ICRP TG95
Internal Dose Coefficients

F. Paquet, M.R. Bailey, R.W. Leggett, T. Fell, T. Smith,
V. Berkovski and J.D. Harrison

ICRP C2

What are
« *Internal Dose Coefficients* » ?

What are
« *Internal Dose* ***Coefficients*** » ?

A Coefficient is
a value that multiplies another value
(Cambridge Dictionary)

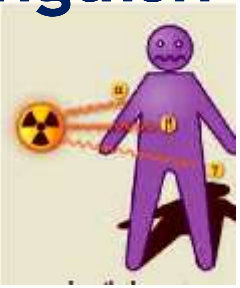
Allows to transform one quantity into another

What are
« *Internal Dose Coefficients* » ?

Every dose to biological tissues is « internal »

« Misuse » of language

Distinguish doses from external exposure



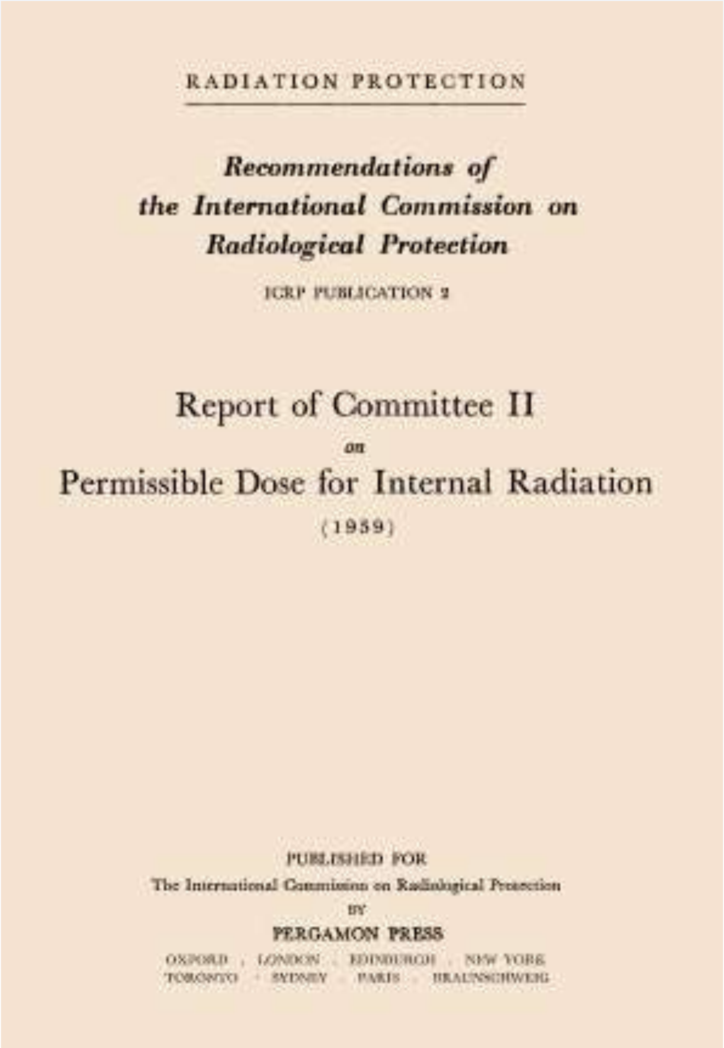
What are
« *Internal Dose* *Coefficients* » ?

Every dose to biological tissues is « internal »

« Misuse » of language

Distinguish doses from external exposure **from doses from internal exposure**

ICRP has been active from the early begining in the field of internal exposure



RADIATION PROTECTION

Recommendations of the International Commission on Radiological Protection

ICRP PUBLICATION 2

Report of Committee II

on

Permissible Dose for Internal Radiation

(1959)

PUBLISHED FOR

The International Commission on Radiological Protection

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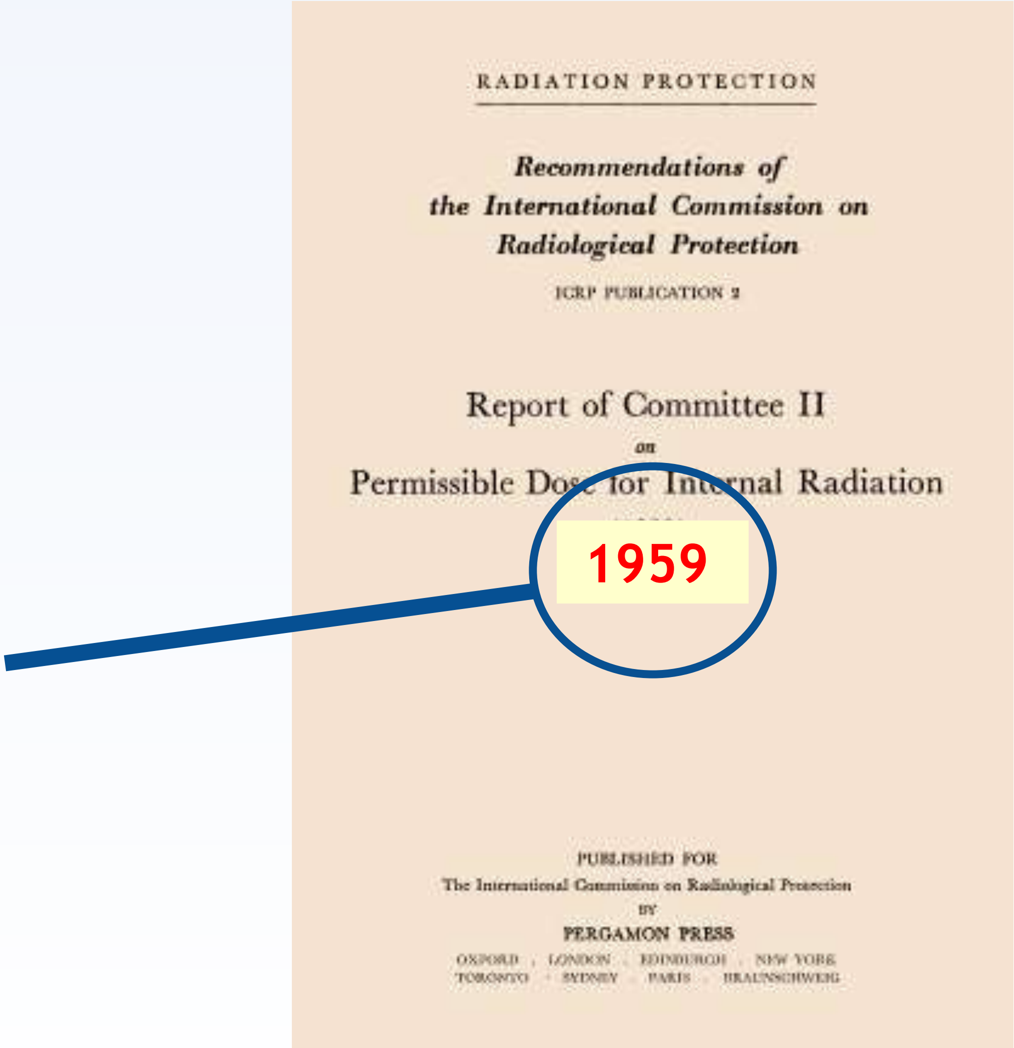


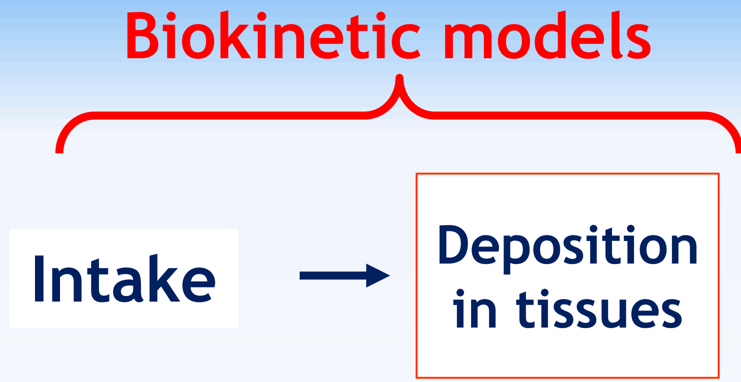
Internal exposures to radiations are managed by the use of the committed effective dose

$$e(\tau) = \sum_{T} w_T \left[\frac{h_T^M(\tau) + h_T^F(\tau)}{2} \right]$$

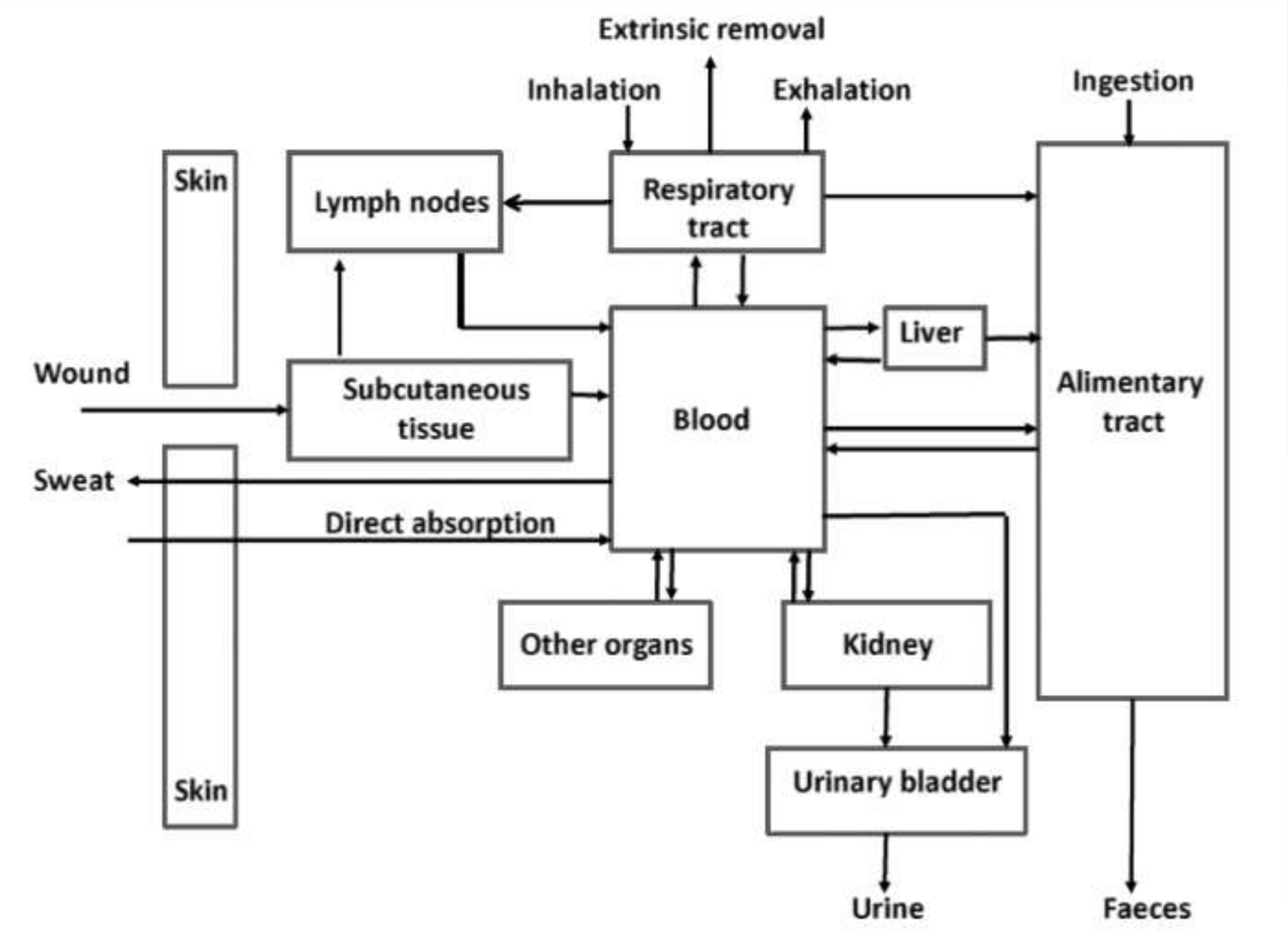
Cannot be measured !!

