Assessment and interpretation of internal doses : uncertainty and variability

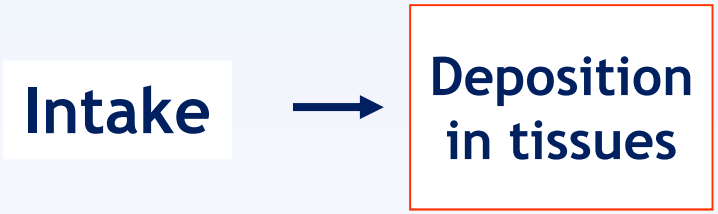
Francois Paquet, Mike Bailey, Rich Leggett, John Harrison

ICRP C2

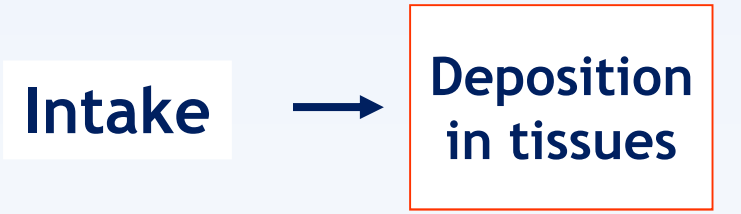
Internal exposures are managed by the use of the committed effective dose

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

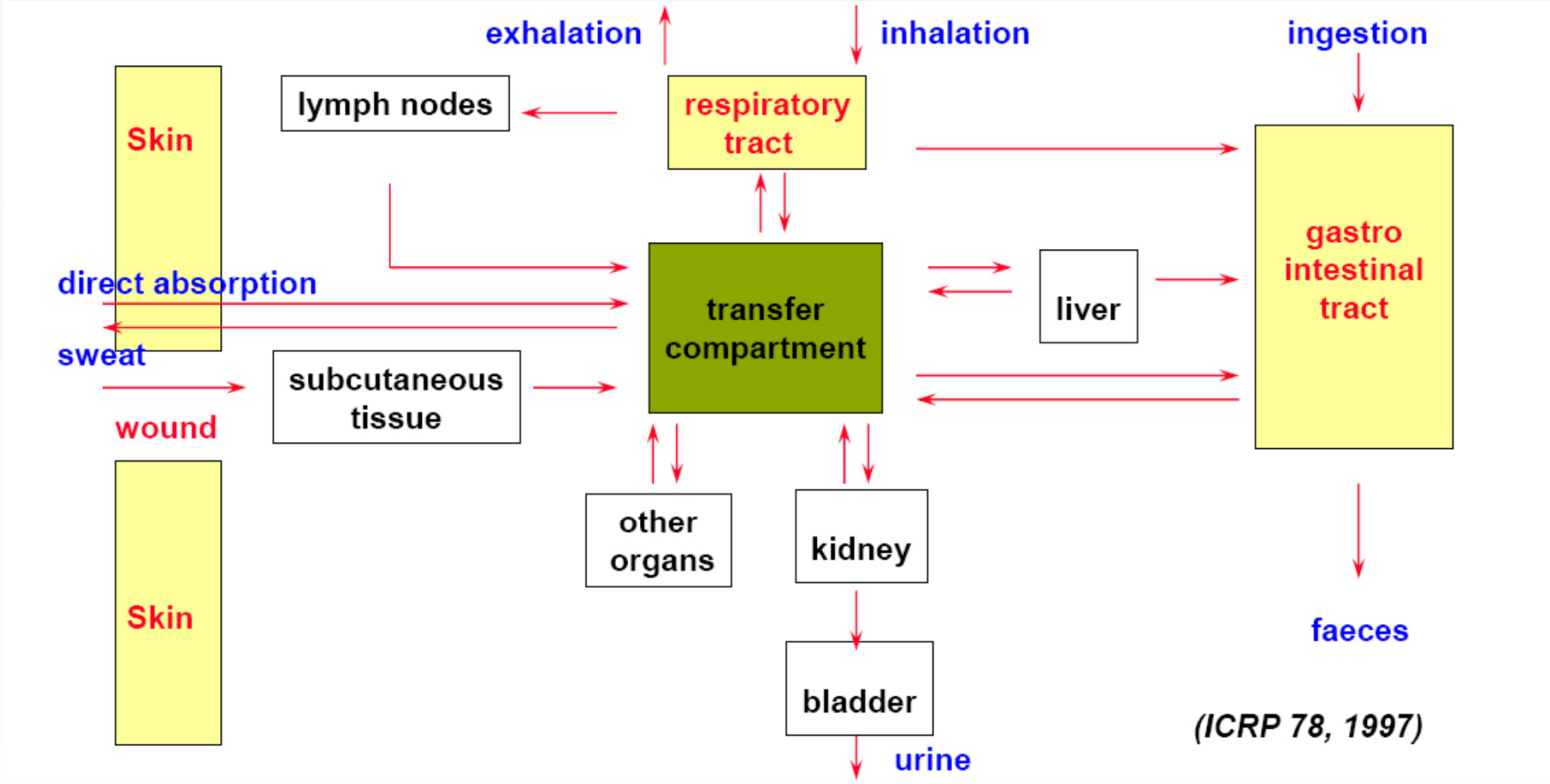
Calculating committed effective dose after internal contamination is a complex procedure

