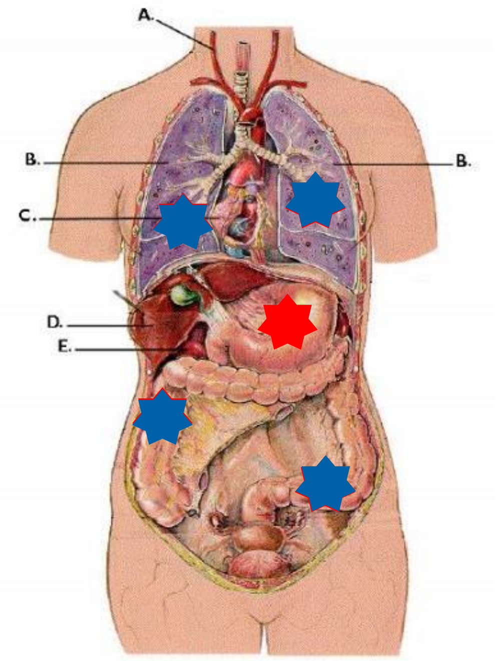
- Physico chemical parameters (part. size, chemical form,..)
- Biological parameters (age, sex, morphometry, physiology (e.g. breathing rate,..)
- Influencing factors : smoking for inhalation or diet for ingestion...

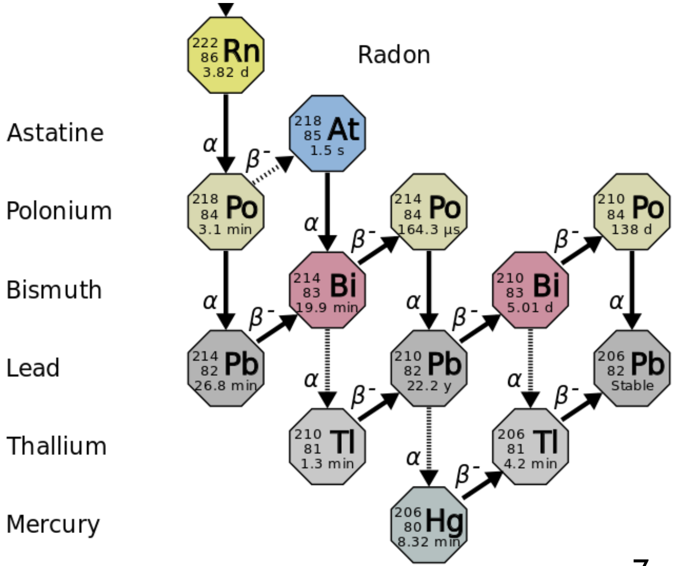
+ transfers between compartments as a function of time, over 50y for the workers or up to 70y for the members of the public

The data required to calculate a dose after internal contamination

Intake (Bq) → Deposition in tissues → **Transformations in tissues**

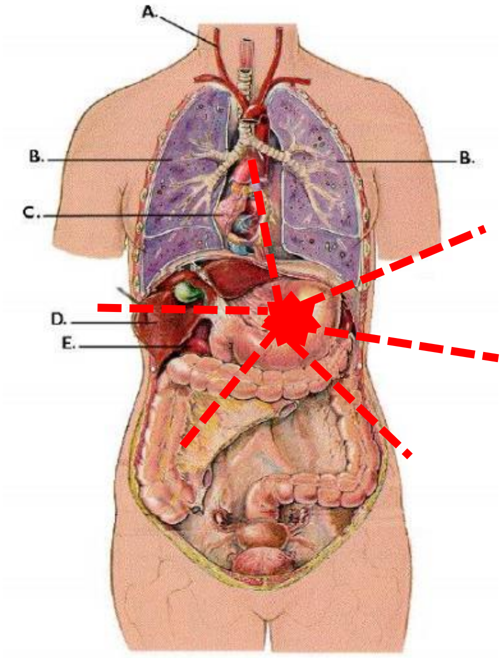


Depends on physical half-life of the element and its progeny



The data required to calculate a dose after internal contamination

Intake (Bq) → Deposition in tissues → Transformations in tissues → Emitted energy (Mev)



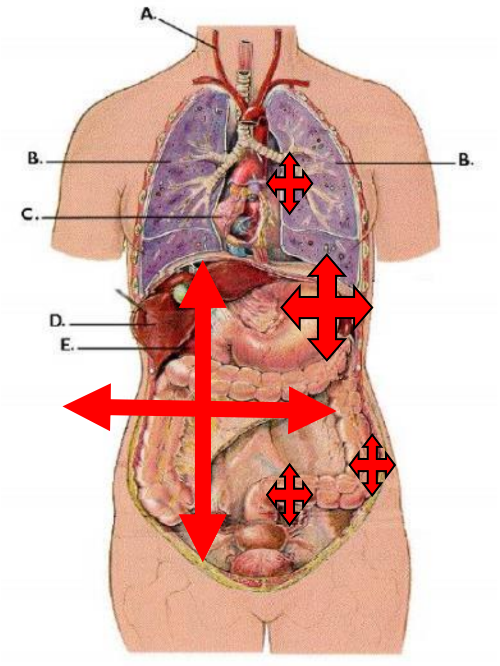
Depends on nuclear emissions of a given radionuclide

(yield, energy, for each type of radiation !!!..)

The data required to calculate a dose after internal contamination

Intake (Bq) → Deposition in tissues → Transformations in tissues → Emitted energy (Mev) → **Absorbed dose in tissues (Gy)**

$$E : \Sigma w_T \Sigma w_R D_{T,R}$$



Depends on the masses of the targets (organs or cells) and geometry (distance between sources and targets)

Varies between individuals and as fonction of age

The data required to calculate a dose after internal contamination

Intake (Bq) → Deposition in tissues → Transformations in tissues

↓

Emitted energy (Mev)

↓

Absorbed dose in tissues (Gy)

↓

Equivalent dose in tissues (Sv)

$$E : \Sigma w_T \Sigma w_R D_{T,R}$$

Depends on relative biological effectiveness of the different types of radiations (which also depends on the biological endpoints)

The data required to calculate a dose after internal contamination

Intake (Bq)

Deposition in tissues

Transformations in tissues

Emitted energy (Mev)

Absorbed dose in tissues (Gy)

Equivalent dose in tissues (Sv)

Committed Effective dose (Sv)

Depends on relative risk for each organ and tissue (which also depends on age, sex and other factors)

$$E : \Sigma w_T \Sigma w_R D_{T,R}$$

The data required to calculate a dose after internal contamination

Intake (Bc

→ Deposition in tissues

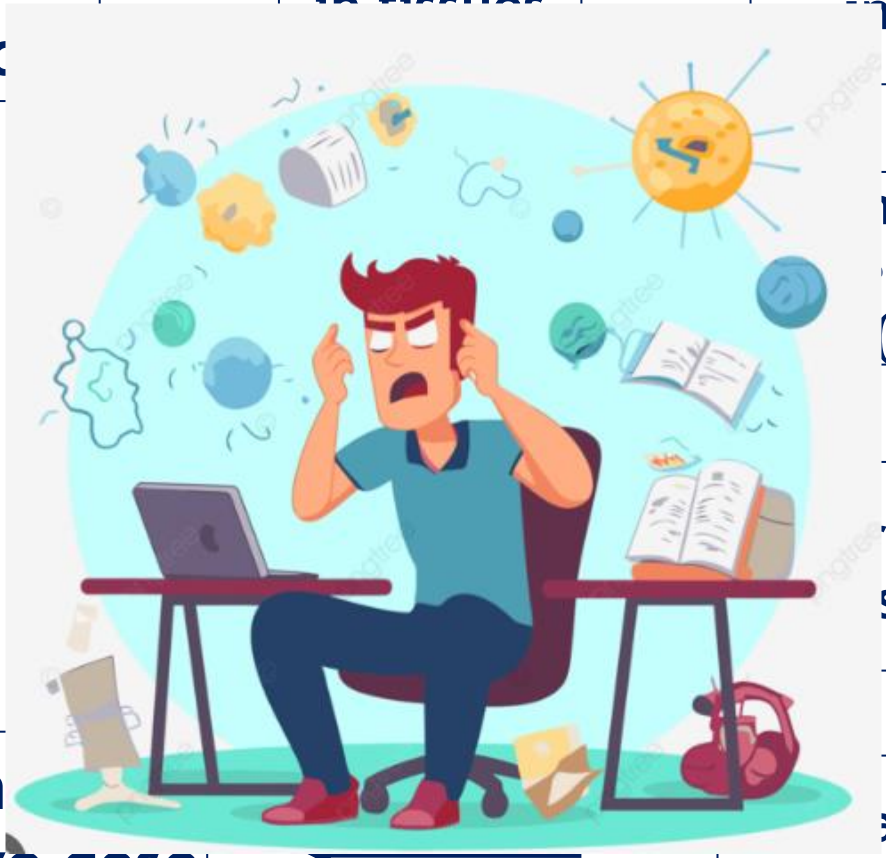
→ Transformations in tissues

↓ nitted nergy (Mev)

↓ bed dose sues (Gy)

↓ alent dose in tissues (Sv)

Comm Effective dose (Sv)



ICRP

ICRP support for dose calculations

ICRP proposes :

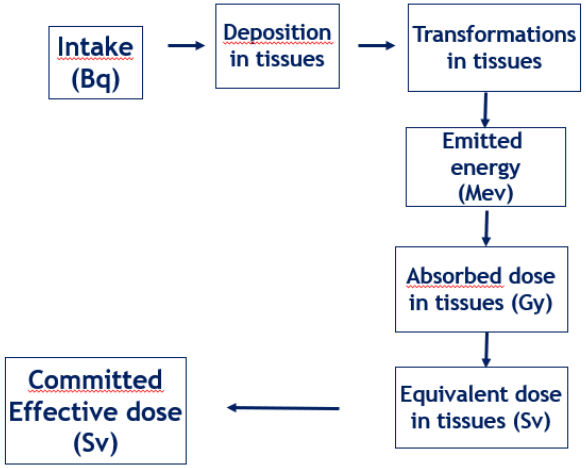
1/ Reducing the diversity of situations

a/ Reference individuals

Reference male, Reference female

Reference ages (Newborn, 1y, 5y, 10y, 15 y, Adult)

All with fixed anatomy and physiology



b/ Reference situations of exposure

Reference sex-averaged workers and reference members of the public

Defaults* parameters for different exposure conditions (particle size, chemical forms,..)

2/ Tools and models for each calculation step

* Can be modified by the operators if needed

ICRP support for dose calculations

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1/ Reducing the diversity of situations

a/ Reference individuals

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Reference ages (Newborn, 1y, 5y, 10y, 15 y, Adult)

All with fixed anatomy and physiology

b/ Reference situations of exposure

Reference sex-averaged workers and reference members of the public

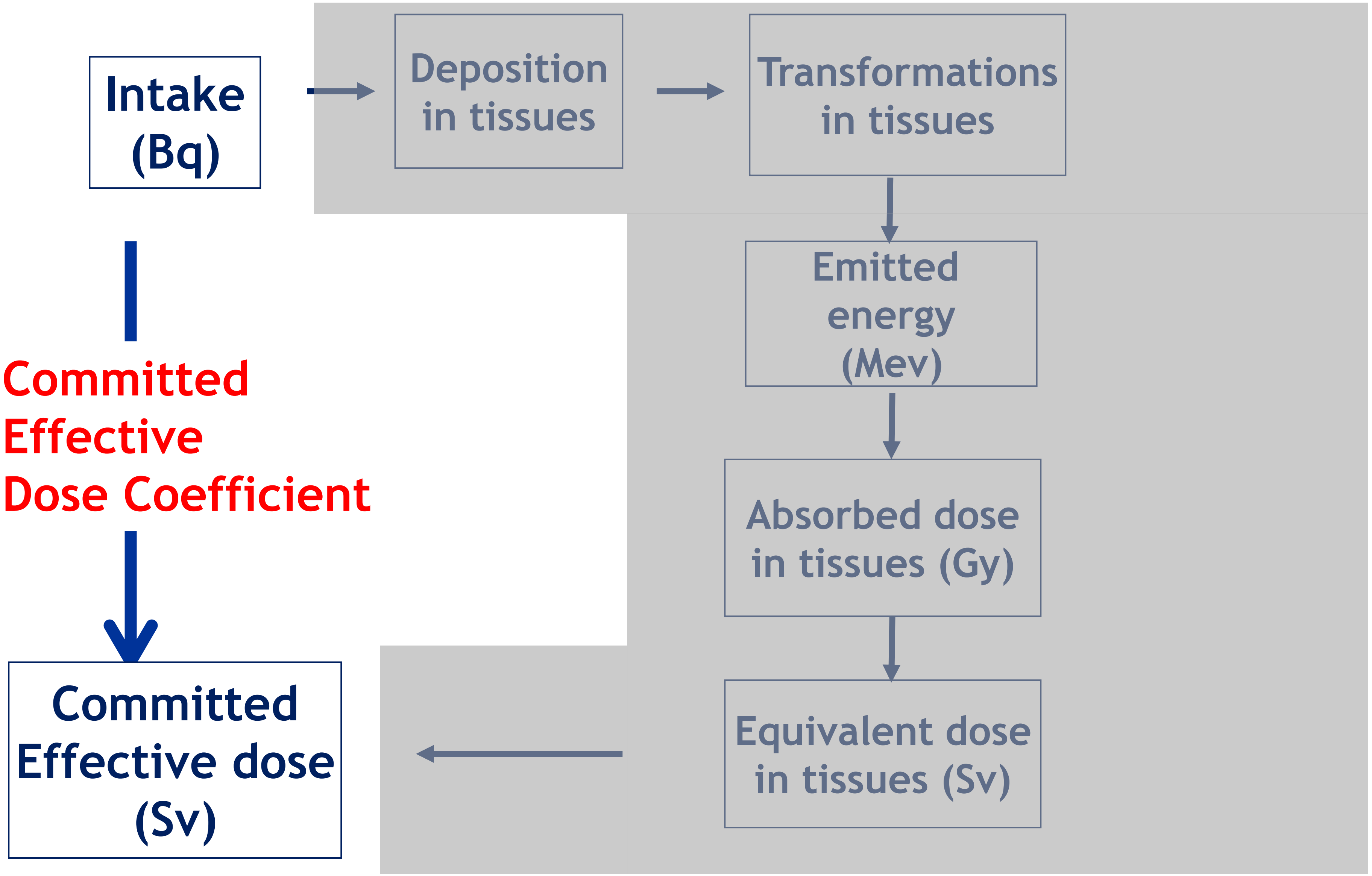
Defaults* parameters for different exposure conditions (particle size, chemical forms,..)