Calculating committed effective dose after internal contamination is a complex procedure

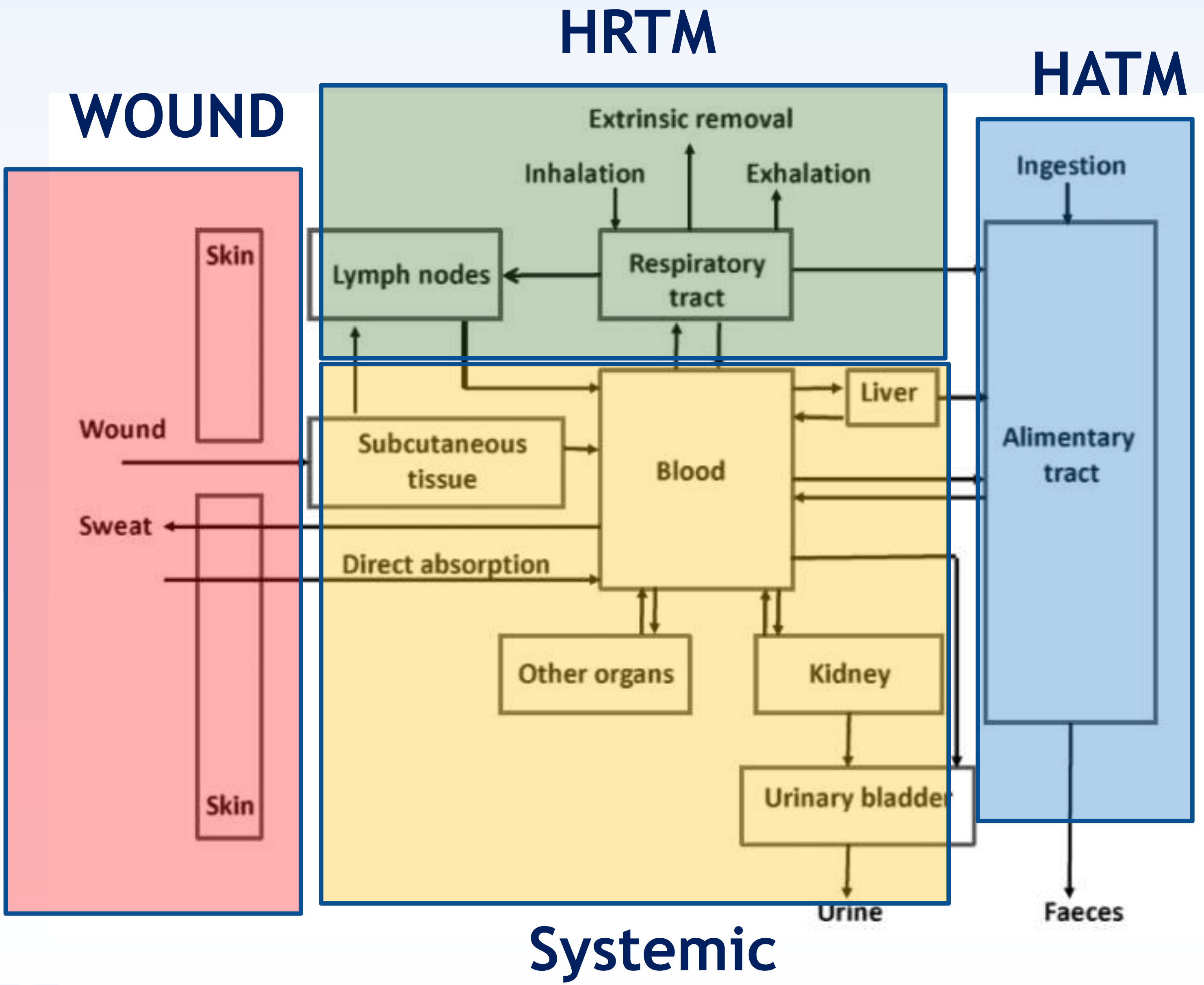
Intake → Deposition in tissues


Biokinetic models
Intake
Deposition in tissues

Generic biokinetic model



ICRP Publication 130, 2015



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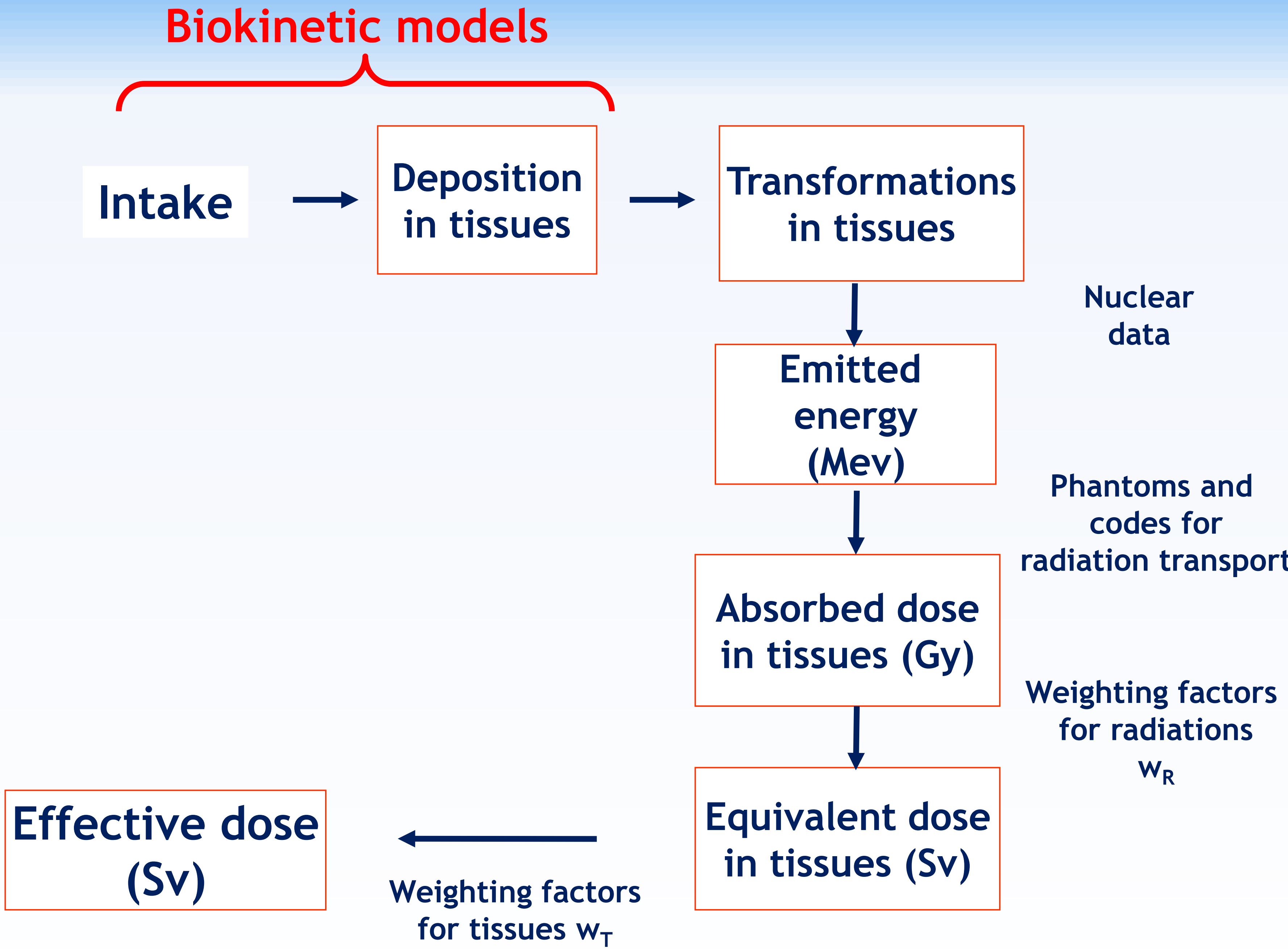
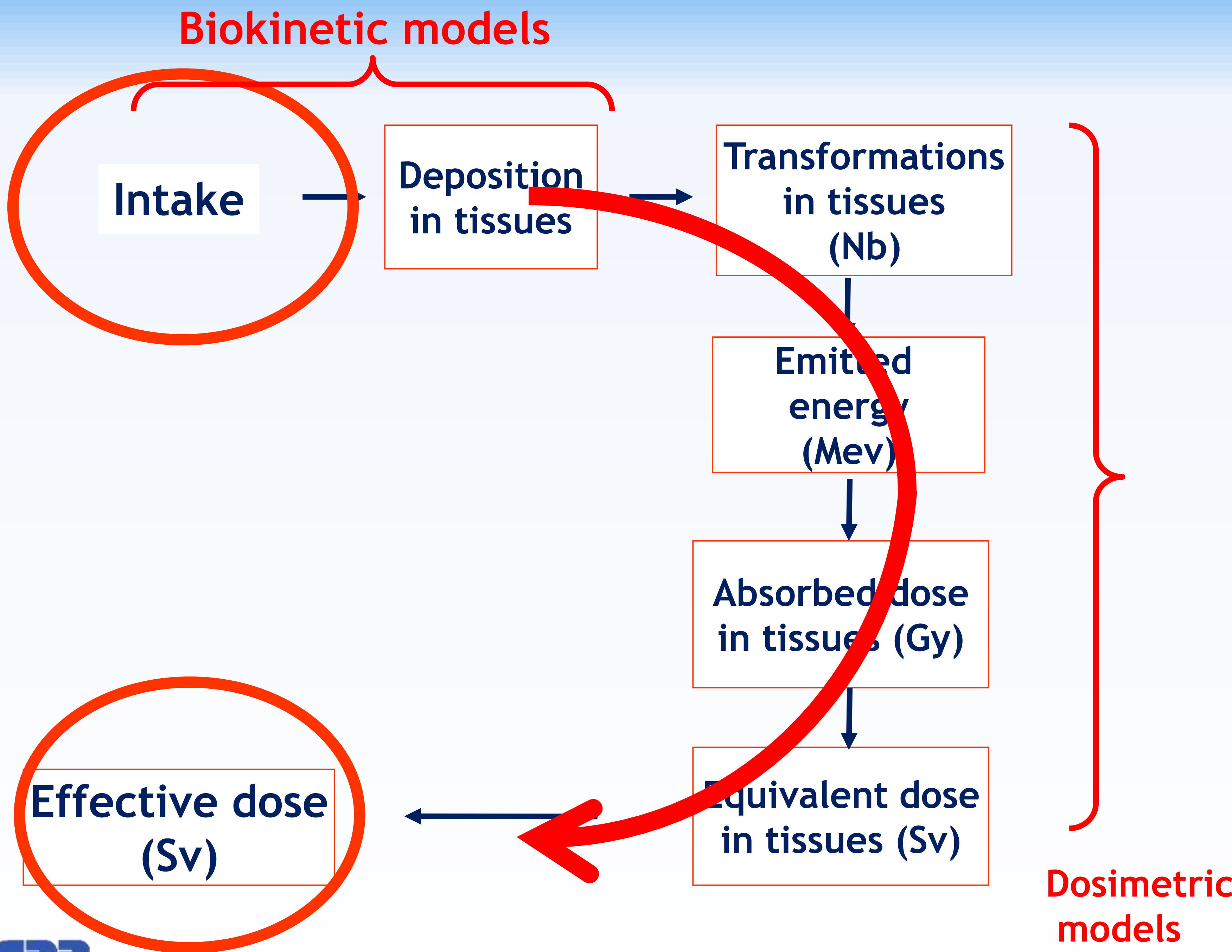