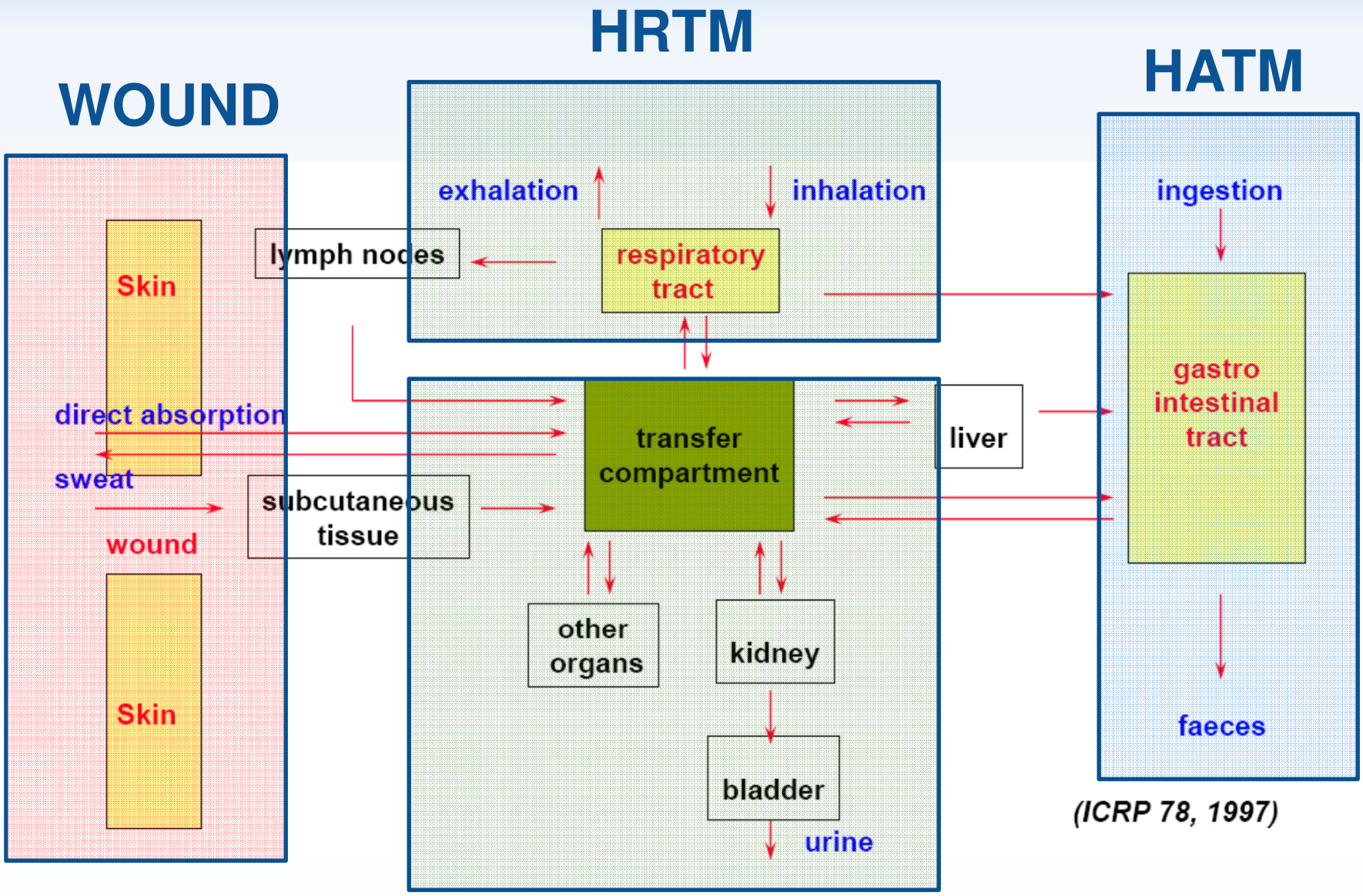

Intake
Deposition
in tissues

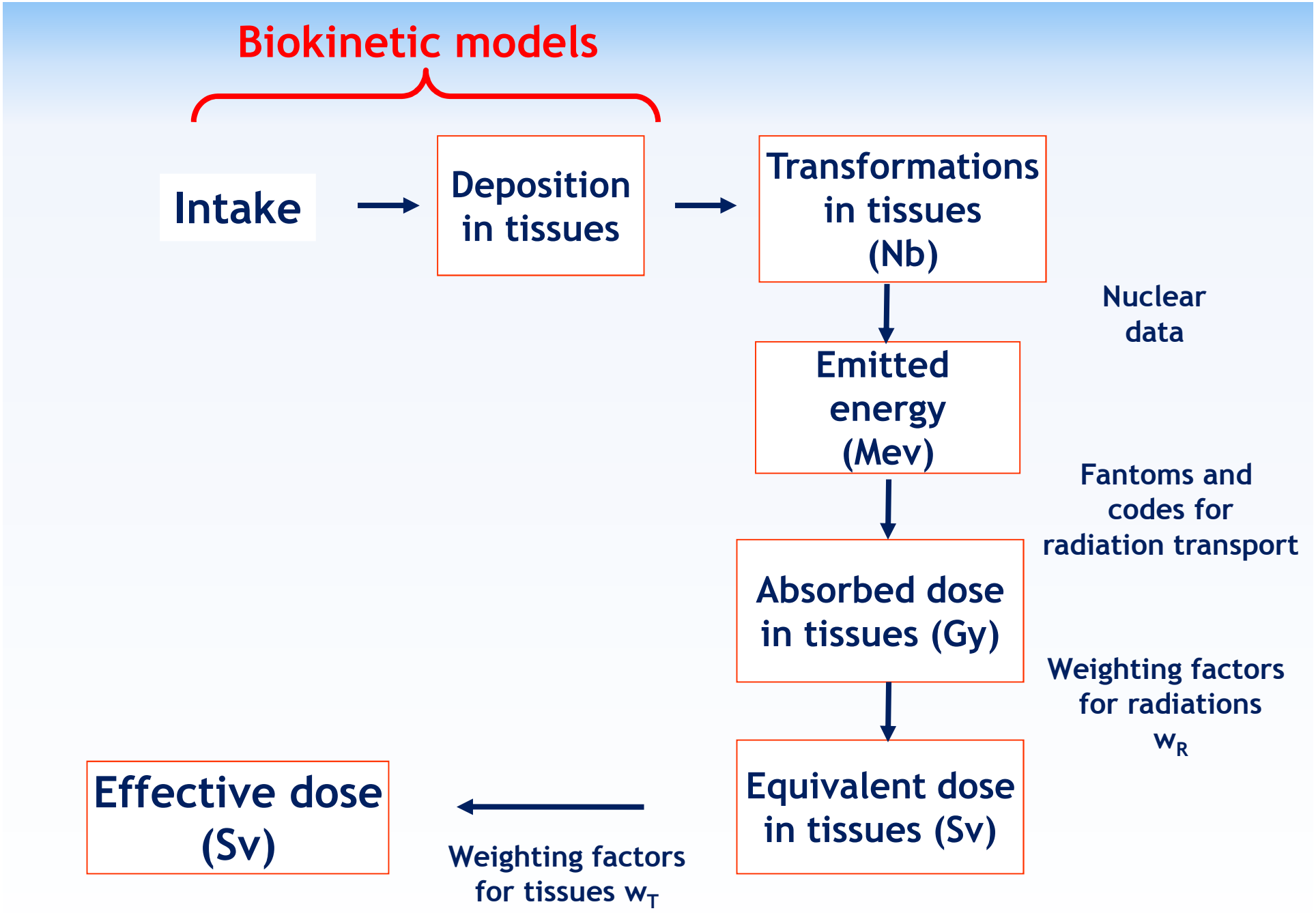
Biokinetic models

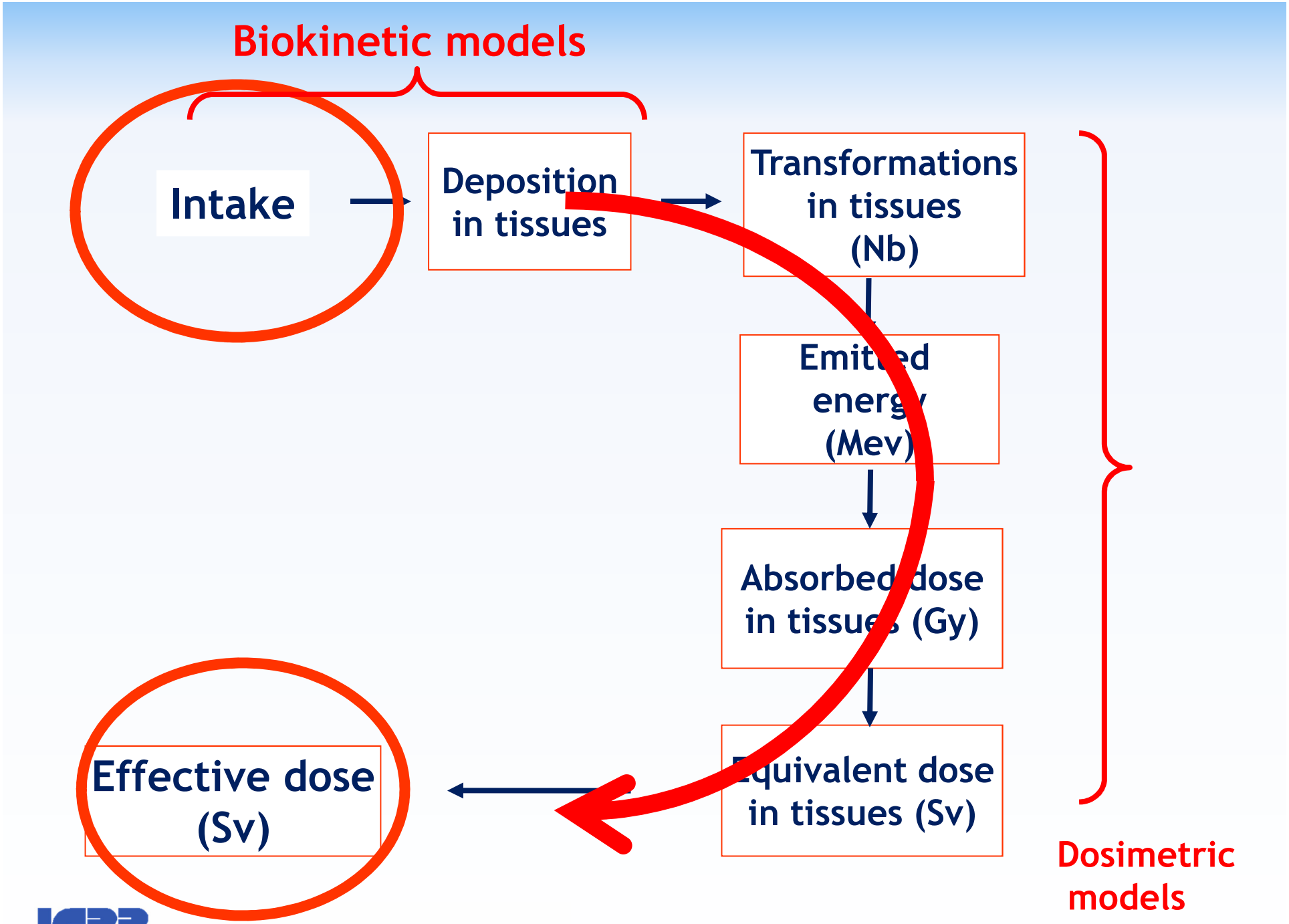


Generic biokinetic model



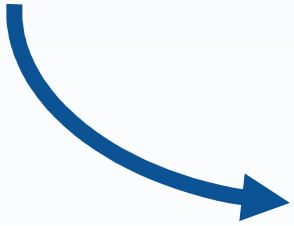

HRTM
WOUND
HATM
exhalation
inhalation
ingestion
lymph nodes
respiratory tract
Skin
gastro intestinal tract
direct absorption
transfer compartment
liver
sweat
subcutaneous tissue
wound
other organs
kidney
Skin
bladder
faeces
urine
(ICRP 78, 1997)
Systemic