2/ Tools and models for each calculation step

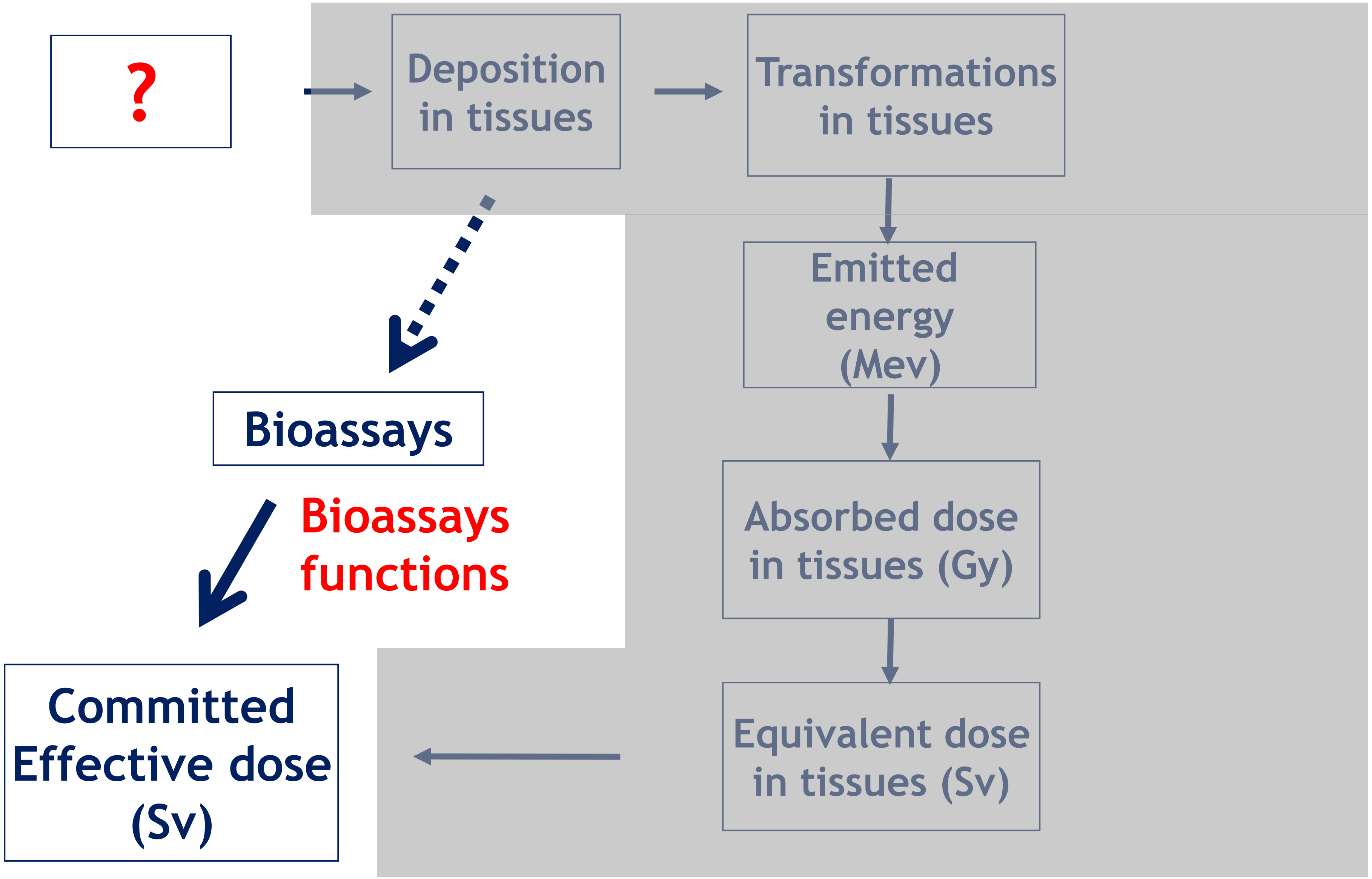
3/ And, to avoid complicated calculations, dose coefficients for these reference situations

* Can be modified by the operators if needed

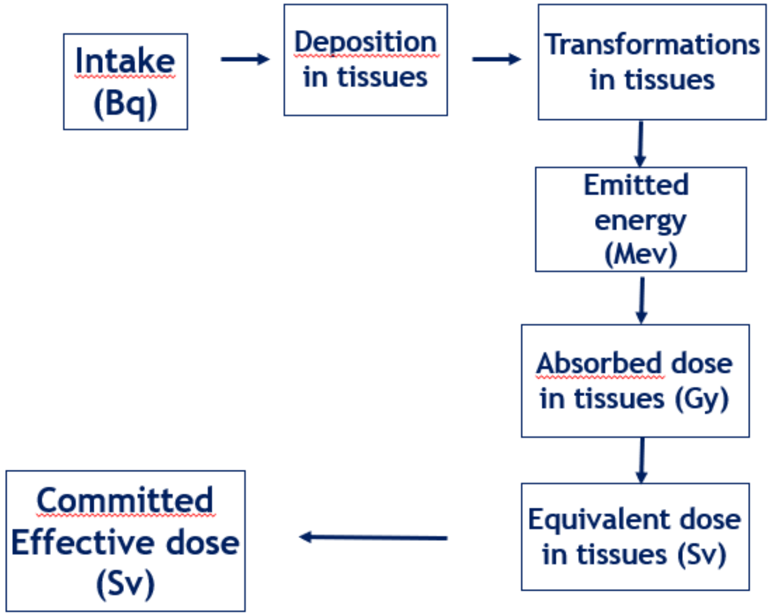
A simplified way to calculate doses



A simplified way to calculate doses



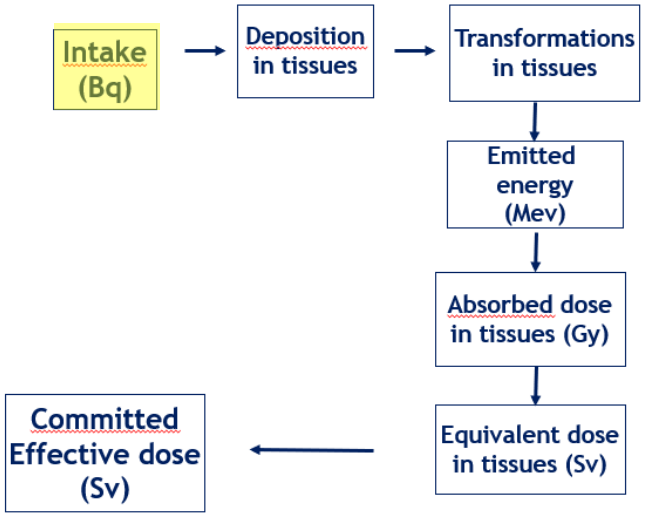
Major advances over the last 20 years



Progress made at every stage of calculation !!!

Major advances over the last 20 years

- New guidances on monitoring programmes and bioassay interpretation (ICRP 130, 2015)



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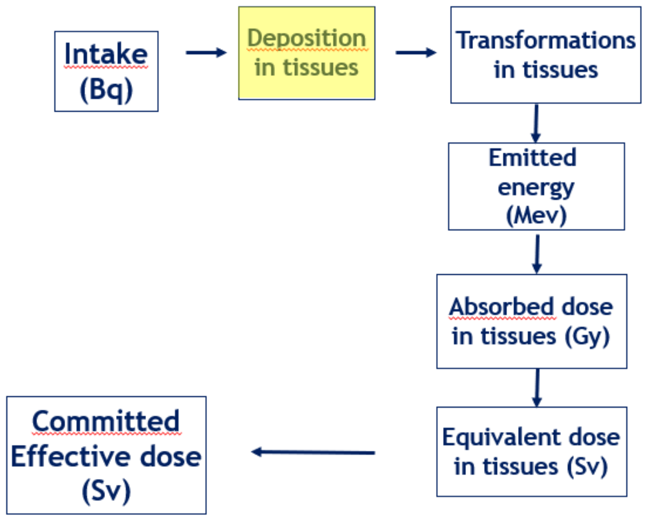
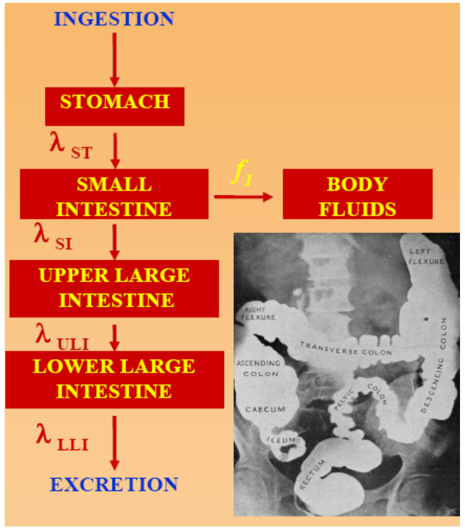
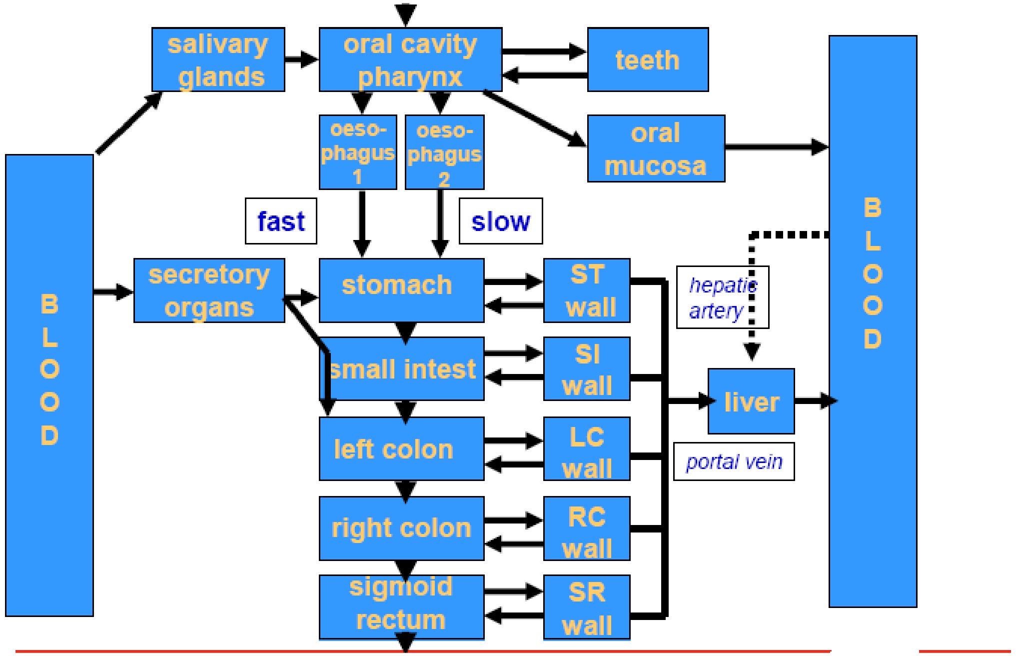
- **New Human Alimentary Tract Model** (ICRP 100, 2006)
- **Updating the Human Respiratory Tract Model** (ICRP 130, 2015)