Biokinetic models
Intake
Deposition in tissues
Transformations in tissues
Nuclear data
Emitted energy (Mev)
Phantoms and codes for radiation transport
Absorbed dose in tissues (Gy)
Weighting factors for radiations w_R
Equivalent dose in tissues (Sv)
Weighting factors for tissues w_T
Effective dose (Sv)

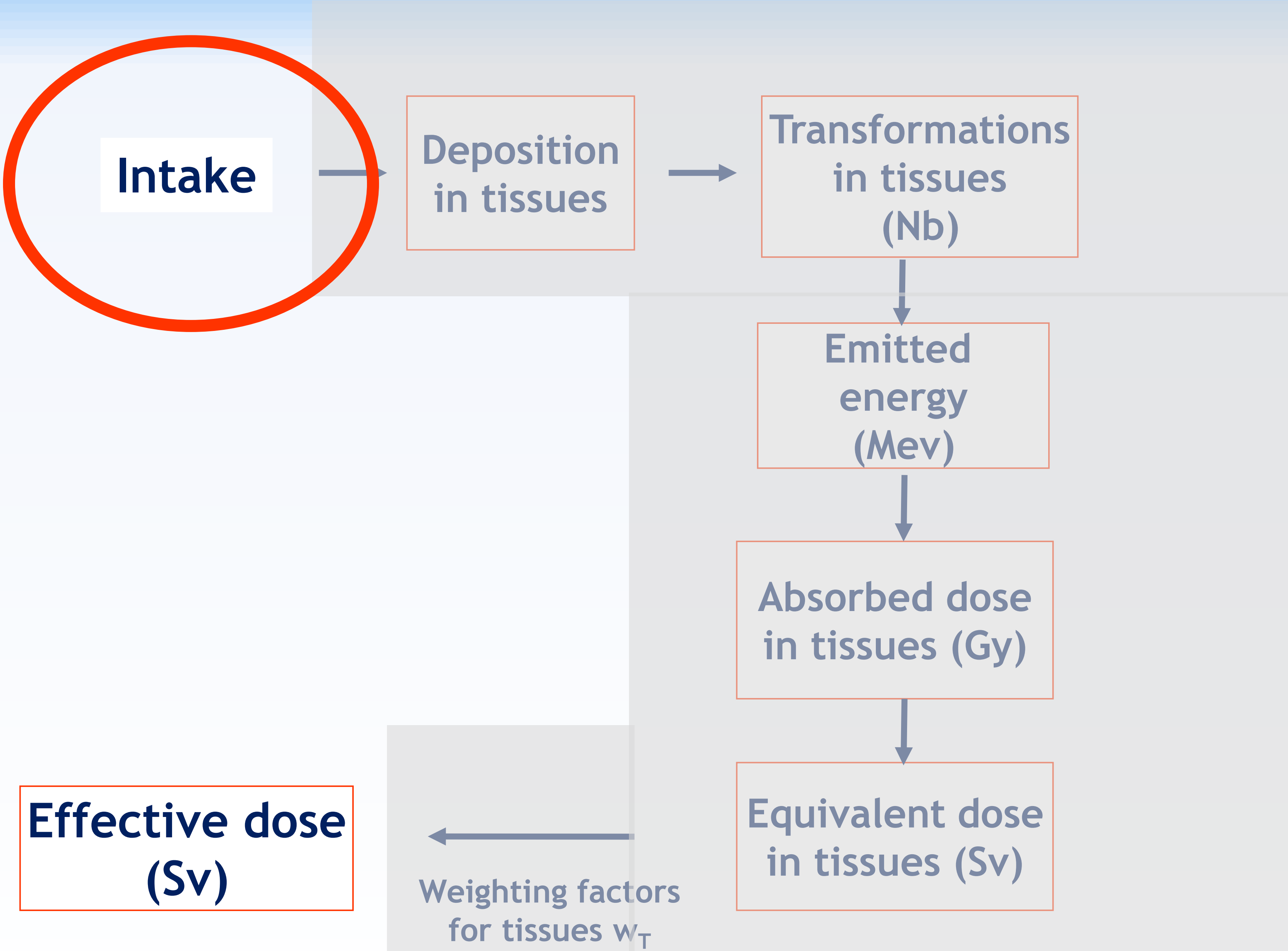

Biokinetic models
Intake
Deposition in tissues
Transformations in tissues (Nb)
Emitted energy (Mev)
Absorbed dose in tissues (Gy)
Equivalent dose in tissues (Sv)
Effective dose (Sv)
Dosimetric models

Complex procedure, limited to experts

ICRP has defined concepts and tools, to allow non-specialists to perform dose assessment

1. Dose per intake coefficient
(DPIC, formerly DPUI)

2. Dose per content function
(DPC)


Intake
Deposition in tissues
Transformations in tissues (Nb)
Emitted energy (Mev)
Absorbed dose in tissues (Gy)
Equivalent dose in tissues (Sv)
Weighting factors for tissues w_T
Effective dose (Sv)

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

DPIC

Type	F	M	S
DPIC μSv/Bq	0.2	1.3	12

For ^{235}U

Dose = Intake x DPIC

Equivalent dose in tissues (Sv)

Weighting factors for tissues w_T

Effective dose (Sv)

Dose per Intake coefficients

Dose per Bq inhaled or ingested

Table 10.7. Committed effective dose coefficients (Sv Bq^{-1}) for the inhalation or ingestion of ^{85}Sr, ^{89}Sr, and ^{90}Sr compounds.

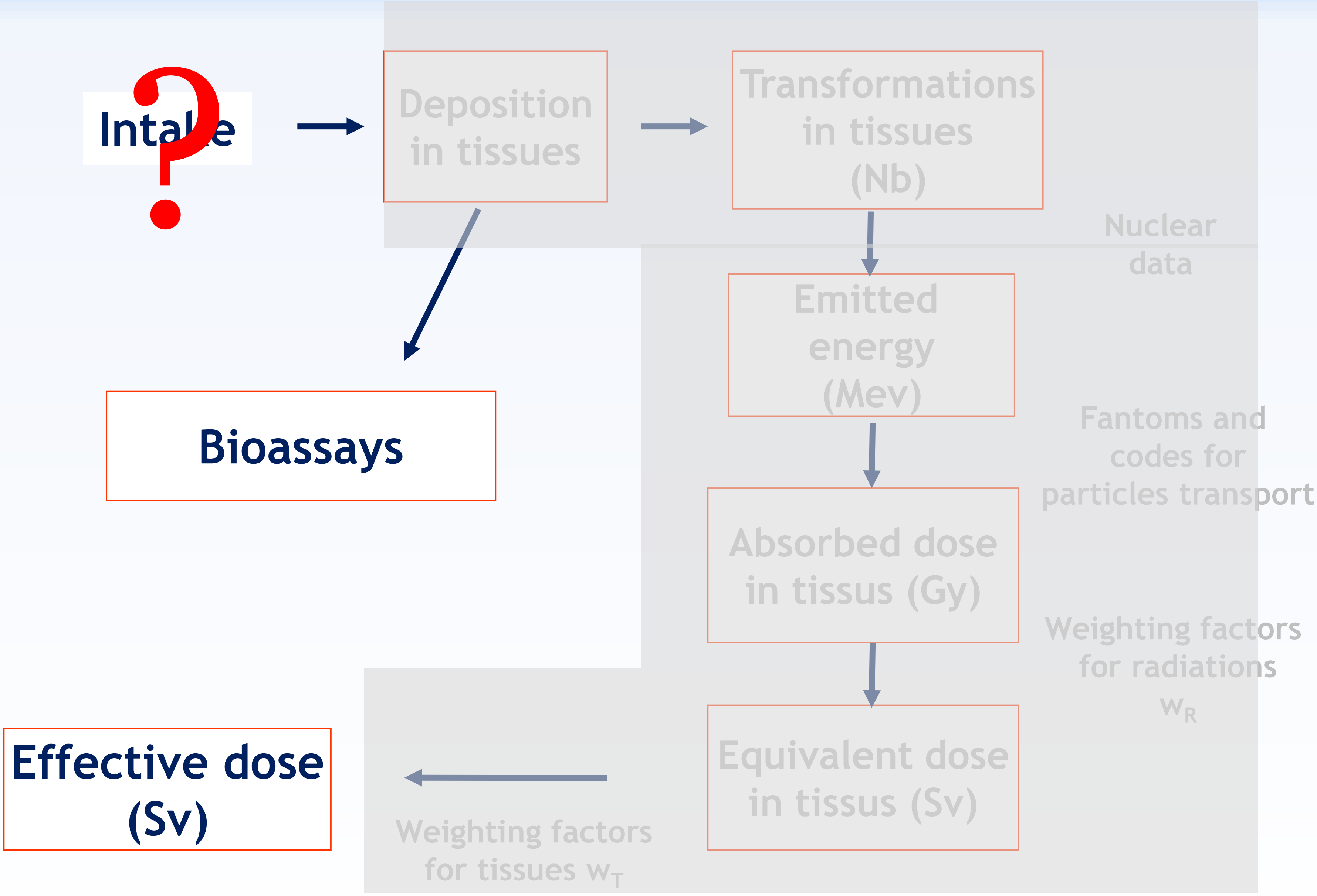
Inhaled particulate materials (5 μm AMAD aerosols)	Effective dose coefficients (Sv Bq^{-1})		
	^{85}Sr	^{89}Sr	^{90}Sr
Type F, strontium chloride, sulphate and carbonate	3.8E-10	9.6E-10	3.2E-08
Type M, fuel fragments, all unspecified forms	5.0E-10	2.2E-09	1.8E-08
Type S, FAP, PSL, strontium titanate	6.7E-10	3.2E-09	2.0E-07
Ingested materials			
$f_A = 0.01$, strontium titanate	2.1E-10	4.0E-10	1.1E-09
$f_A = 0.25$, all other chemical forms	3.8E-10	8.9E-10	2.4E-08

AMAD, activity median aerodynamic diameter; FAP, fused aluminosilicate particles; PSL, polystyrene.