Biokinetic models
Intake
Deposition in tissues
Transformations in tissues (Nb)
Nuclear data
Emitted energy (Mev)
Fantoms 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

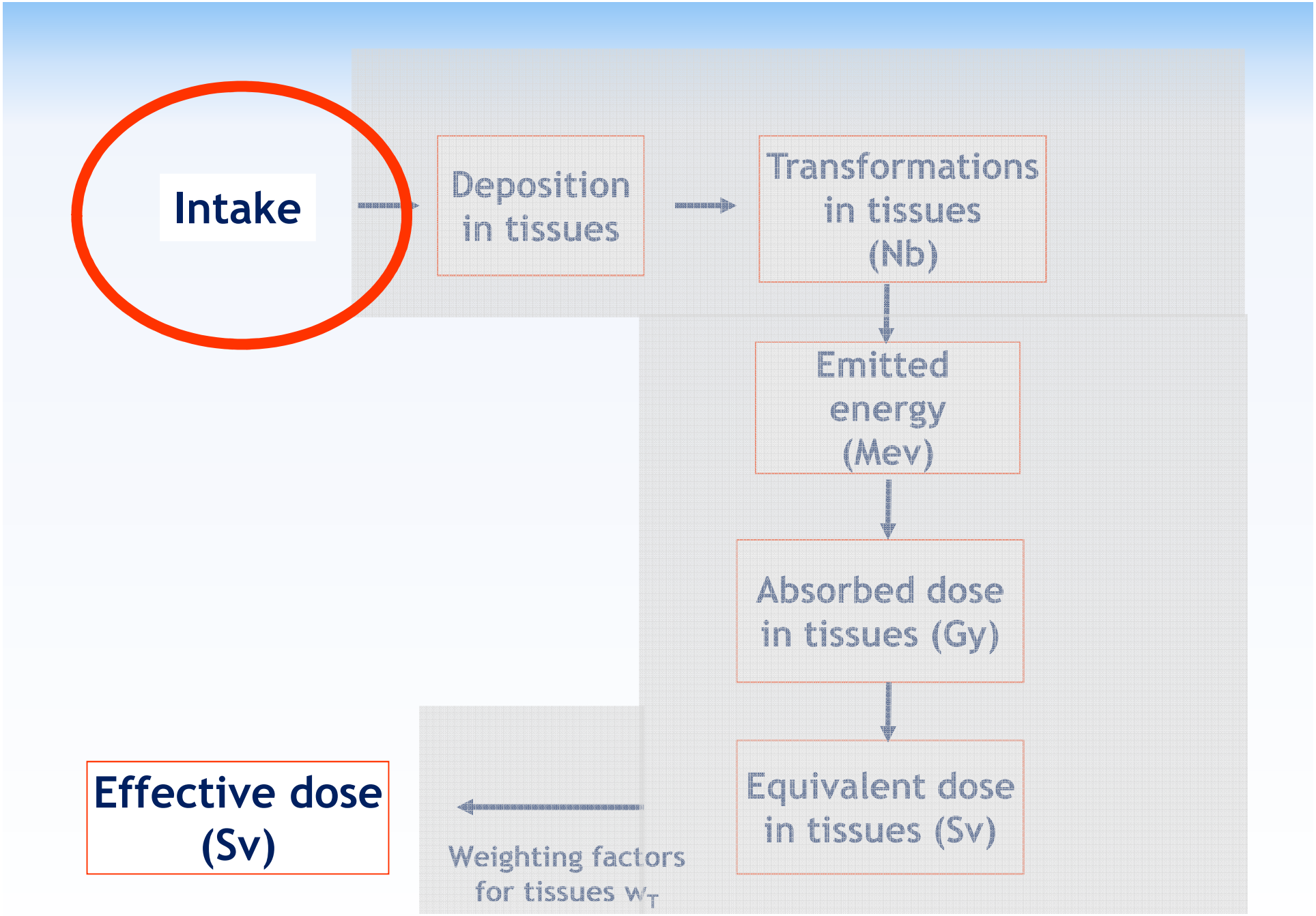
Complex procedure, limited to experts

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



1. Dose per unit intake

2. Retention functions