The Human alimentary tract model



ICRP Publication 30 (1979)



ICRP Publication 100 (2006)

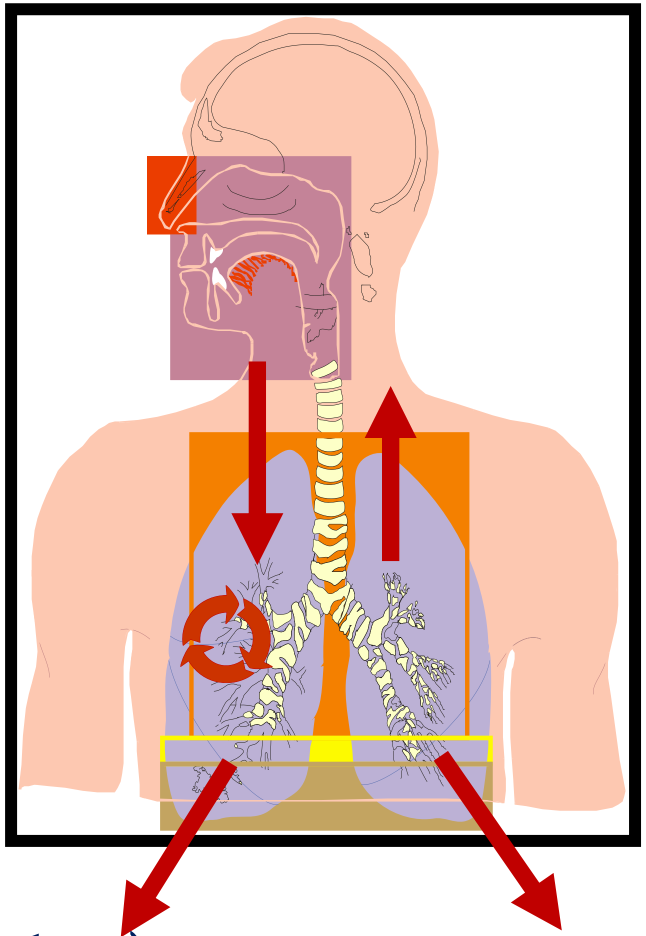
ICRP

The Human Respiratory Tract model

Describes

The time-dependant behaviour of gases and particules

- Deposition
- Transport
- Absorption



According to :

Chemical forms (and their evolution)

Aerosols parameters (AMAD, AMTD,hygroscopy,..)

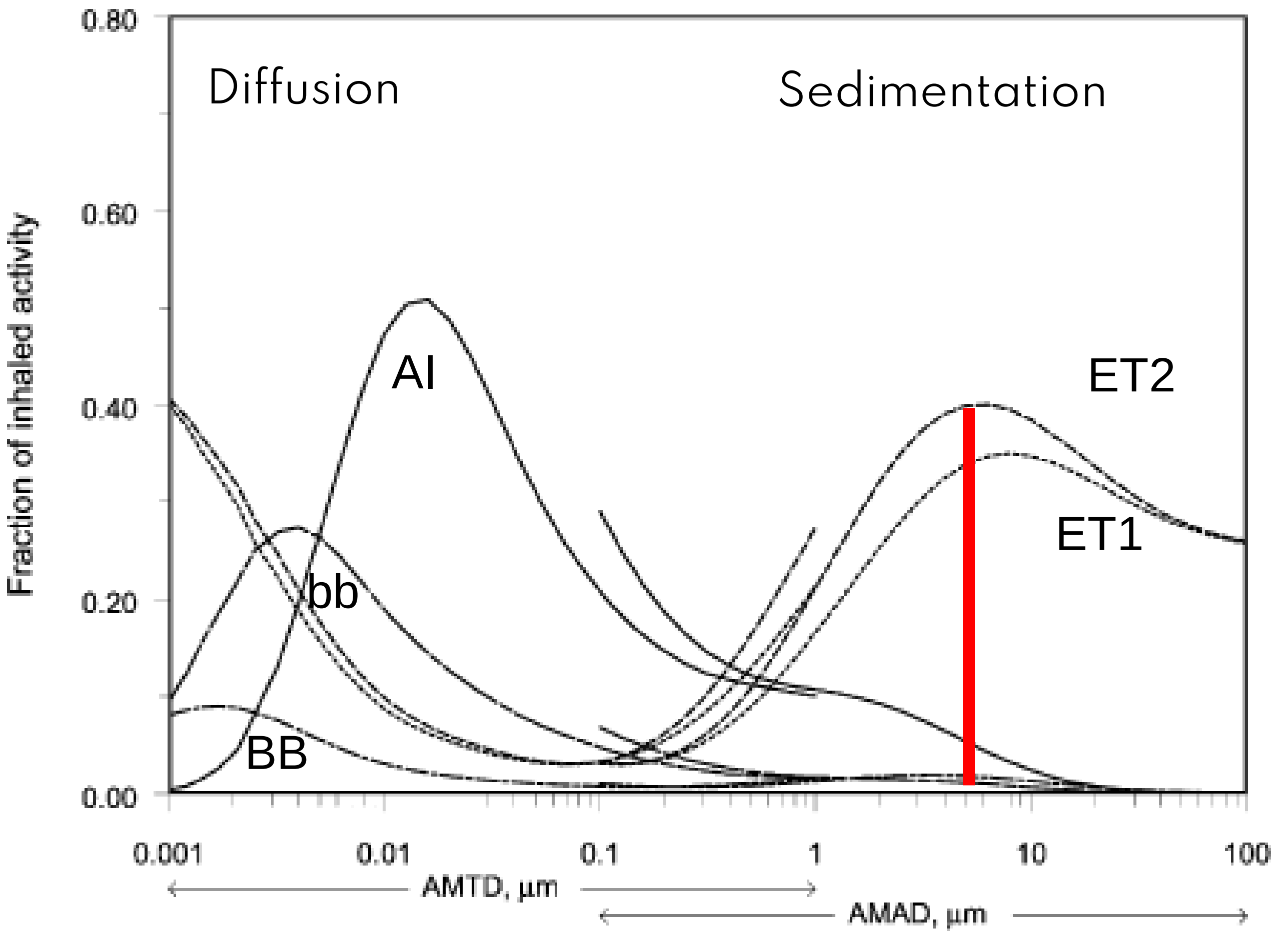
Anatomical parameters (age and sexe dependant)

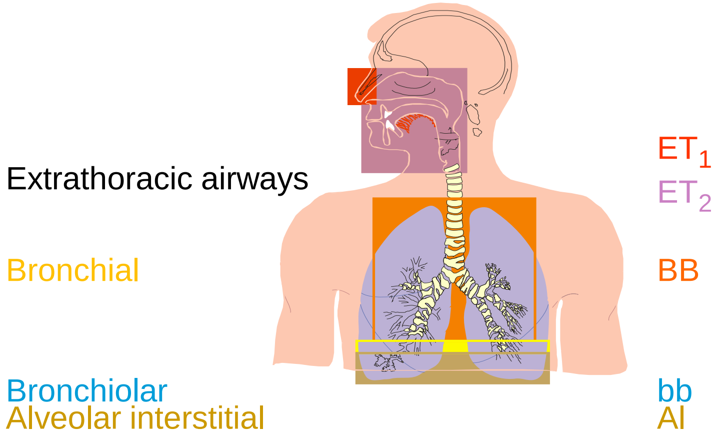
Physiological parameters (age, sexe, ethnic group, activity)

Modifying factors (smoking, disease, pharmaceuticals, air pollutants ..)

The Human Respiratory Tract model

Deposition of particles for a reference worker





The Human Respiratory Tract model

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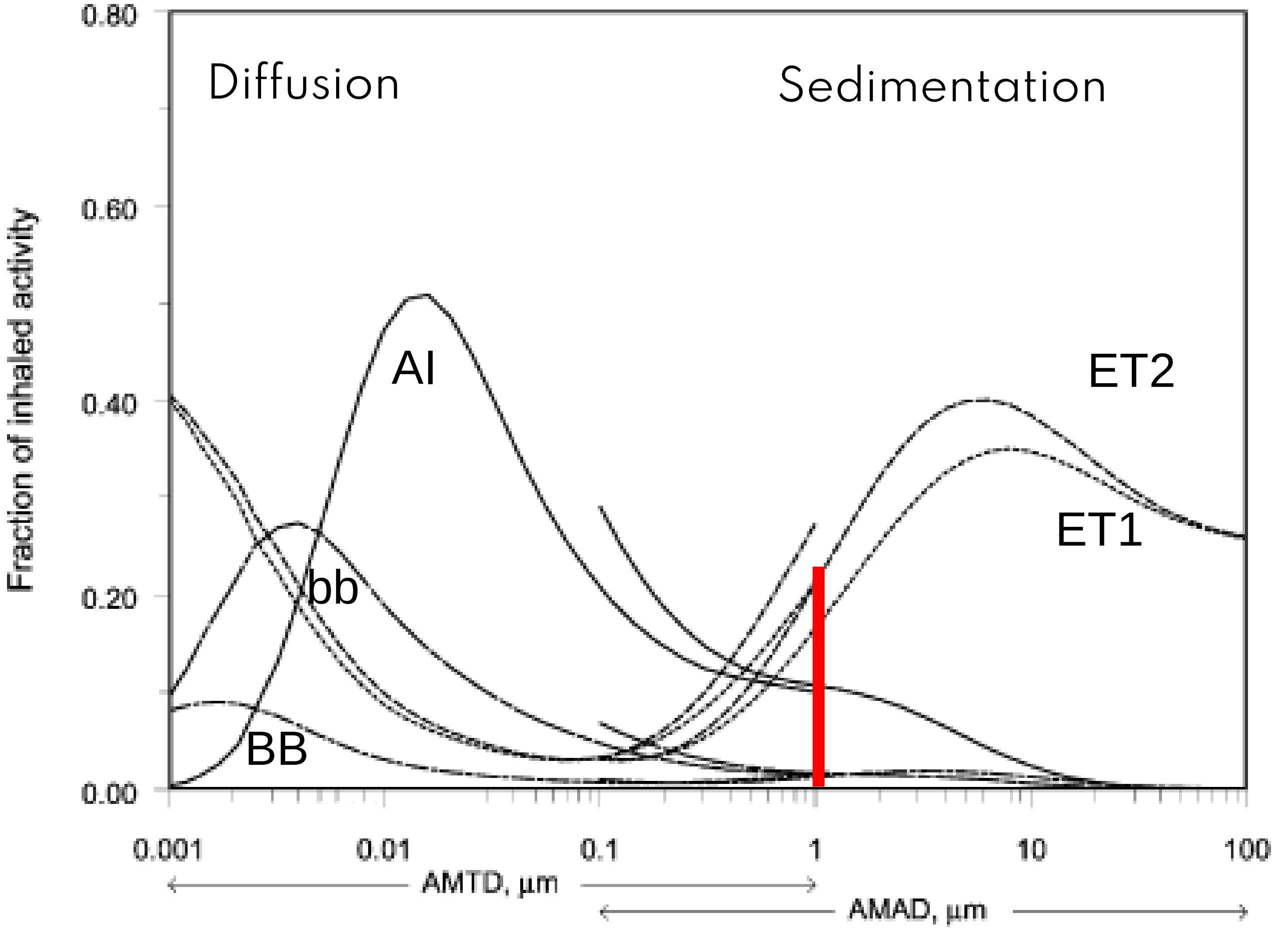
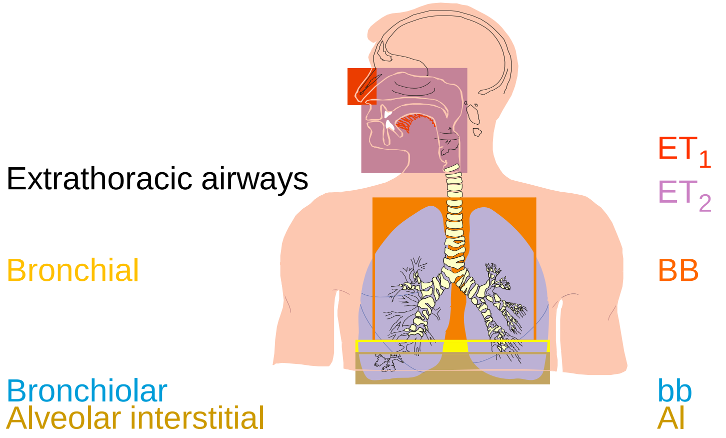
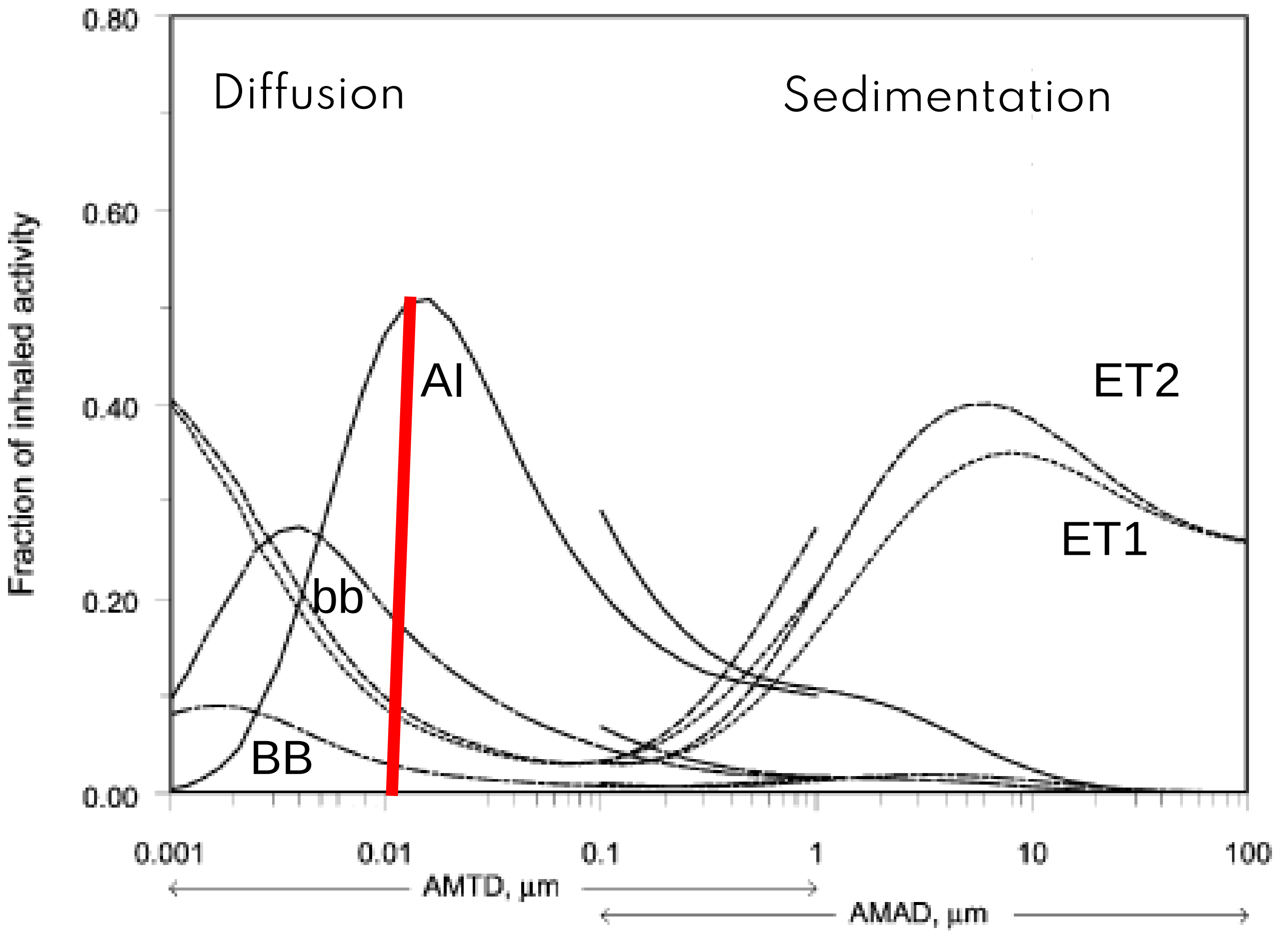
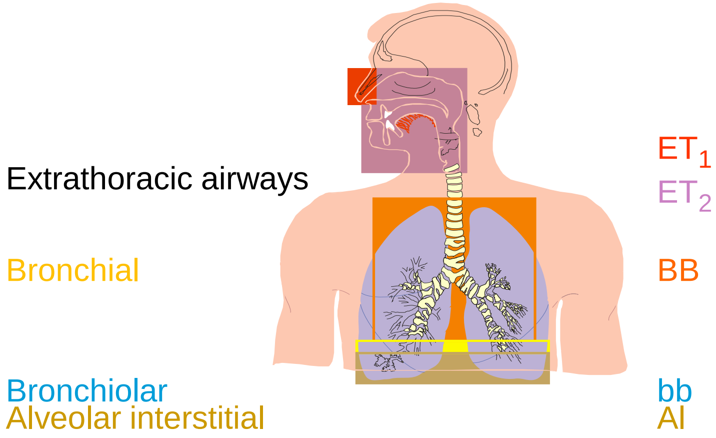