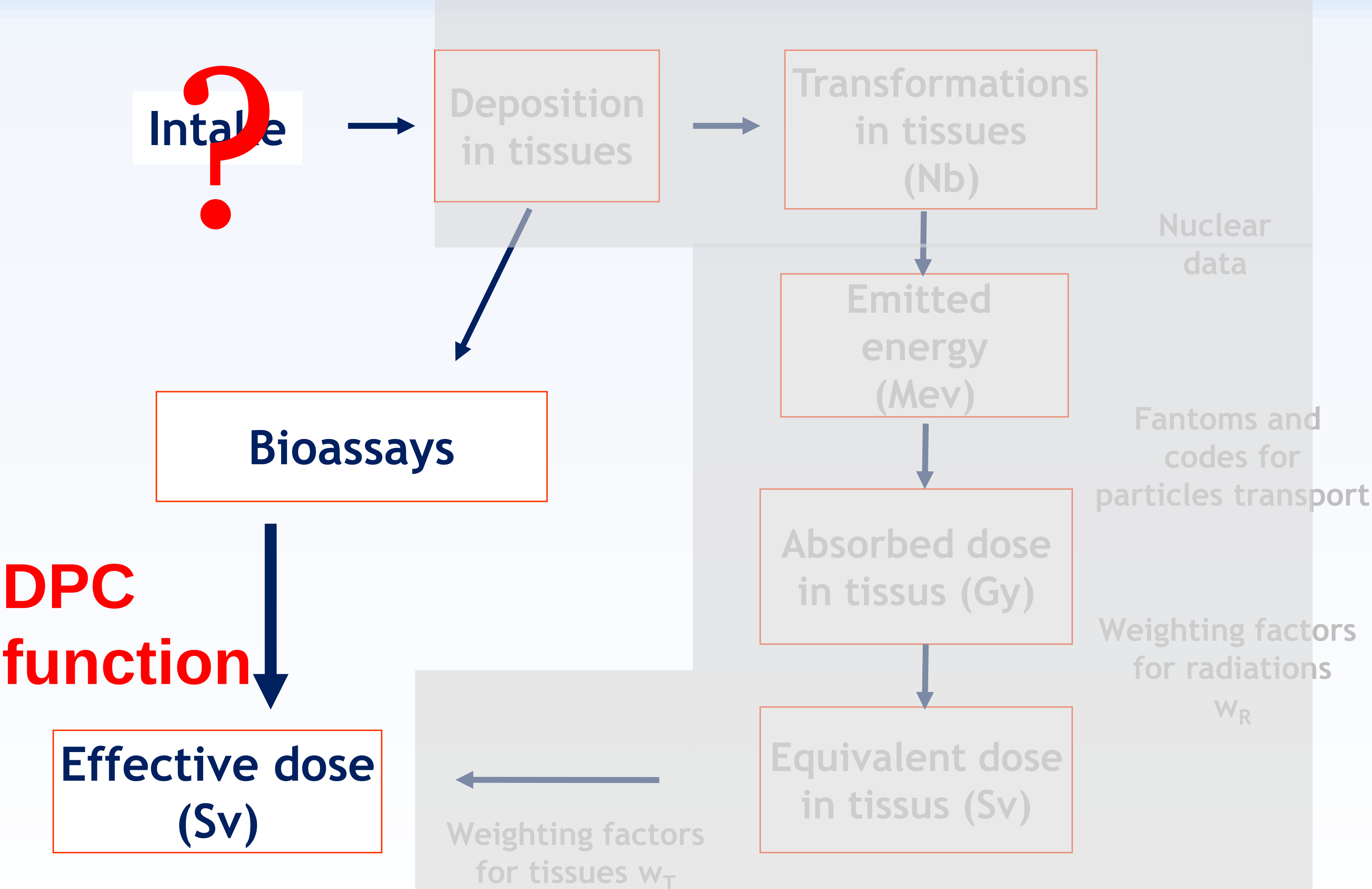
From ICRP Publication 134, 2016

ICRP provides dose coefficients for inhalation and ingestion of the most important isotopes and for (almost) every element

General procedures for assessing doses



General procedures for assessing doses



Dose per Content Function *z(t)*

Dose per Bq measured in organs or tissues

Table 12.6. Dose per activity content of ^{95}Zr in the total body, lungs and in daily excretion of urine (Sv Bq^{-1}); 5 µm activity median aerodynamic diameter aerosols inhaled by a reference worker at light work.

	Type F			Type M			Type S		
Time after intake (d)	Total body	Lungs	Urine	Total body	Lungs	Urine	Total body	Lungs	Urine
1	4.6E-09	2.4E-07	6.4E-07	3.2E-09	3.8E-08	5.7E-06	4.3E-09	4.2E-08	1.5E-04
2	7.1E-09	2.6E-07	1.7E-06	5.9E-09	4.0E-08	1.3E-05	8.0E-09	4.4E-08	3.5E-04
3	1.1E-08	2.9E-07	2.2E-06	1.3E-08	4.2E-08	1.7E-05	1.8E-08	4.6E-08	4.8E-04
4	1.3E-08	3.2E-07	2.5E-06	2.2E-08	4.3E-08	1.9E-05	3.2E-08	4.7E-08	5.4E-04
5	1.4E-08	3.5E-07	2.8E-06	2.9E-08	4.5E-08	2.1E-05	4.2E-08	4.8E-08	5.9E-04
6	1.5E-08	3.8E-07	3.1E-06	3.2E-08	4.6E-08	2.2E-05	4.6E-08	5.0E-08	6.4E-04
7	1.5E-08	4.2E-07	3.4E-06	3.3E-08	4.8E-08	2.4E-05	4.8E-08	5.1E-08	6.9E-04
8	1.6E-08	4.6E-07	3.7E-06	3.4E-08	4.9E-08	2.6E-05	5.0E-08	5.2E-08	7.5E-04
9	1.6E-08	5.1E-07	4.0E-06	3.5E-08	5.0E-08	2.8E-05	5.1E-08	5.3E-08	8.1E-04
10	1.6E-08	5.6E-07	4.4E-06	3.6E-08	5.2E-08	3.0E-05	5.2E-08	5.4E-08	8.8E-04
15	1.7E-08	8.8E-07	7.0E-06	3.9E-08	5.7E-08	4.1E-05	5.7E-08	5.9E-08	1.3E-03
30	2.1E-08	3.2E-06	2.6E-05	4.8E-08	7.6E-08	8.7E-05	7.0E-08	7.2E-08	3.2E-03
45	2.5E-08	9.5E-06	7.8E-05	5.8E-08	9.9E-08	1.4E-04	8.4E-08	8.7E-08	5.6E-03
60	3.0E-08	2.1E-05	1.7E-04	6.9E-08	1.3E-07	1.9E-04	1.0E-07	1.1E-07	7.7E-03
90	4.1E-08	5.1E-05	4.1E-04	1.0E-07	2.2E-07	3.3E-04	1.5E-07	1.5E-07	1.2E-02
180	1.1E-07	2.7E-04	2.0E-03	2.9E-07	1.1E-06	1.5E-03	4.6E-07	4.8E-07	3.7E-02
365	8.2E-07	3.3E-03	2.4E-02	2.3E-06	2.6E-05	2.6E-02	4.4E-06	4.7E-06	3.4E-01

From ICRP Publication 134, 2016

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3	1.1E-08	2.9E-07	2.2E-06	1.3E-08	4.2E-08	1.7E-05	1.8E-08	4.6E-08	4.8E-04
4	1.3E-08	3.2E-07	2.5E-06	2.2E-08	4.3E-08	1.9E-05	3.2E-08	4.7E-08	5.4E-04
5	1.4E-08	3.5E-07	2.8E-06	2.9E-08	4.5E-08	2.1E-05	4.2E-08	4.8E-08	5.9E-04
6	1.5E-08	3.8E-07	3.1E-06	3.2E-08	4.6E-08	2.2E-05	4.6E-08	5.0E-08	6.4E-04
7	1.5E-08	4.2E-07	3.4E-06	3.3E-08	4.8E-08	2.4E-05	4.8E-08	5.1E-08	6.9E-04
8	1.6E-08	4.6E-07	3.7E-06	3.4E-08	4.9E-08	2.6E-05	5.0E-08	5.2E-08	7.5E-04
9	1.6E-08	5.1E-07	4.0E-06	3.5E-08	5.0E-08	2.8E-05	5.1E-08	5.3E-08	8.1E-04
10	1.6E-08	5.6E-07	4.4E-06	3.6E-08	5.2E-08	3.0E-05	5.2E-08	5.4E-08	8.8E-04
15	1.7E-08	8.8E-07	7.0E-06	3.9E-08	5.7E-08	4.1E-05	5.7E-08	5.9E-08	1.3E-03
30	2.1E-08	3.2E-06	2.6E-05	4.8E-08	7.6E-08	8.7E-05	7.0E-08	7.2E-08	3.2E-03
45	2.5E-08	9.5E-06	7.8E-05	5.8E-08	9.9E-08	1.4E-04	8.4E-08	8.7E-08	5.6E-03
60	3.0E-08	2.1E-05	1.7E-04	6.9E-08	1.3E-07	1.9E-04	1.0E-07	1.1E-07	7.7E-03
90	4.1E-08	5.1E-05	4.1E-04	1.0E-07	2.2E-07	3.3E-04	1.5E-07	1.5E-07	1.2E-02
180	1.1E-07	2.7E-04	2.0E-03	2.9E-07	1.1E-06	1.5E-03	4.6E-07	4.8E-07	3.7E-02
365	8.2E-07	3.3E-03	2.4E-02	2.3E-06	2.6E-05	2.6E-02	4.4E-06	4.7E-06	3.4E-01

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2	7.1E-09	2.6E-07	1.7E-06	5.9E-09	4.0E-08	1.3E-05	8.0E-09	4.4E-08	3.5E-04
3	1.1E-08	2.9E-07	2.2E-06	1.3E-08	4.2E-08	1.7E-05	1.8E-08	4.6E-08	4.8E-04
4	1.3E-08	3.2E-07	2.5E-06	2.2E-08	4.3E-08	1.9E-05	3.2E-08	4.7E-08	5.4E-04
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6	1.5E-08	3.8E-07	3.1E-06	3.2E-08	4.6E-08	2.2E-05	4.6E-08	5.0E-08	6.4E-04
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9	1.6E-08	5.1E-07	4.0E-06	3.5E-08	5.0E-08	2.8E-05	5.1E-08	5.3E-08	8.1E-04
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15	1.7E-08	8.8E-07	7.0E-06	3.9E-08	5.7E-08	4.1E-05	5.7E-08	5.9E-08	1.3E-03
30	2.1E-08	3.2E-06	2.6E-05	4.8E-08	7.6E-08	8.7E-05	7.0E-08	7.2E-08	3.2E-03
45	2.5E-08	9.5E-06	7.8E-05	5.8E-08	9.9E-08	1.4E-04	8.4E-08	8.7E-08	5.6E-03
60	3.0E-08	2.1E-05	1.7E-04	6.9E-08	1.3E-07	1.9E-04	1.0E-07	1.1E-07	7.7E-03
90	4.1E-08	5.1E-05	4.1E-04	1.0E-07	2.2E-07	3.3E-04	1.5E-07	1.5E-07	1.2E-02
180	1.1E-07	2.7E-04	2.0E-03	2.9E-07	1.1E-06	1.5E-03	4.6E-07	4.8E-07	3.7E-02
365	8.2E-07	3.3E-03	2.4E-02	2.3E-06	2.6E-05	2.6E-02	4.4E-06	4.7E-06	3.4E-01

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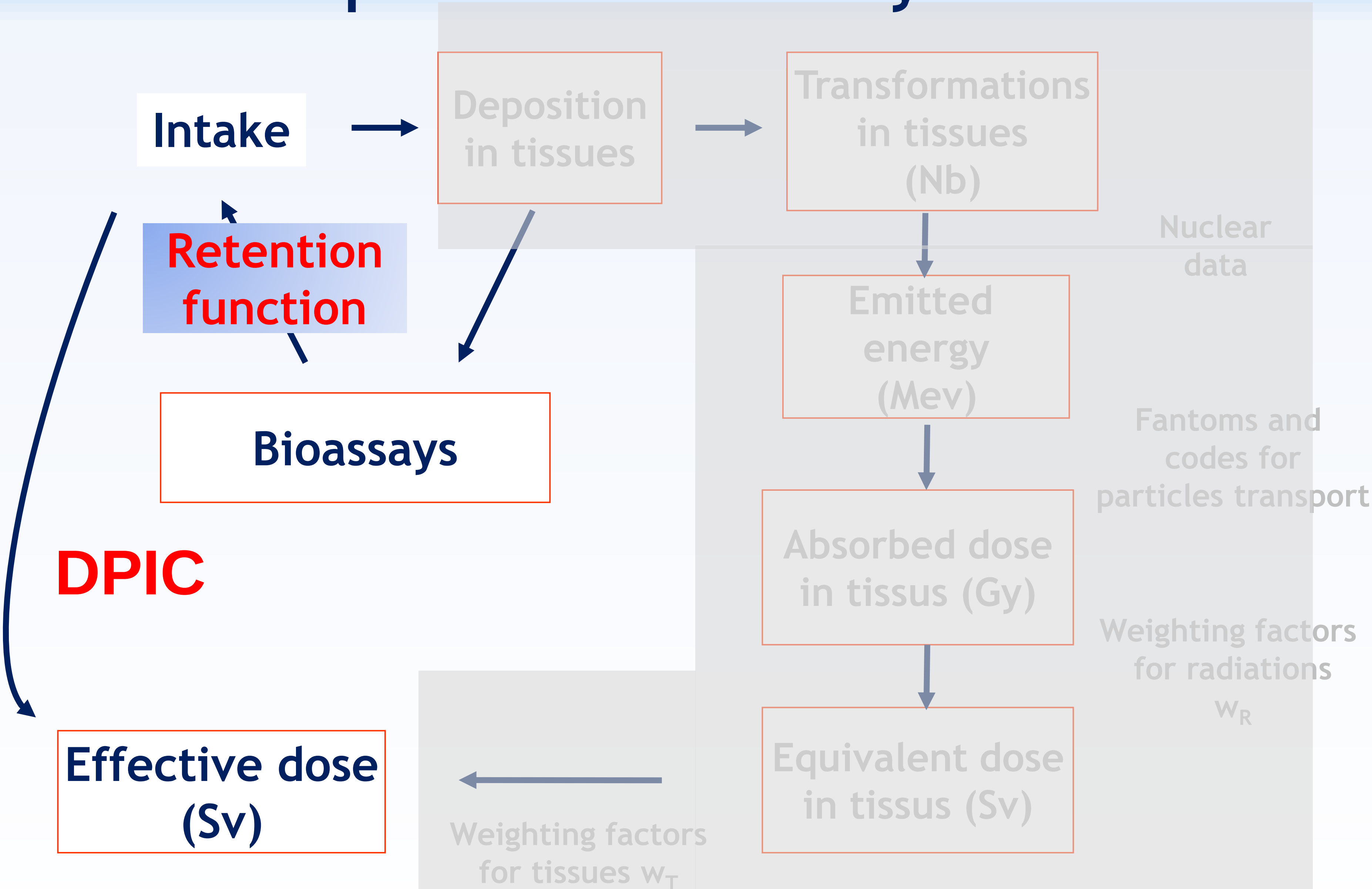
2	7.1E-09	2.6E-07	1.7E-06	5.9E-09	4.0E-08	1.3E-05	8.0E-09	4.4E-08	3.5E-04
3	1.1E-08	2.9E-07	2.2E-06	1.3E-08	4.2E-08	1.7E-05	1.8E-08	4.6E-08	4.8E-04
4	1.[illegible]E-08	3.2E-07	2.5E-06	2.2E-08	4.3E-08	1.9E-05	3.2E-08	4.7E-08	5.4E-04
5	1.4E-08	3.5E-07	2.8E-06	2.9E-08	4.5E-08	2.1E-05	4.2E-08	4.8E-08	5.9E-04
6	1.5E-08	3.8E-07	3.1E-06	3.2E-08	4.6E-08	2.2E-05	4.6E-08	5.0E-08	6.4E-04
7	1.5E-08	4.2E-07	3.4E-06	3.3E-08	4.8E-08	2.4E-05	4.8E-08	5.1E-08	6.9E-04
8	1.6E-08	4.6E-07	3.7E-06	3.4E-08	4.9E-08	2.6E-05	5.0E-08	5.2E-08	7.5E-04
9	1.6E-08	5.1E-07	4.0E-06	3.5E-08	5.0E-08	2.8E-05	5.1E-08	5.3E-08	8.1E-04
10	1.6E-08	5.6E-07	4.4E-06	3.6E-08	5.2E-08	3.0E-05	5.2E-08	5.4E-08	8.8E-04
15	1.7E-08	8.8E-07	7.0E-06	3.9E-08	5.7E-08	4.1E-05	5.7E-08	5.9E-08	1.3E-03
30	2.1E-08	3.2E-06	2.6E-05	4.8E-08	7.6E-08	8.7E-05	7.0E-08	7.2E-08	3.2E-03
45	2.5E-08	9.5E-06	7.8E-05	5.8E-08	9.9E-08	1.4E-04	8.4E-08	8.7E-08	5.6E-03
60	3.0E-08	2.1E-05	1.7E-04	6.9E-08	1.3E-07	1.9E-04	1.0E-07	1.1E-07	7.[illegible]E-03
90	4.1E-08	5.1E-05	4.1E-04	1.0E-07	2.2E-07	3.3E-04	1.5E-07	1.5E-07	1.2E-02
180	1.1E-07	2.7E-04	2.0E-03	2.9E-07	1.1E-06	1.5E-03	4.6E-07	4.8E-07	3.7E-02
365	8.2E-07	3.3E-03	2.4E-02	2.3E-06	2.6E-05	2.6E-02	4.4E-06	4.7E-06	3.4E-01

From ICRP Publication 134, 2016

ICRP INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION

Replace the former system



Reference Bioassay function

Predicted activity in organs or tissues for intake of 1 Bq

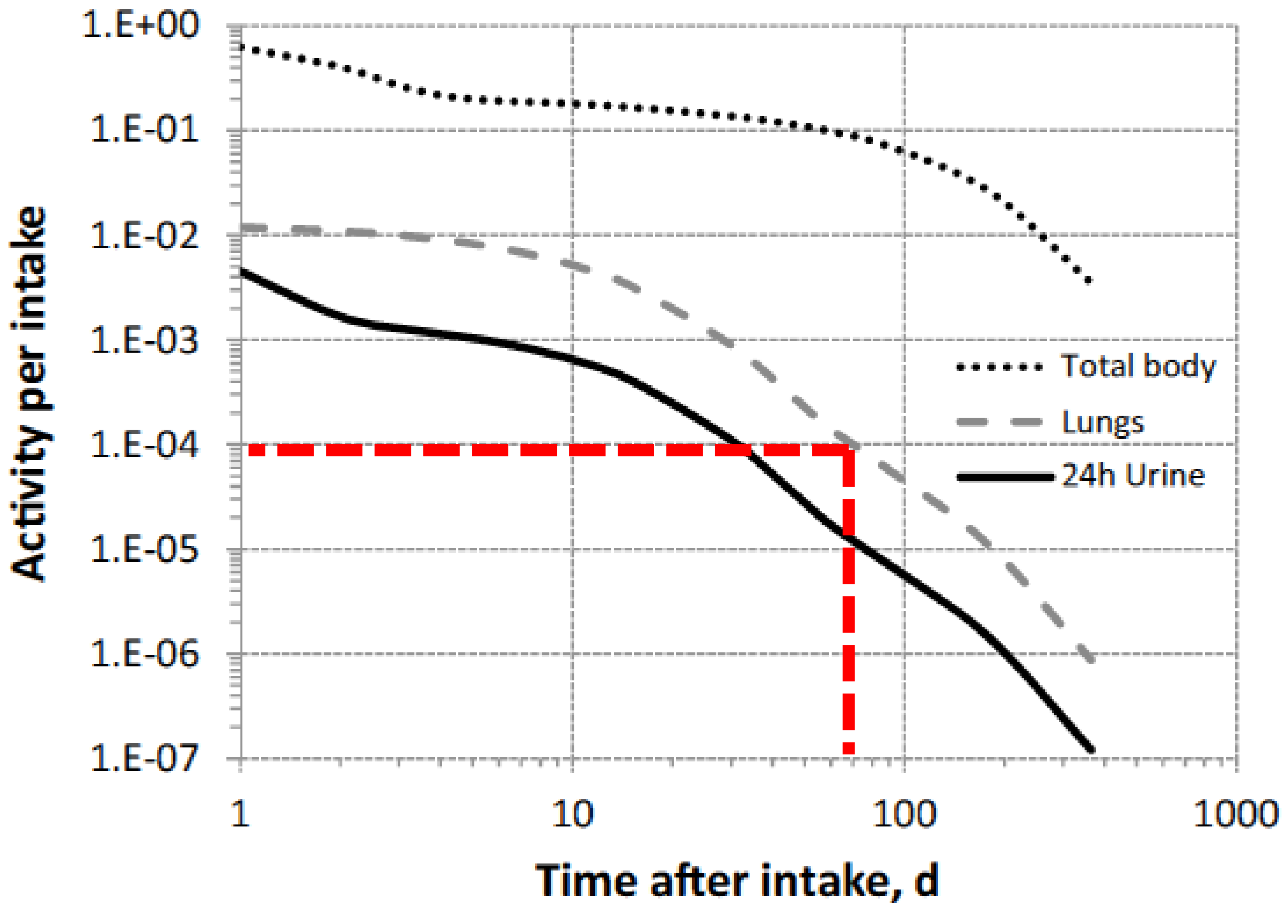


Fig. 12.3. Total body and lung contents, and daily urinary excretion of ^{95}Zr following inhalation of 1 Bq Type F.

From ICRP Publication 134, 2016

Main past ICRP publications on these topics

For workers

Publication 30 series **(ICRP, 1979, 1980, 1981, 1988)**

dose coefficients and ALI for inhalation and ingestion.
based on Reference man (Publication 23, 1975) and 1977 recommendations (Publication 26, 1977).

Publication 68 **(ICRP, 1994)**

updated dose coefficients following 1991 Recommendations (Publication 60, 1991), HRTM (Publication 66, 1994), new skeletal data (Publication 70, 1995) and revised systemic biokinetic models.
No ALI anymore.

Publications 54 and 78 **(ICRP, 1988, 1997)**

guidance on the design of monitoring programs and the interpretation of results, to estimate doses to workers following radionuclide inhalation or ingestion. Provide predicted values of measured quantities after intake.

Main past ICRP publications on these topics

For the members of the public

Publications 56, 67, 69, 71 and 72 **(ICRP, 1989, 1993, 1995)**

age-specific dose coefficients for inhalation and ingestion for 91 elements, using up-to-date models and latest ICRP recommendations.

Publications 88 and 95 **(2001,2004)**

Dose to embryo/fetus and infants

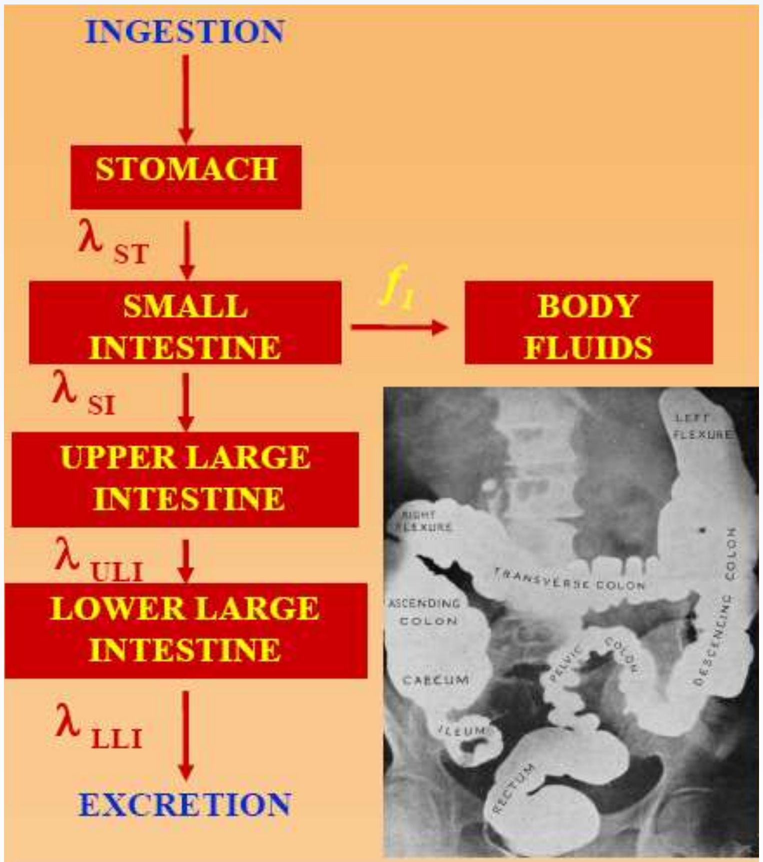
Progress and changes made during this period