The Human Respiratory Tract model

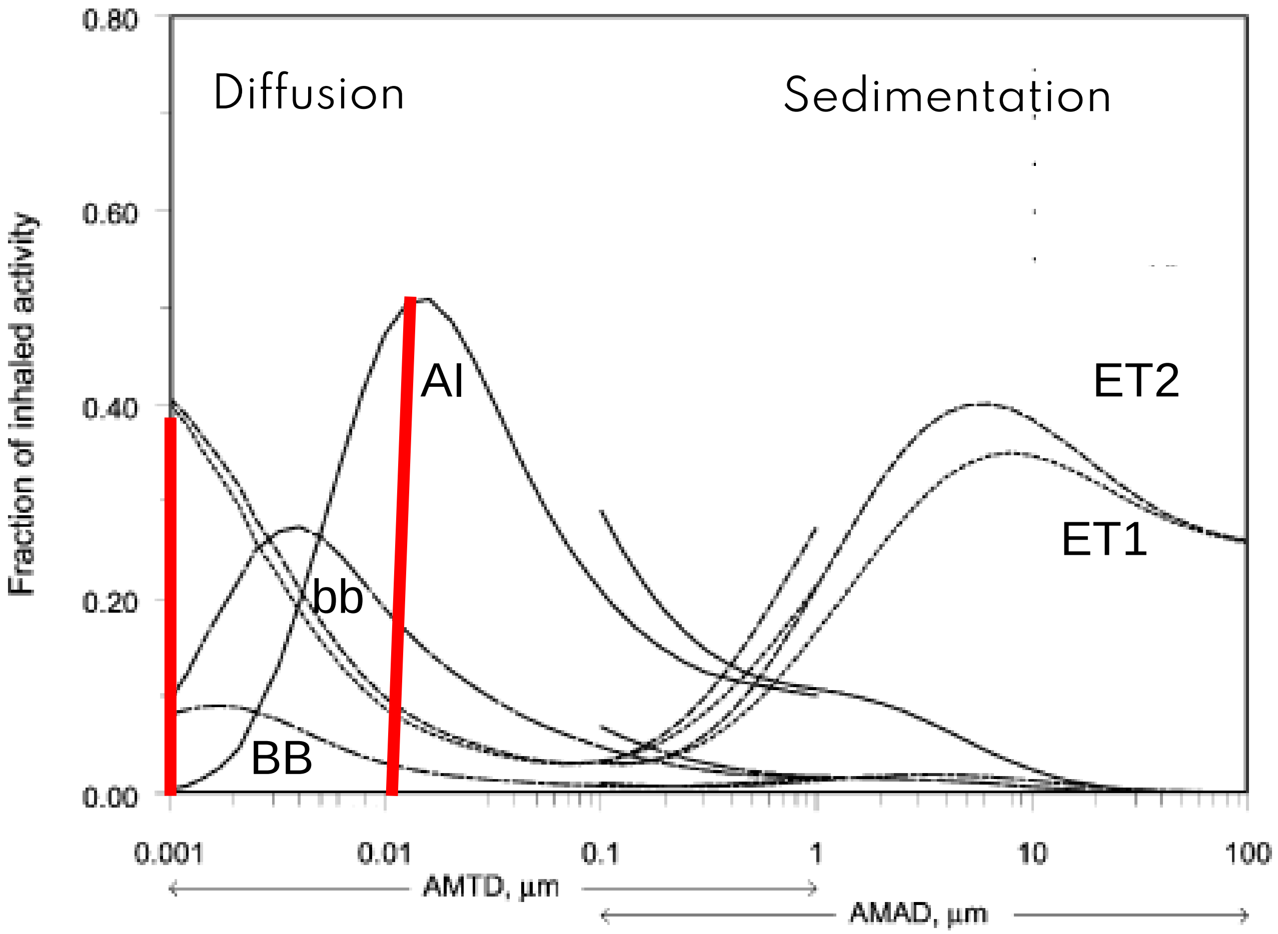
Deposition of particles for a reference worker





The Human Respiratory Tract model

Deposition of particles for a reference worker



Masses of target tissues in Ref Adult males (kg)

BB_{sec} : 8.6E-4
bb : 1.9E-3
AI : 1.1

Differences in masses

↓

Differences in doses !!!!

Major advances over the last 20 years

- New guidances on monitoring programmes and bioassay interpretation (ICRP 130, 2015)

- New Human Alimentary Tract Model (ICRP 100, 2006)
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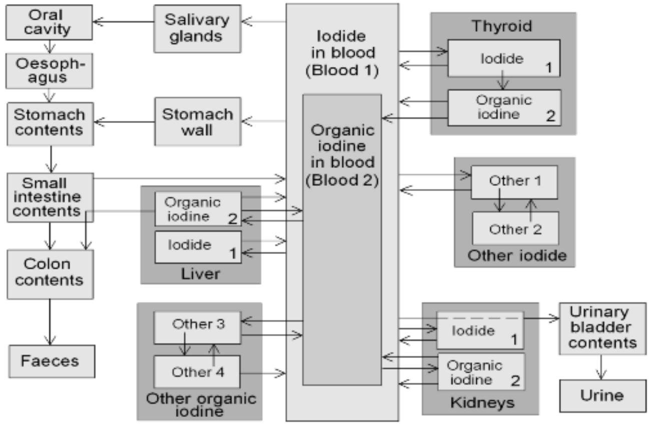
- **New element-specific systemic models, physiologically realistic (OIR series)**



The iodine model
ICRP Publication 137 (2017)

Major advances over the last 20 years

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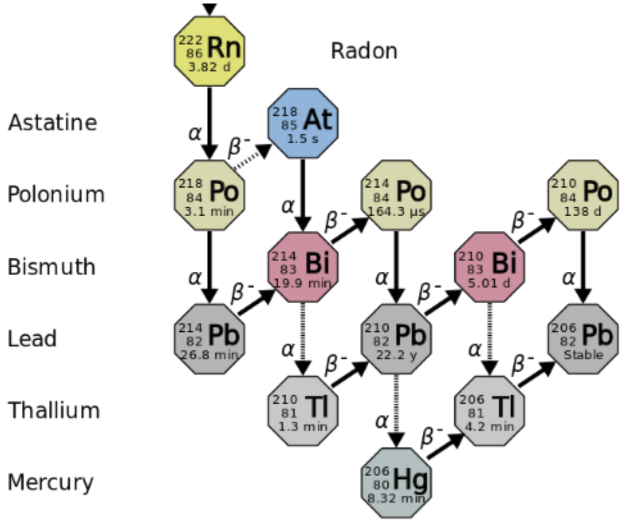
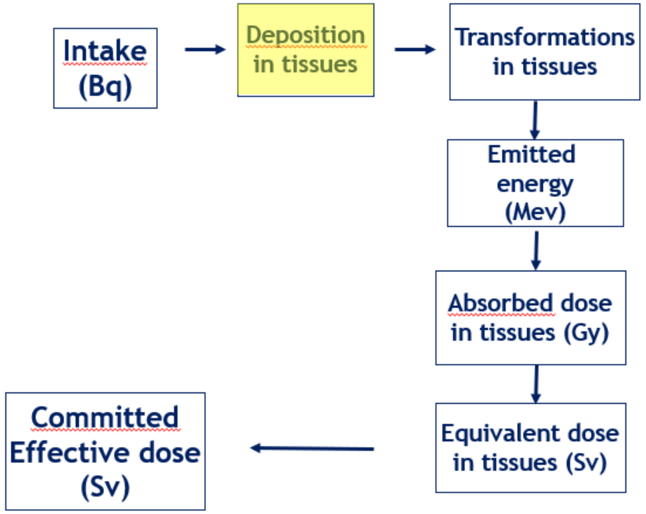
- **More realistic treatment of the biokinetics of radionuclide daughters (ICRP 130, 2015)**