In physiology and biokinetic models

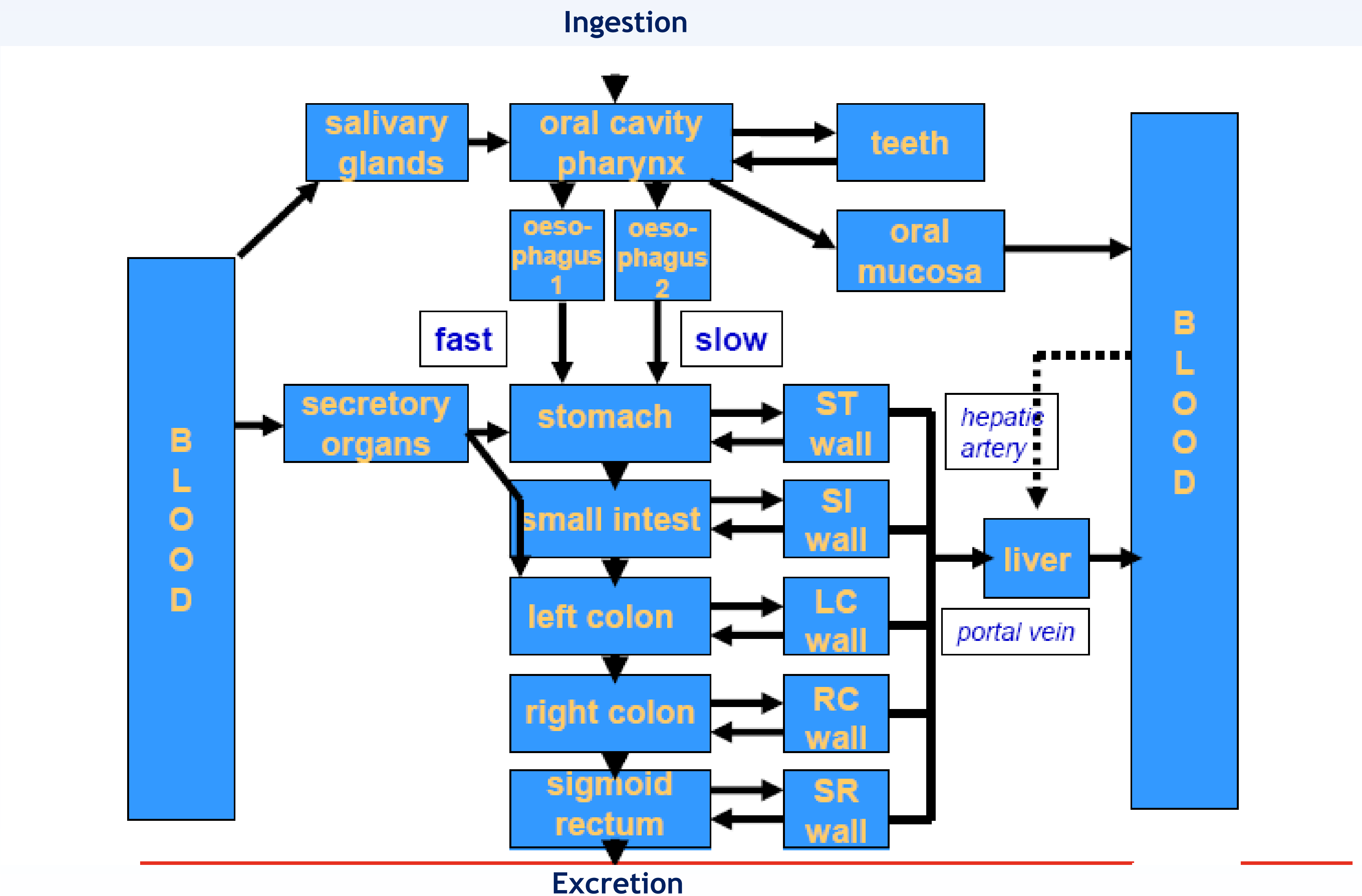
- New data on Reference man (ICRP 89, 2002)
- Human Alimentary Tract Model (ICRP 100, 2006)

The Human alimentary tract model

The former model



The Human alimentary tract model (2006)

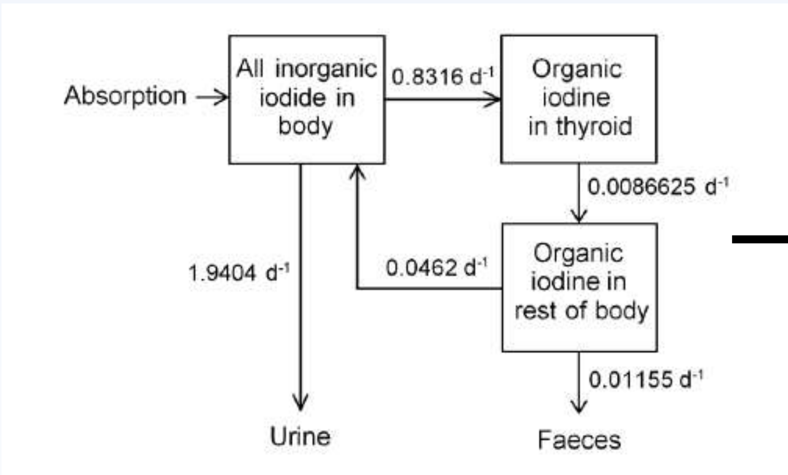


Progress and changes made during this period

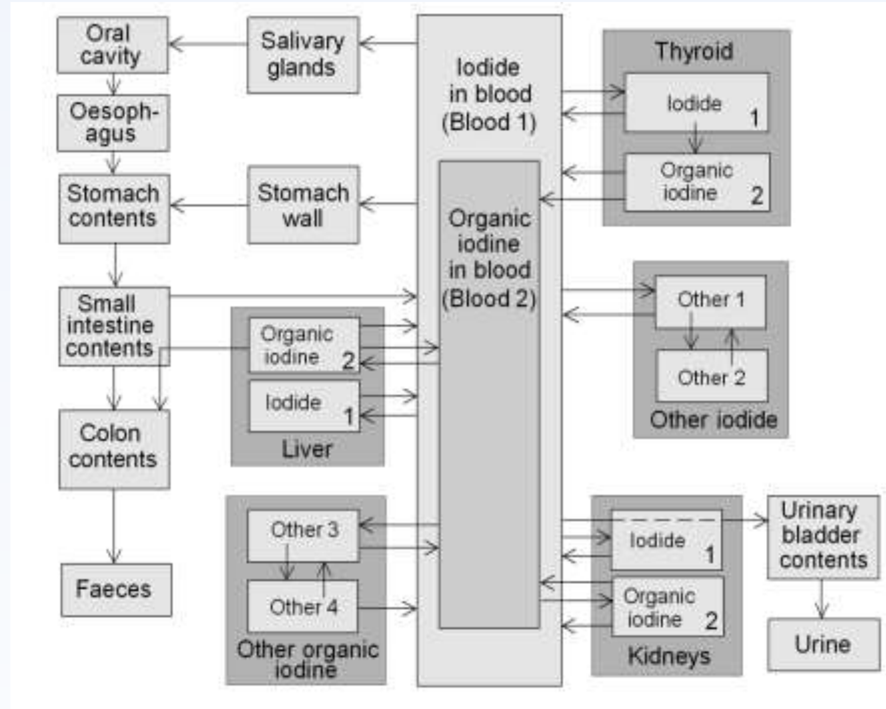
In physiology and biokinetic models

- New data on Reference man (ICRP 89, 2002)
- Human Alimentary Tract Model (ICRP 100, 2006)
- New element specific systemic models, physiologically realistic

Systemic model for Iodine



The former model (ICRP 1994, 1997)



The new model
ICRP Publication 137, In Press

Three subsystems:

- circulating inorganic iodide;
- thyroidal organic iodine
- extrathyroidal organic iodine.

Systemic model for Strontium

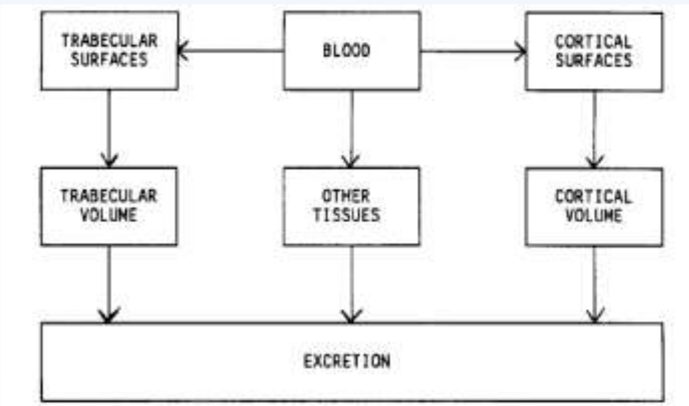
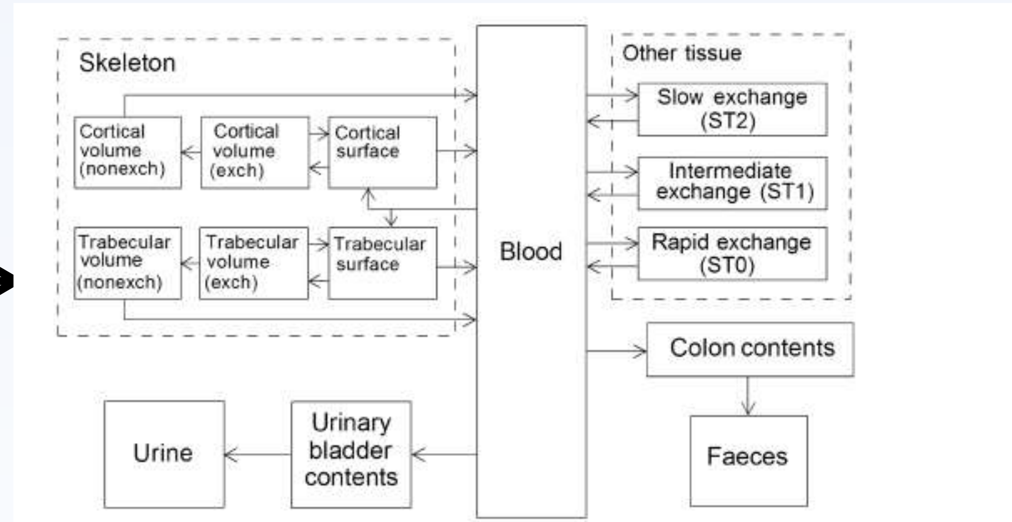


Fig. 2. Diagram of the biokinetic model for strontium.



Structure of the biokinetic model for systemic strontium. ST, soft tissue; exch, exchangeable; nonexch, non-exchangeable.