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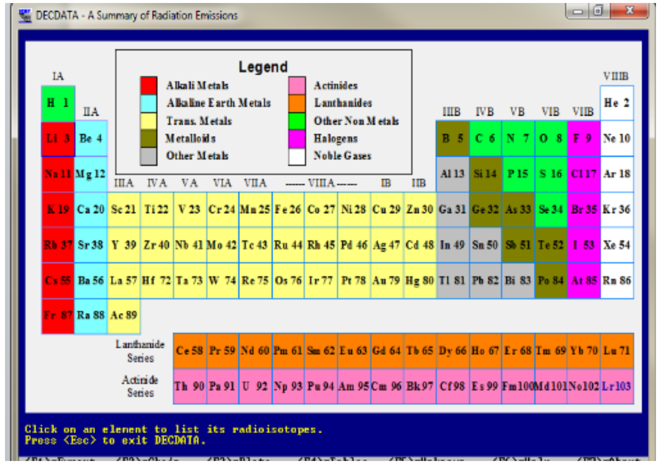
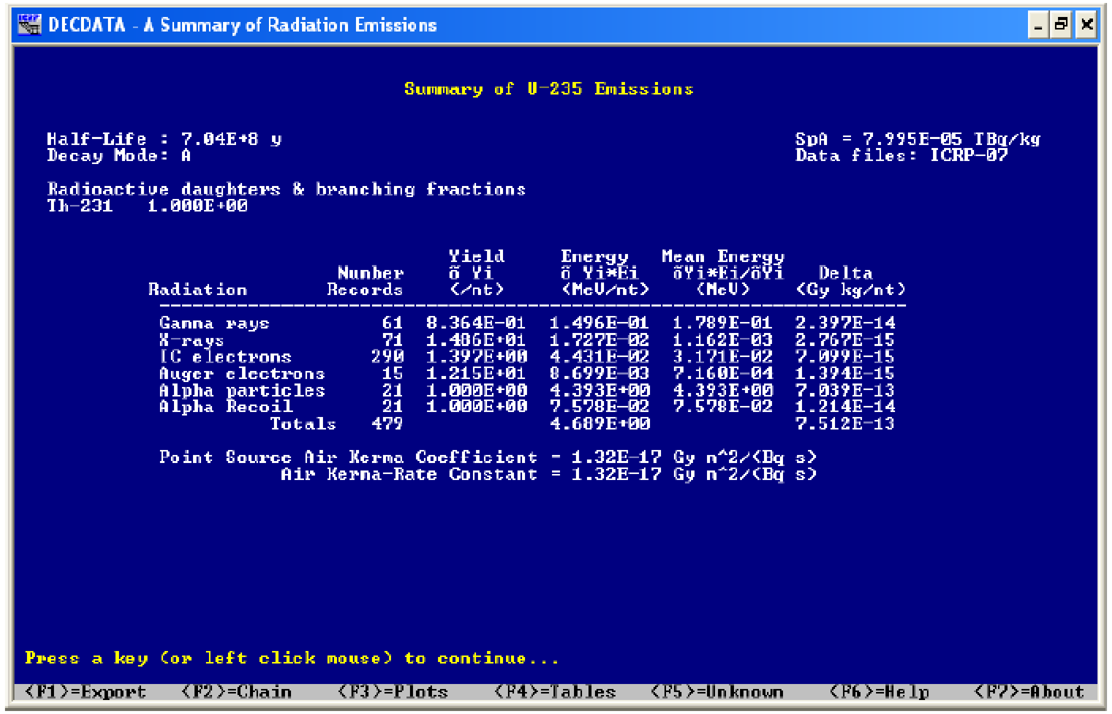
- New element-specific systemic models, pl
- More realistic treatment of the biokinetic

- **Revised nuclear decay data** (ICRP 107, 2008)





Committed Effective dose (Sv) ← Equivalent dose in tissues (Sv)

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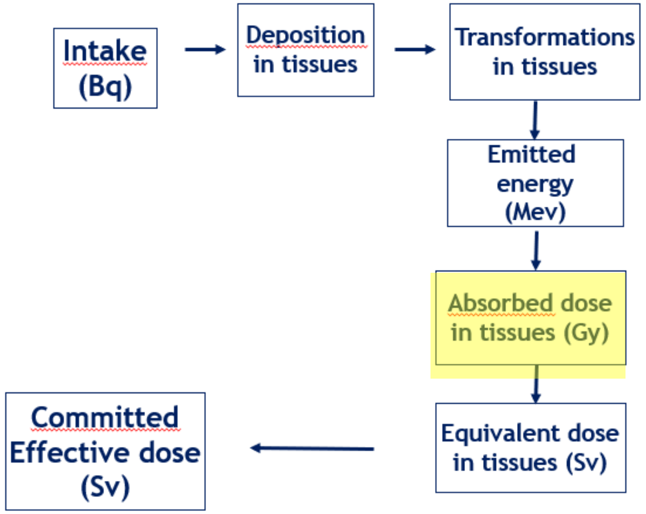
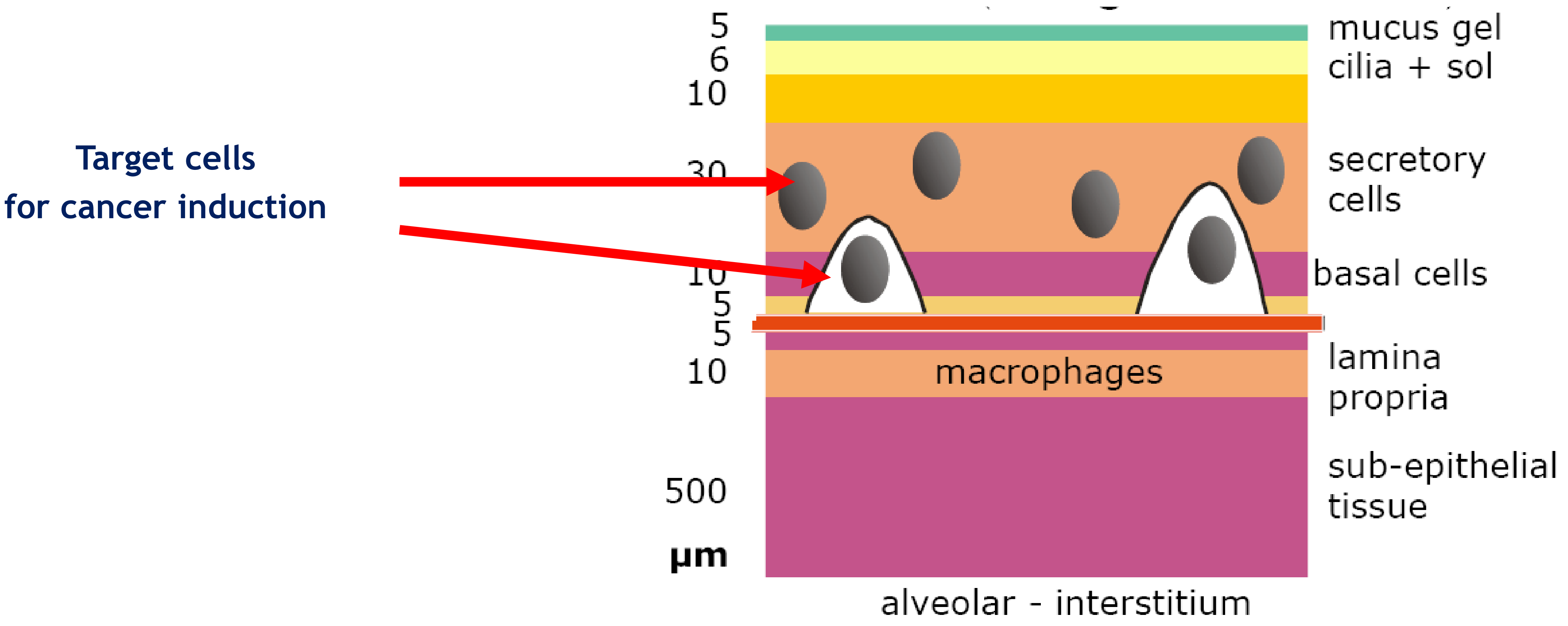
- Revised nuclear decay data (ICRP 107, 2008)

- New references values for anatomy and physiology (including age and sex-specific data) (ICRP 89, 2002)
- New targets for cancer induction in skeleton, HAT, HRT (ICRP 100, 2006; ICRP 130, 2015)



Location of target cells : the case of bronchial wall in the Human respiratory tract

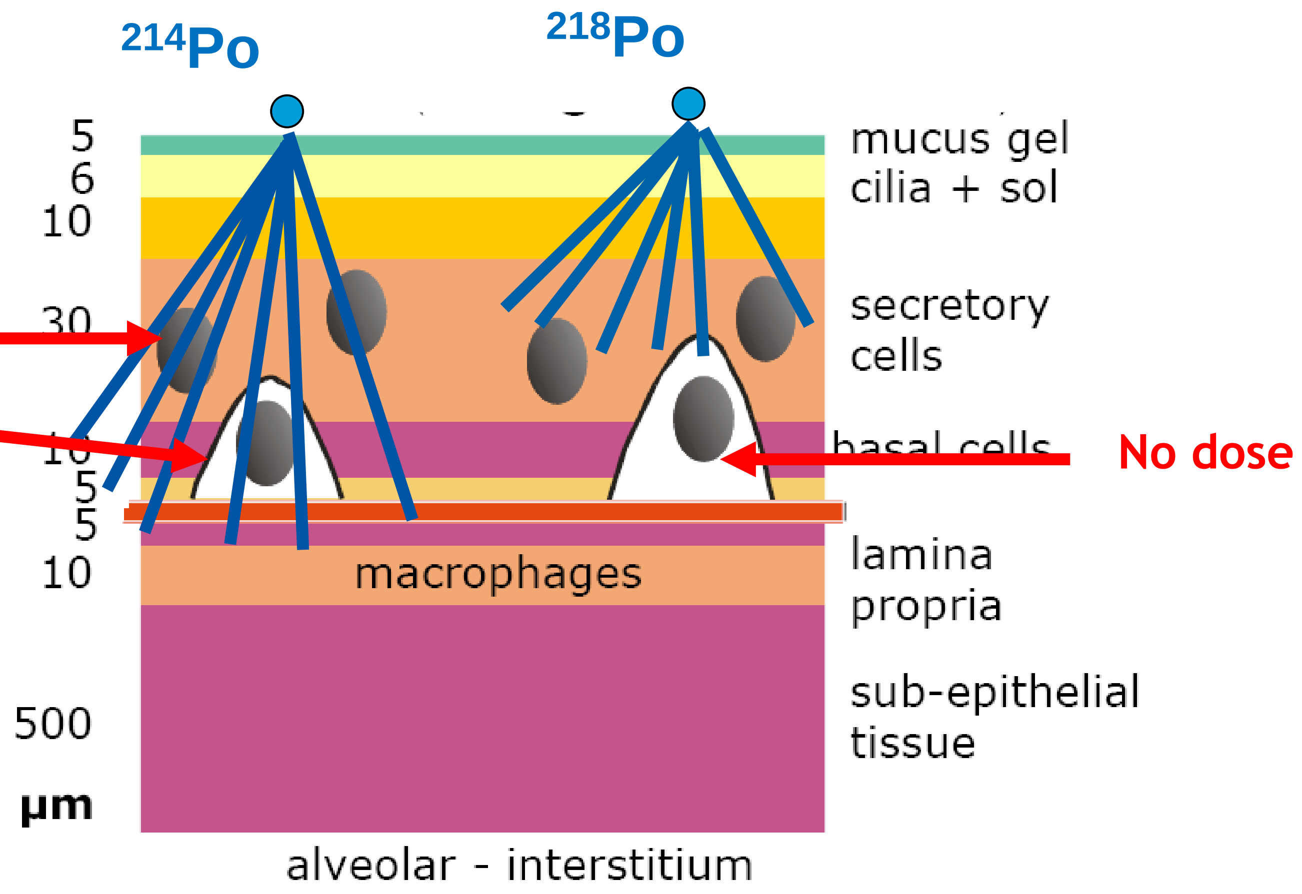


Consequences in dosimetry : the case of ^{222}Rn progeny

Po-214
7.7 MeV
71 µm

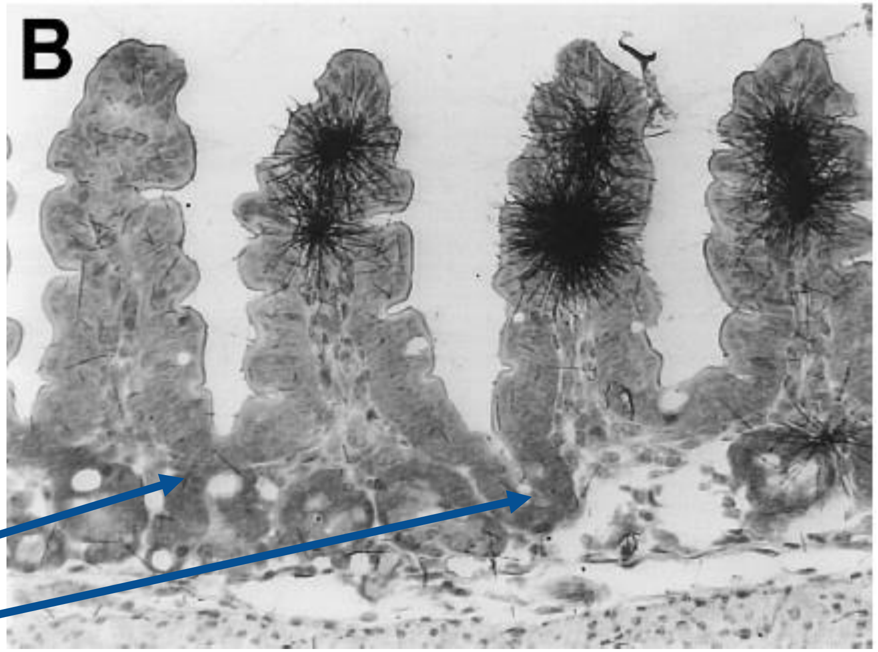
Po-218
6.0 MeV
47 µm

Target cells
for cancer induction



The Human alimentary tract model

Plutonium in small intestine of Guinea pigs



Target cell depths in adult males

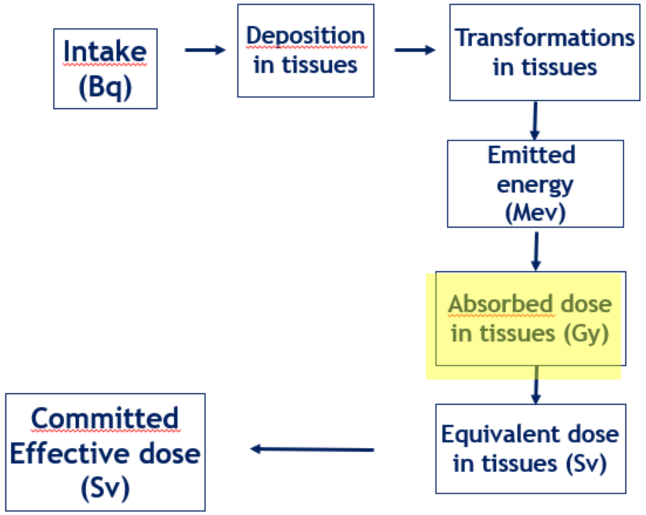
Small intestine
130 - 150 μm

According to the model,
No dose from alpha disintegration

ICRP

ICRP Publication 100, 2006

Major advances over the last 20 years



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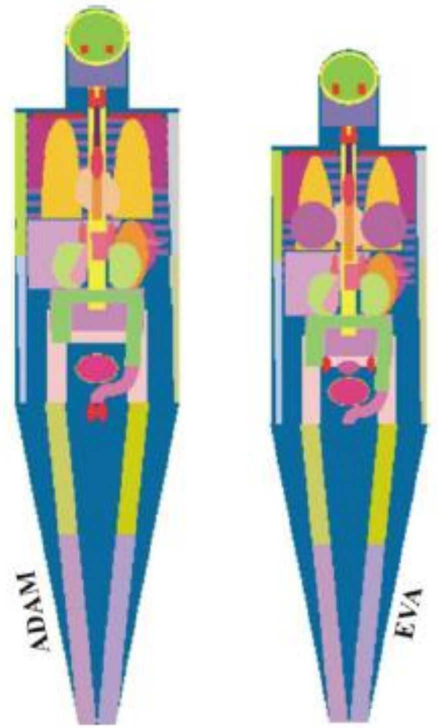
- New targets for cancer induction in skeleton, HAT, HRT (ICRP 100, 2006;ICRP 130, 2015)
- **New adult and pediatric reference computational phantoms (ICRP 110, 2009; ICRP 143, 2020; ICRP 145, 2020; ICRP 156, 2024)**

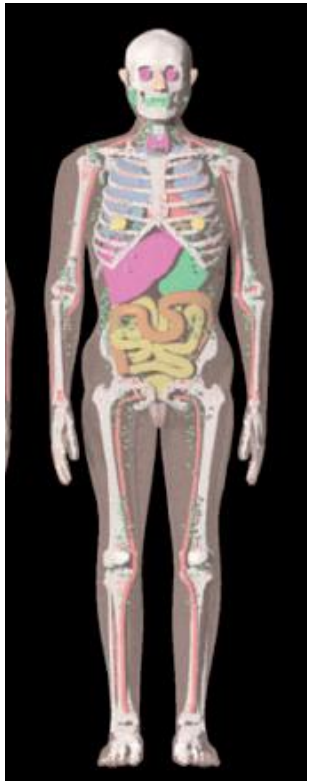
Define anatomy and geometry of targets tissues and cells

Phantoms : evolution over the years

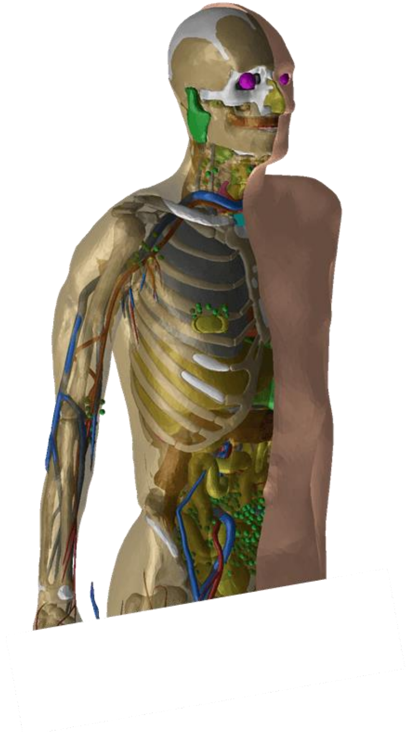


Stylized Phantoms
80s

Voxel phantoms
ICRP 110, 2009

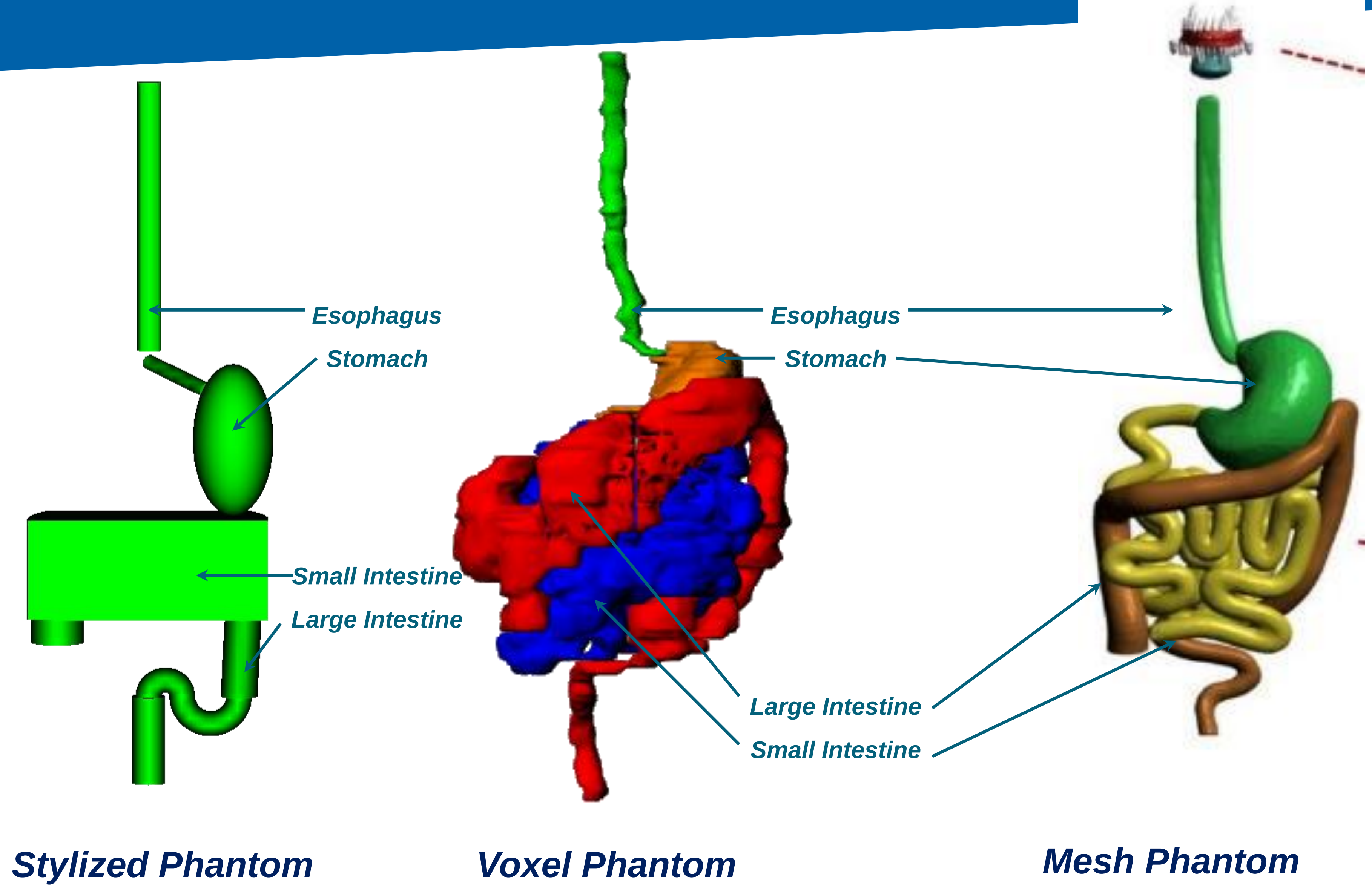


Voxel phantoms
ICRP 143, 2020



MRCP phantoms
ICRP 145, 2020
ICRP 156, 2024

Phantoms : evolution over the years



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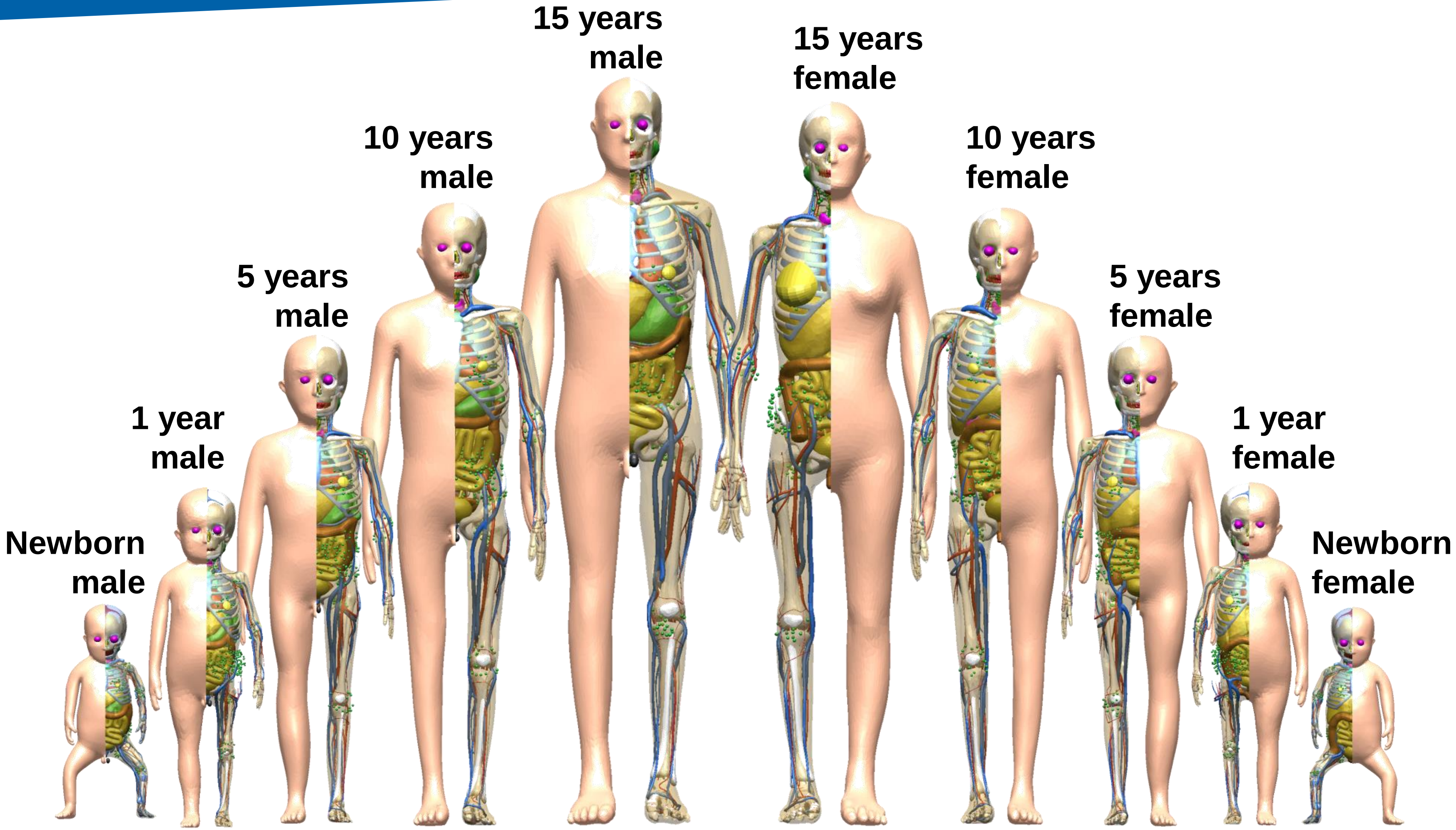
A family of phantoms