The former model (ICRP 1989)

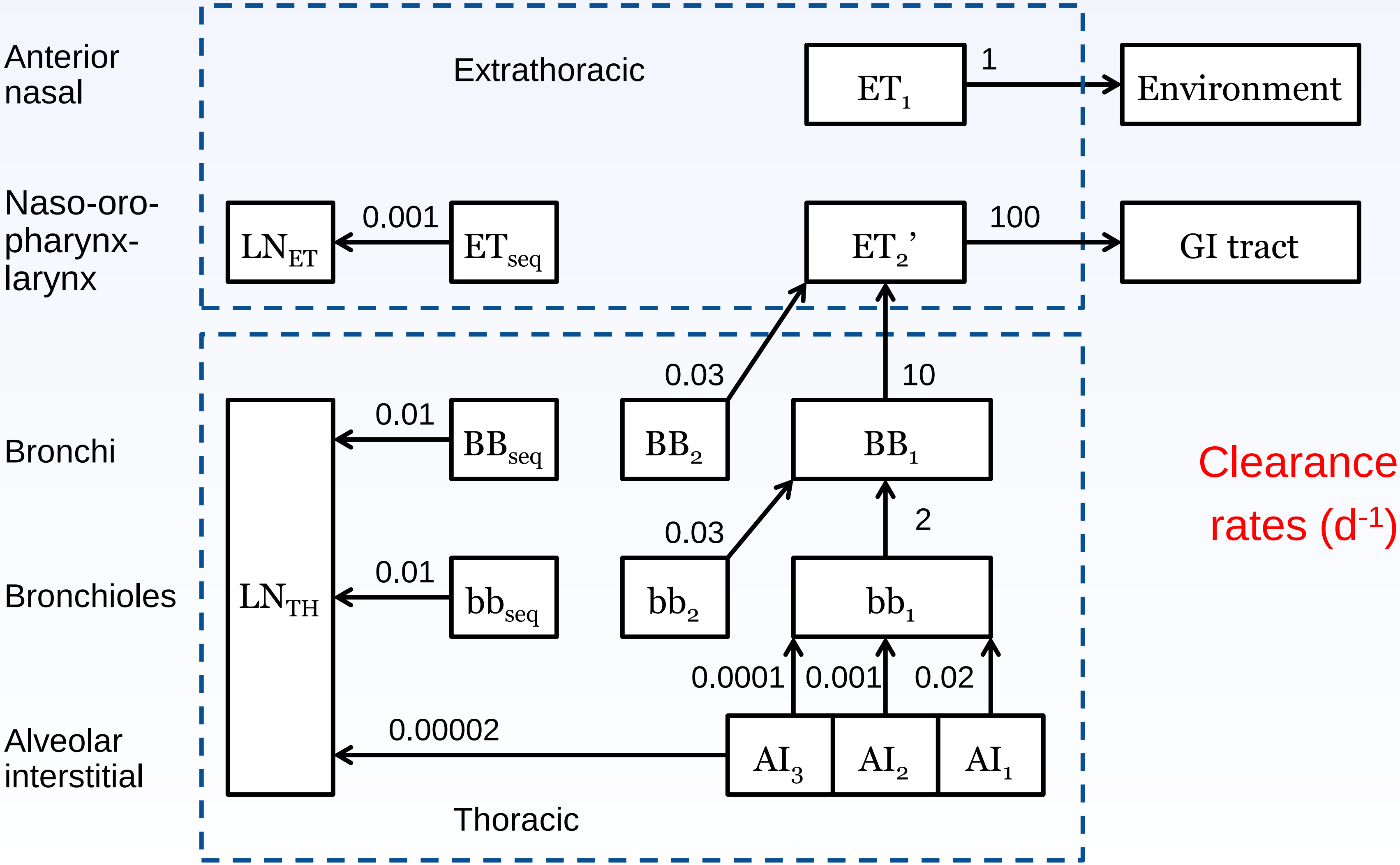
The new model
ICRP Publication 134, 2016

Progress and changes made during this period

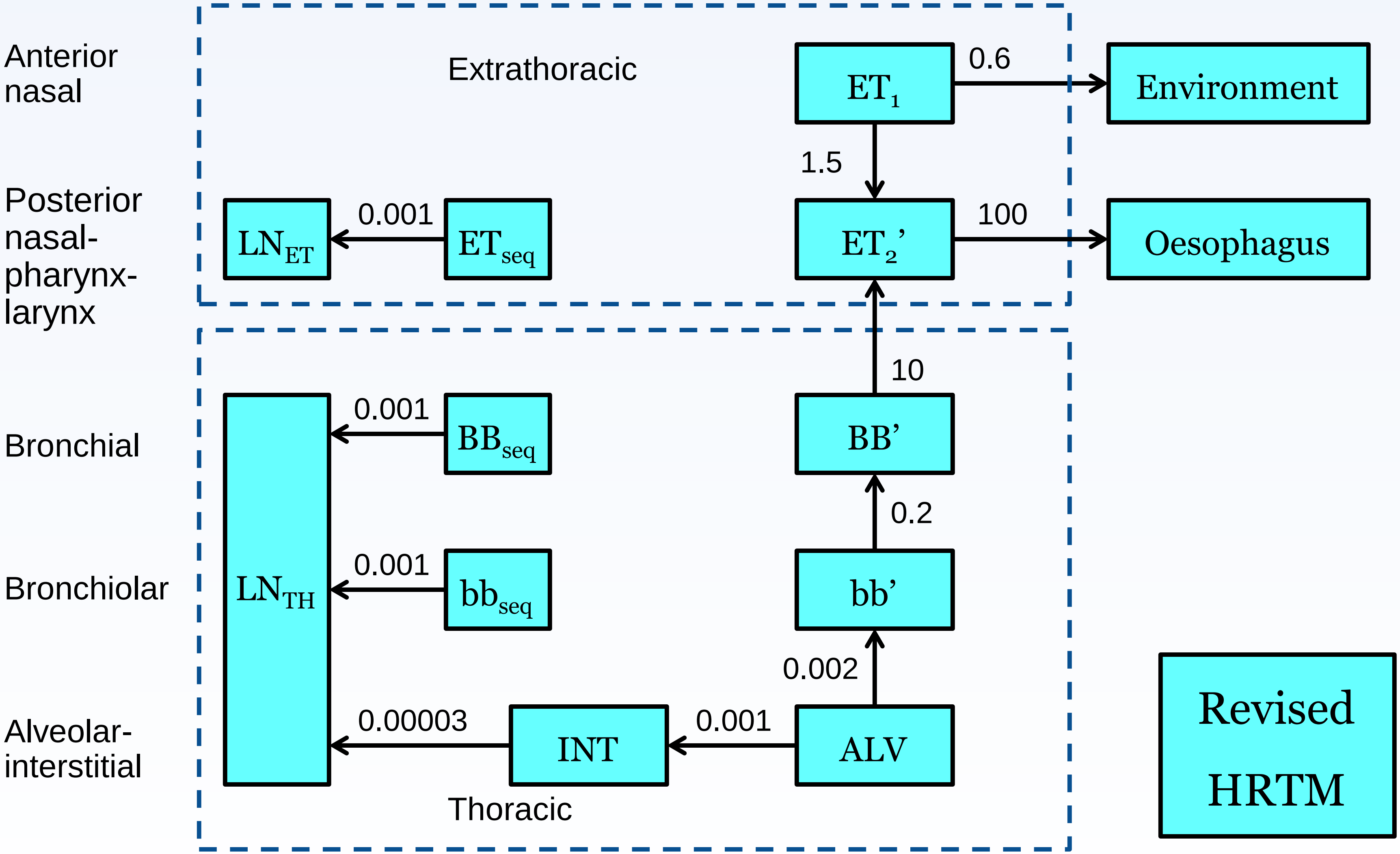
In physiology and biokinetic models

- New data on Reference man (ICRP 89, 2002)
- Human Alimentary Tract Model (ICRP 100, 2006)
- New element specific systemic models, physiologically realistic
- More realistic treatment of the biokinetics of radionuclide daughters
- New data supporting update of the Human Respiratory Tract Model

Particle transport model (ICRP 66 HRTM)



Particle transport model (ICRP 103)



Default parameter values
Type F, M, S

		f_r	s_r (d^{-1})	s_s (d^{-1})
Type F	ICRP 66	1	100	
	OIR	*1*	*30*	
Type M	ICRP 66	0.1	100	0.005
	OIR	*0.2*	*3*	*0.005*
Type S	ICRP 66	0.001	100	0.0001
	OIR	*0.01*	*3*	*0.0001*

Element-specific values for s_r. Range from 0.4 to 100 d^{-1}

Example of Uranium absorption

Compound	Absorption parameter values			Type
	f_r	s_r (d^{-1})	s_s (d^{-1})	
Default Type F (UF6, U-TBP)	***1.0***	***10***		
Uranyl nitrate, $UO_2(NO_3)_2$	0.8	1	0.01	(F/M)
Uranium peroxide hydrate	0.8	1	0.01	(F/M)
Ammonium diuranate, ADU	0.8	1	0.01	(F/M)
Default Type M (UF4)	***0.2***	***3***	***0.005***	
Uranium Octoxide U_3O_8; Uranium dioxide	0.03	1	0.0005	(M/S)
Default Type S	***0.01***	***3***	***0.0001***	

Progress and changes made during this period

In physiology and biokinetic models

- New data on Reference man (ICRP 89, 2002)
- Human Alimentary Tract Model (ICRP 100, 2006)
- New element specific systemic models, physiologically realistic
- More realistic treatment of the biokinetics of radionuclide daughters
- New data supporting update of the Human Respiratory Tract Model

In dosimetry and monitoring

- Development of adult reference computational phantom, based on the new ref man (ICRP 110, 2009)
- New skeletal dosimetry (ICRP 116, 2010)
- Revised nuclear decay data (ICRP 107, 2008)
- Concept of dose per content

Progress and changes made during this period

In ICRP recommendations

- Adoption of the use of realistic phantoms (ICRP 103, 2007)
- Changes in weighting factors (ICRP 103, 2007)
- Changes in calculation of equivalent dose (ICRP 103, 2007)

Progress and changes made during this period

These new data and recommendations supported a revision of the past reports and provision of new dose coefficients with guidance on monitoring programs and data interpretation

Done for external dosimetry (ICRP 116, 2010)
Need to be done for internal dosimetry

Revision of the reports on internal exposure

Division of the work in two parts :

- Revision of models and dose coefficients for workers *(OIR series)*

- Revision of models and dose coefficients for members of the public *(EIR series,..)*

The OIR series
5 volumes

OIR Part 1 (ICRP Publication 130, 2015)

- Control of occupational exposures to radionuclides
- Biokinetic and dosimetric models
- Methods of individual and workplace monitoring
- Monitoring programmes
- General aspects of retrospective dose assessment

The OIR series
5 volumes

OIR Part 2 to 5

For each element section:

- Chemical forms in the workplaces
- Principal radioisotopes, physical half-lives and decay modes
- Review of data on inhalation, ingestion and systemic biokinetics
- Structure of biokinetic models and parameter values
- Monitoring techniques and typical detection limits
- Dose coefficients, reference bioassays functions and dose per content functions in printed document and/or electronic annexes

The OIR series
5 volumes

OIR Part 2 *ICRP Publication 134*

Hydrogen (H), Carbon (C), Phosphorus (P), Sulp **2016** um (Ca), Iron (Fe), Cobalt (Co), Zinc (Zn), Strontium (Sr), Yttrium (Zr), Niobium (Nb), Molybdenum (Mo) and Technetium (Tc).

OIR Part 3

Ruthenium (Ru), Antimony (Sb), Tellurium (Te **2017** aesium (Cs), Barium (Ba), Iridium (Ir), Lead (Pb), Bismuth (Bi), Polonium Rn), Radium (Ra), Thorium (Th) and Uranium (U).