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ICRP Publication 156, 2024

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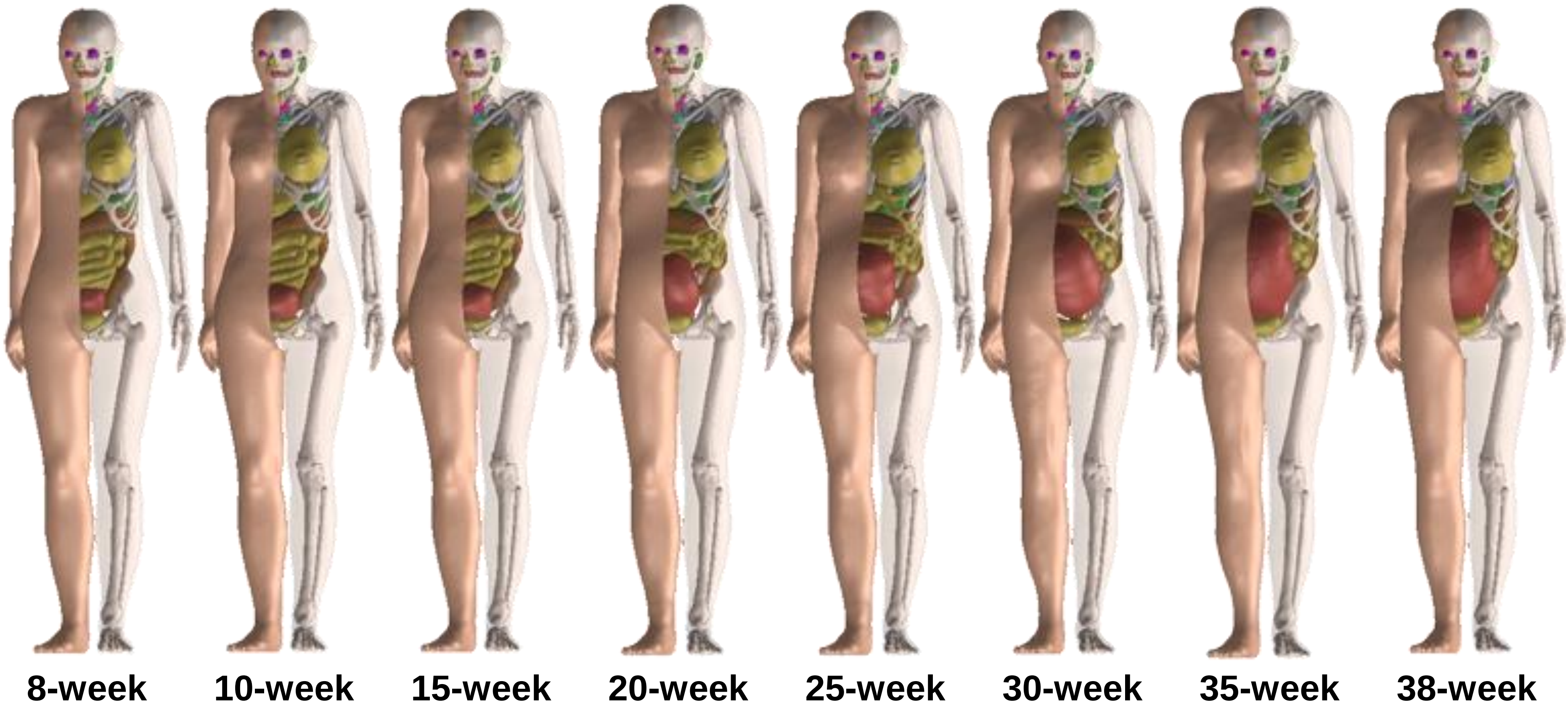

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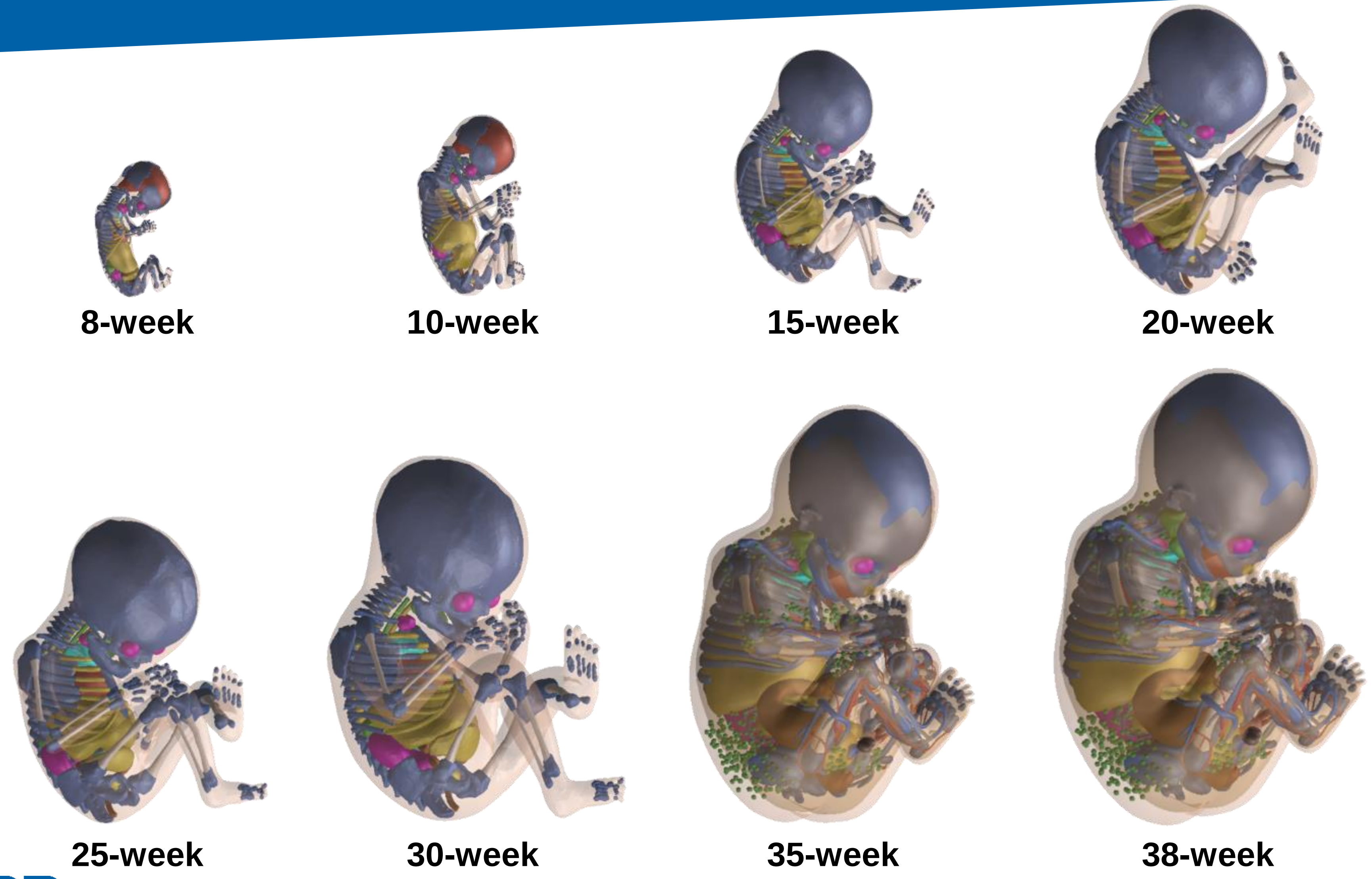

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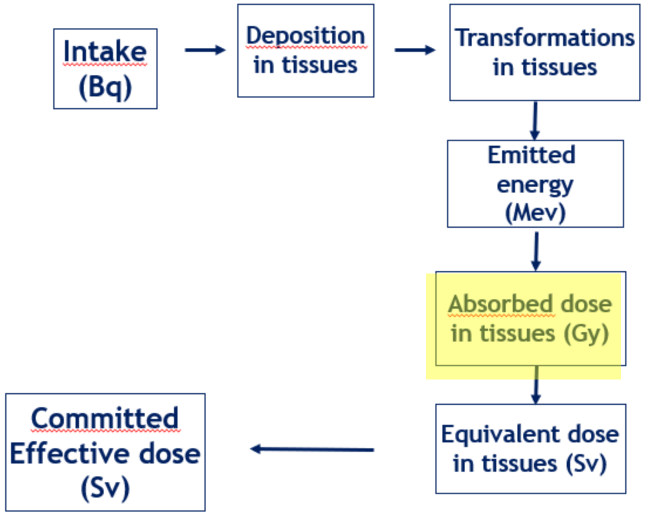
- New targets for cancer induction in skeleton, HAT, HRT (ICRP 100, 2006;ICRP 130, 2015)
- New adult and pediatric reference computational phantoms (ICRP 110, 2009; ICRP 143, 2020; ICRP Publication 145, 2020; ICRP 156, 2024)
- **New SAFs for adults and paediatric individuals (ICRP 133, 2016; ICRP 155, 2024)**



SAFs

SAF : Specific Absorbed Fractions

The specific absorbed fraction (SAF) is the fraction of energy emitted by a source organ that is absorbed per unit mass of a target organ (or cells !!).

Absorbed fraction

$$\Phi\left(r_T \leftarrow r_S, E_{R,i}\right) = \frac{\phi\left(r_T \leftarrow r_S, E_{R,i}\right)}{m_T}$$

(en kg^{-1})

Mass of the target

SAFs

79 source regions (given in biokinetic models)
43 target regions
6 ages (NB, 1y, 5y, 10y, 15y and adults)
2 sexes
4 radiation types (alpha, electrons, photons, neutrons from spontaneous fission)
28 (electrons, photons) or 24 (alpha) different energies (New !!)

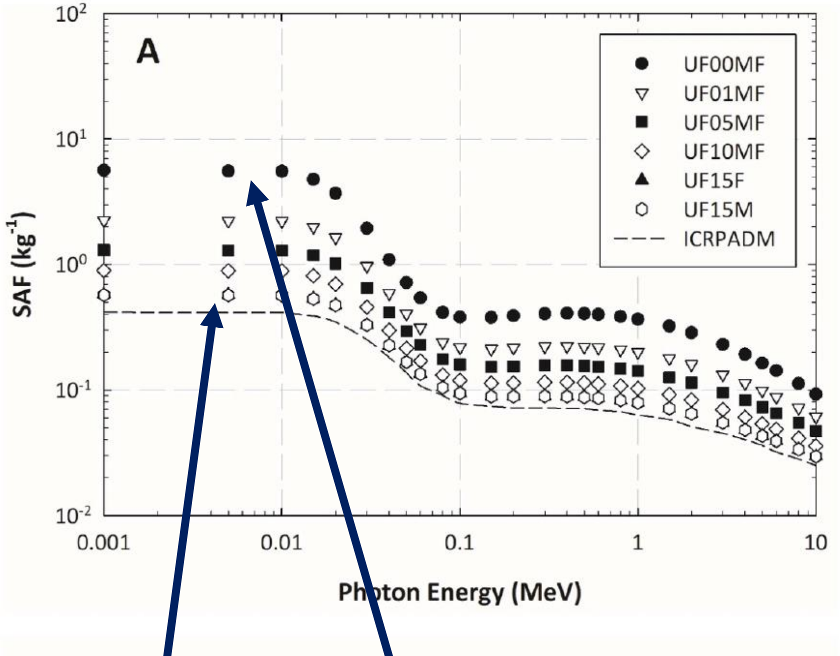
More than 3 millions data points !!!!!

From D. Jokisch, presented during TG95 webinar, Dec 2023

ICRP

SAFs. Some examples for photons

Liver ← Liver



Thyroid ← Lymph nodes

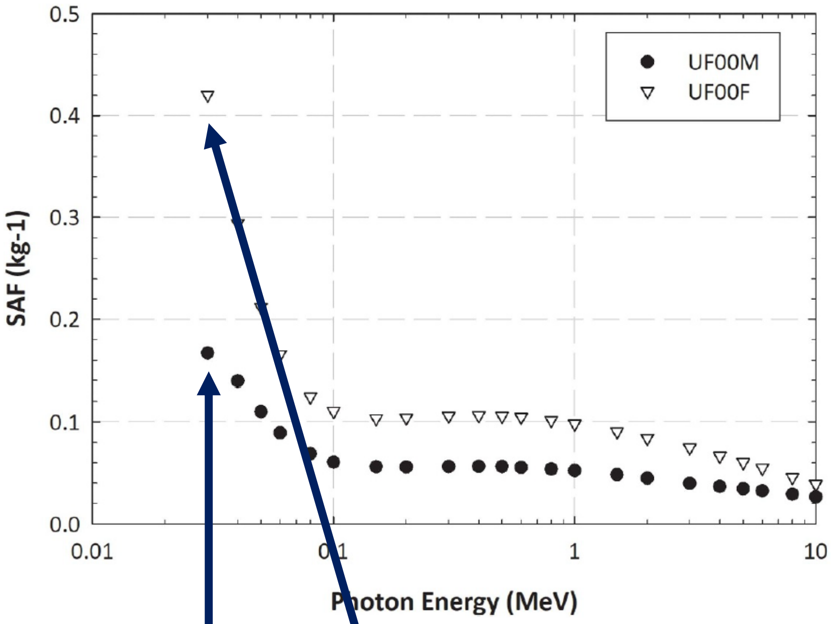


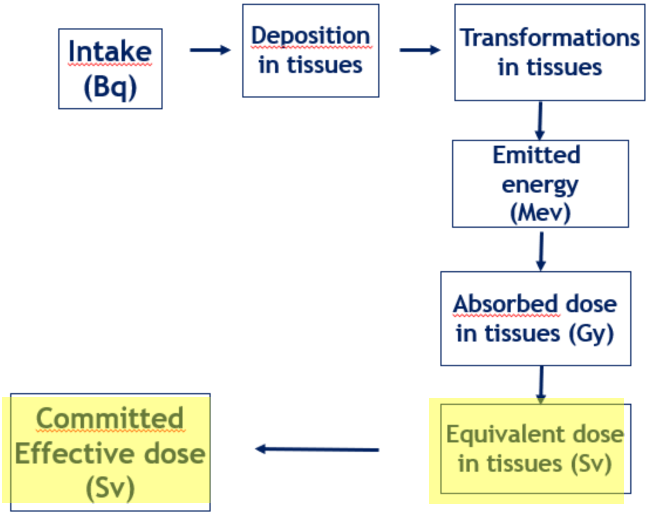
Figure 14. Photon SAFs for thyroid ← thoracic lymph node cross-irradiation in the revised UF00M and UF00F computational phantoms.

Differences according to the age

Sex differences

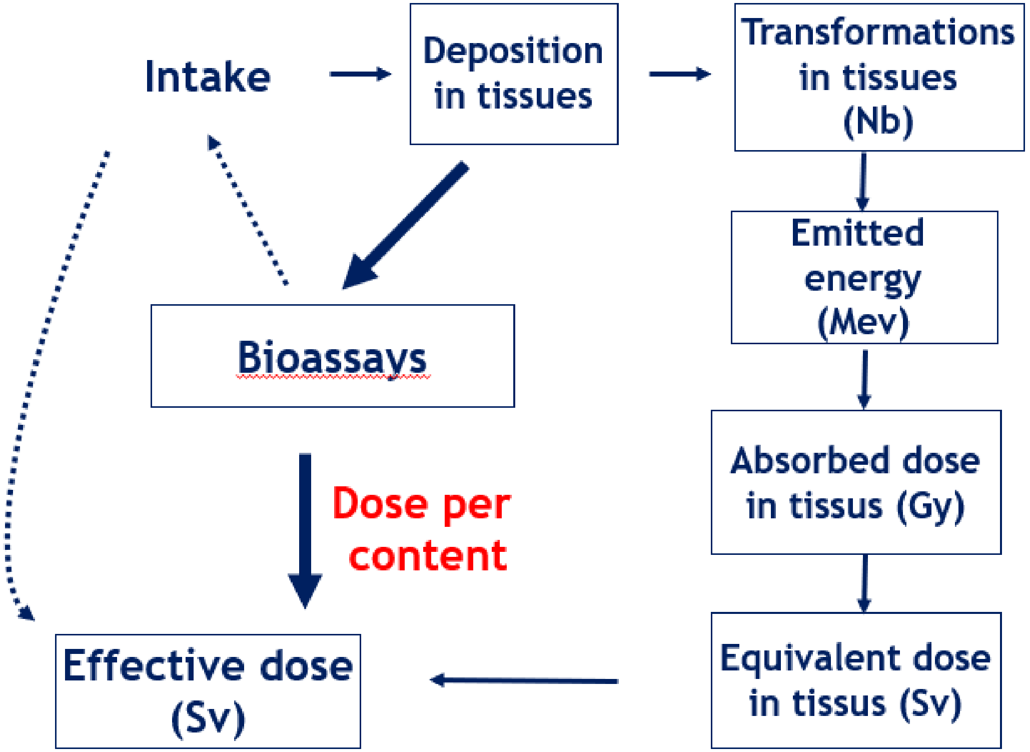
Major advances over the last 20 years (Con't)

- **Changes in weighting factors** (ICRP 103, 2007)



Major advances over the last 20 years (Con’t)

- Changes in weighting factors (ICRP 103, 2007)
- **Concept of dose per content** (ICRP 130, 2015)



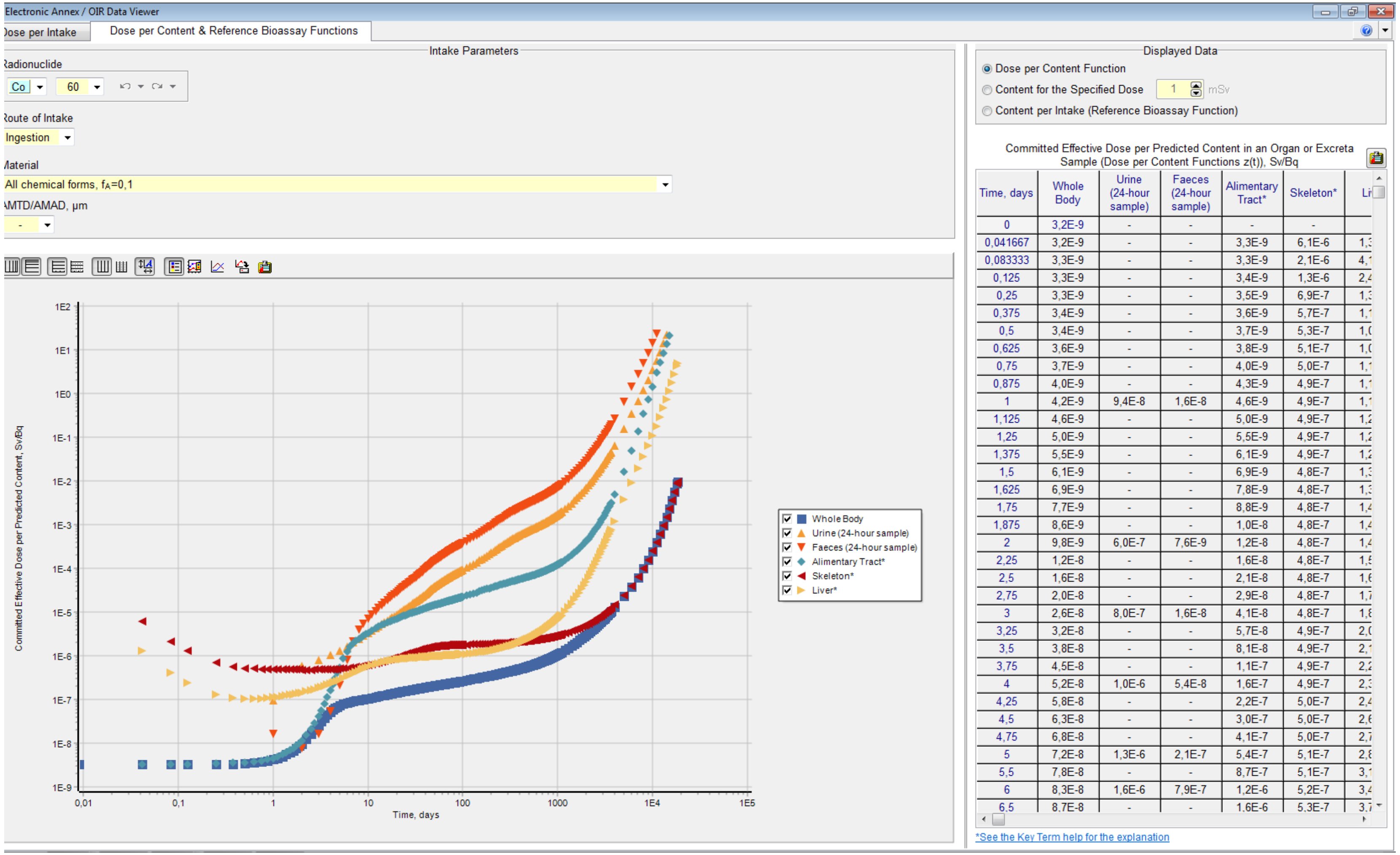
The outcome of all this progress

OIR series for workers

5 publications from 2015 to 2022
ICRP Publications 130, 134, 137, 141, 151

Review of data on inhalation, ingestion and systemic behaviour
Biokinetic models and data
Monitoring techniques and detection limits
Coefficients and bioassay functions for about 1200 isotopes
Different chemical forms at workplaces
Particule size from 0.001 µm to 20 µm
Exposure by submersion for noble gases
Production of the app data viewer
Open access data on www.icrp.org

OIR Data viewer



The outcome of all this progress

EIR series for members of the public

Similar models and information than for workers

Part 1 (29 elements) in Press

Hydrogen, Carbon, Phosphorus, Sulphur, Calcium, Iron, Cobalt, Nickel, Zinc, Selenium, Strontium, Yttrium, Zirconium, Niobium, Molybdenum, Technetium, Ruthenium, Silver, Antimony, Tellurium, Iodine, Caesium, Barium, Iridium, Lead, Bismuth, Polonium, Radon, and Radium.

Part 2 (actinides and lanthanides). Approved for publication

Part 3 (every other elements) to be posted on ICRP website for public consultation for end of 2025

Part 4-5 (embryo/foetus and nursing infants) from 2026 to 2027

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The challenges to face

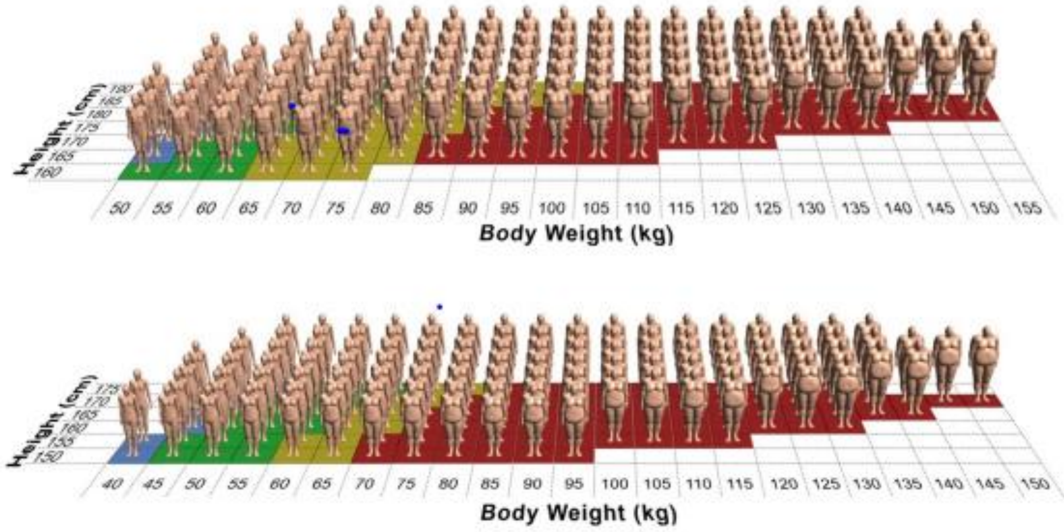
Despite all these major advances, these coefficients do not allow an estimate of a "real" individual dose and therefore an individual risk

$$E = \underbrace{\Sigma w_T \, \Sigma w_R}_{\text{Risk component}} \; \underbrace{D_{T,R}}_{\text{Physical component}}$$

Much to do

Major progress

Almost ready to « individual » absorbed dose if needed



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Take-home messages

- Internal dosimetry is a complex discipline but doses can be easily calculated using dose coefficients provided by ICRP

- Extremely sophisticated models and new dose coefficients have just been produced for workers and are currently being developped for members of the public

- Despite the incredible level of details in the models, dose coefficients remain for radioprotection only, i.e. not for individual risk assessment

- ICRP is working on this issue and has set up a task group on individualisation and stratification in radiological protection

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