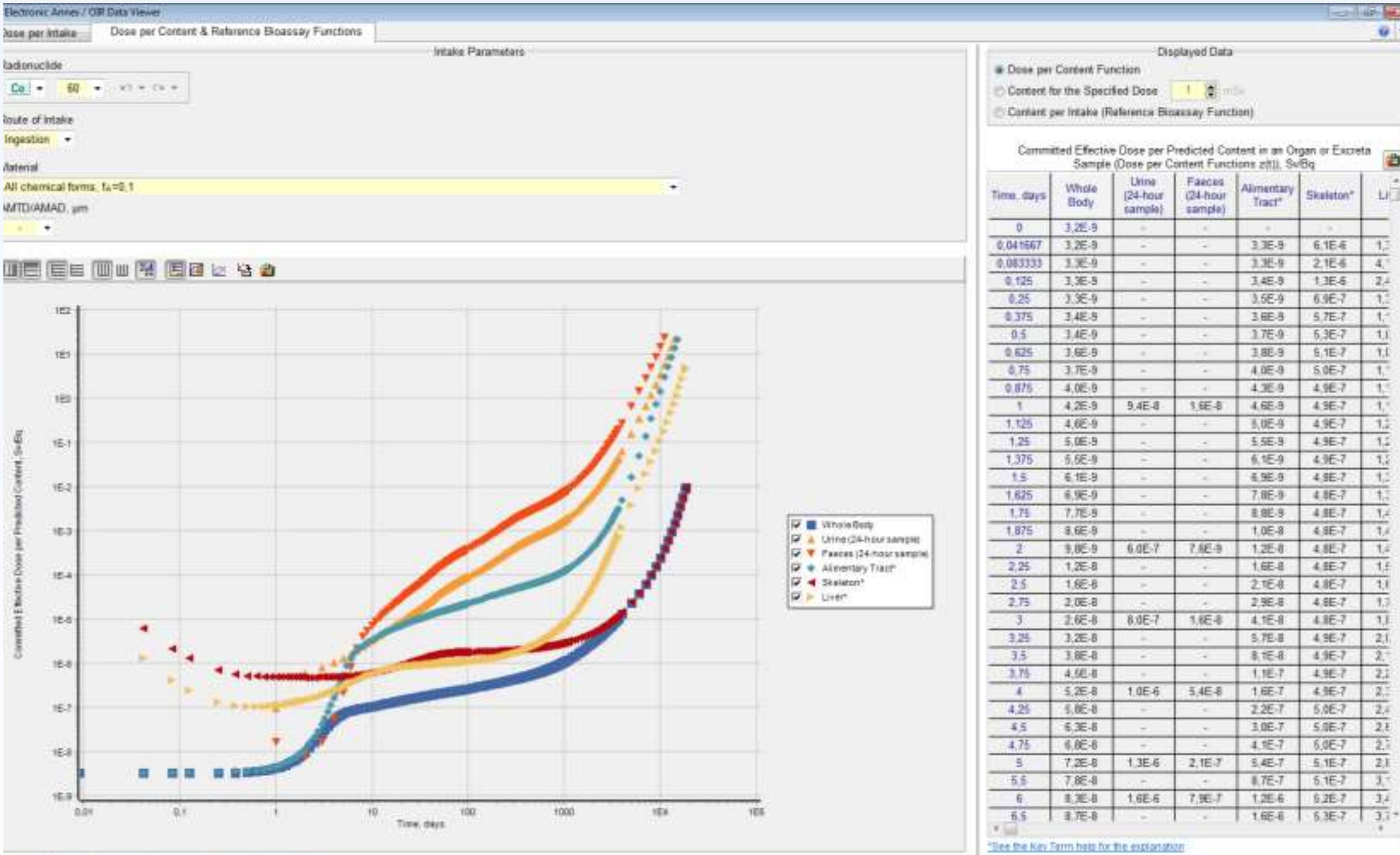
OIR Part 4

Lanthanides series, actinium (Ac), protactiniur **2018** nsuranic elements

OIR Part 5

Fluorine (F), Sodium (Na), Magnesium (Mg), Potassium (K), Manganese (Mn), Nickel (Ni), Selenium (Se), Molybdenum (Mo), Technetium (Tc) and Silver (Ag) and most of the others

OIR Data viewer



The EIR series
4 volumes

EIR Part 1 (in Progress)

Same information and data for every element currently described in OIR P2 to 4 (plus Ag, Ni, Se)

EIR Part 2

Same information for every other element

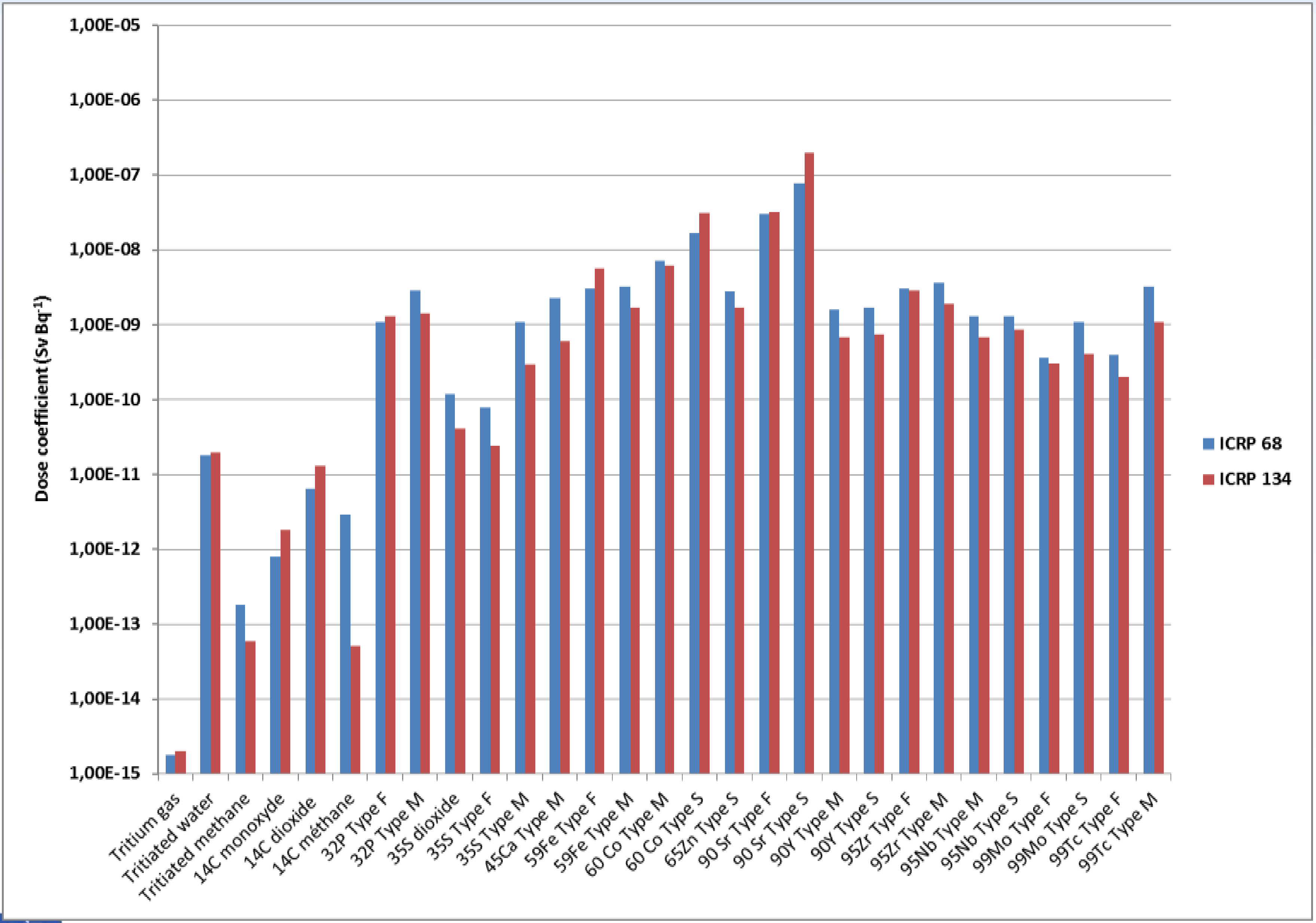
EIR Part 3

Breast-feeding Infant Internal Dose Coefficients for Maternal Intakes

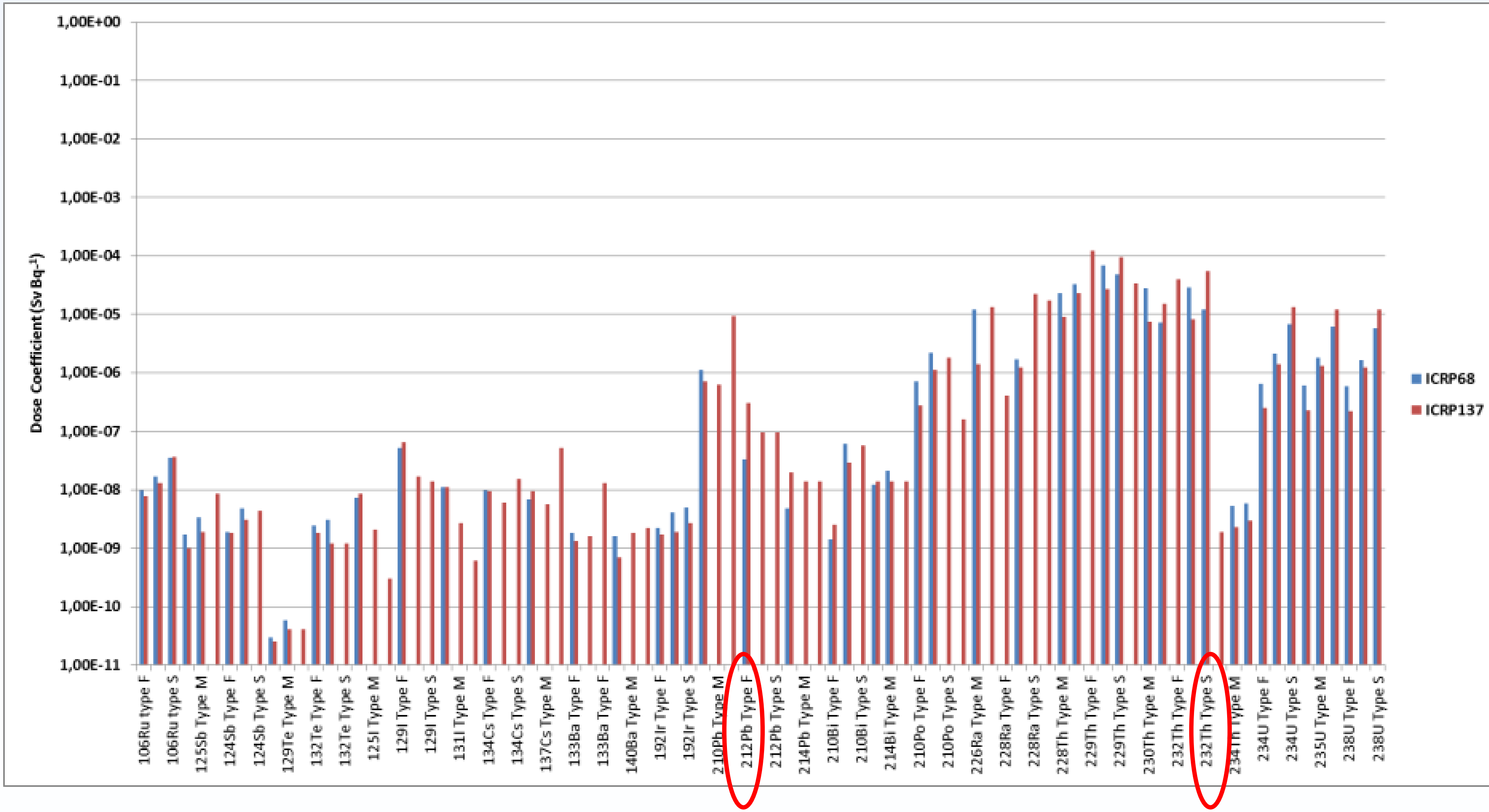
EIR Part 4

In utero Internal Dose Coefficients for Maternal Intakes

Comparison of dose coefficients between ICRP 68 and OIR P2



Comparison of dose coefficients between ICRP 68 and OIR P3



The authors of this work

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L Bertelli	J Marsh T Smith	
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A Giussani	D Nosske	

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the CPRT (TG 96)and the committee 2 members …

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