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

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

DPUI

Type	F	M	S
DPUI µSv/Bq	0.6	2.1	6.8

For ^{234}U

Dose = Intake x DPUI

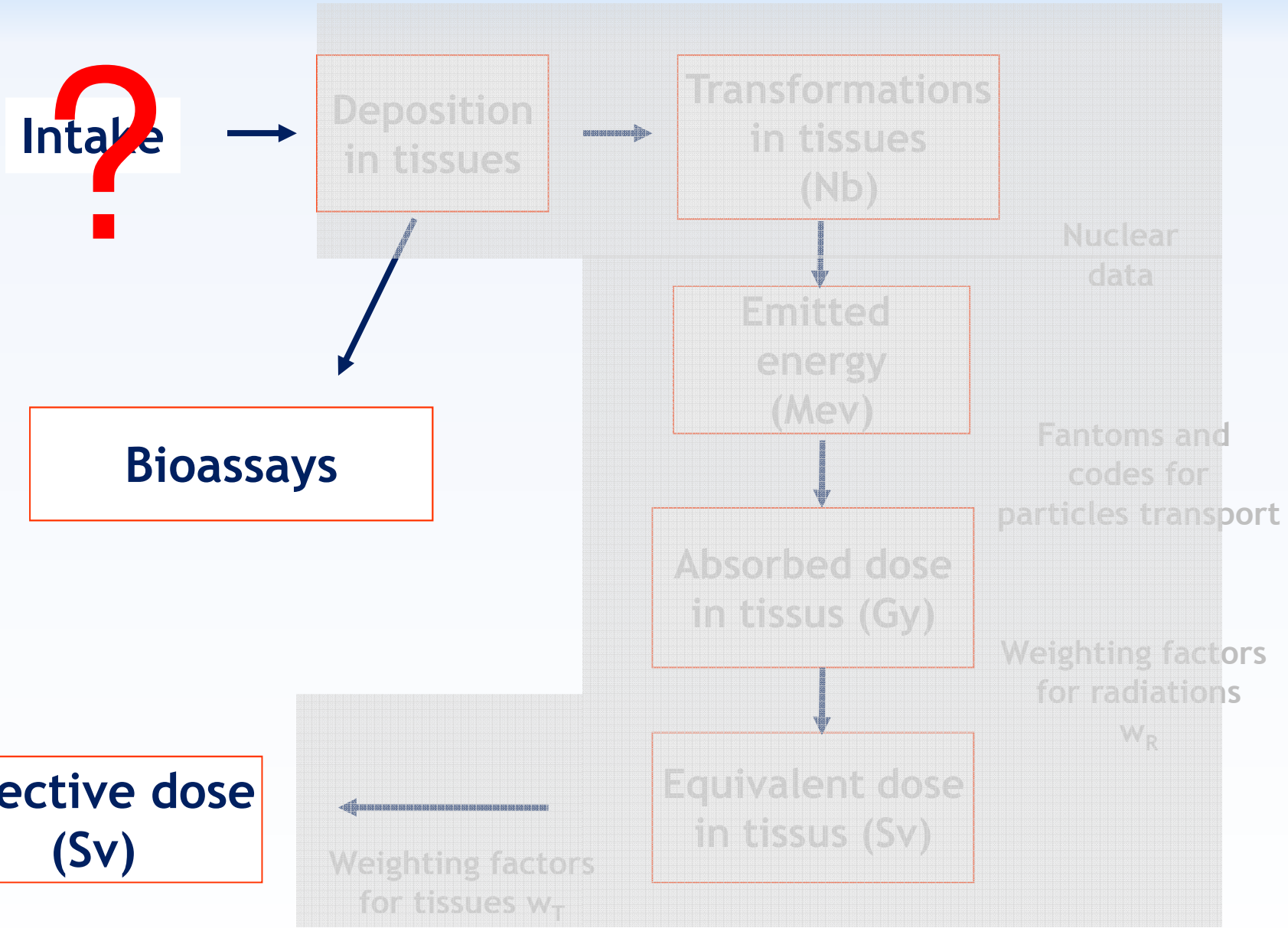
Effective dose (Sv) ← Weighting factors for tissues w_T ← Equivalent dose in tissues (Sv)

Table B.1.—(*continued*)

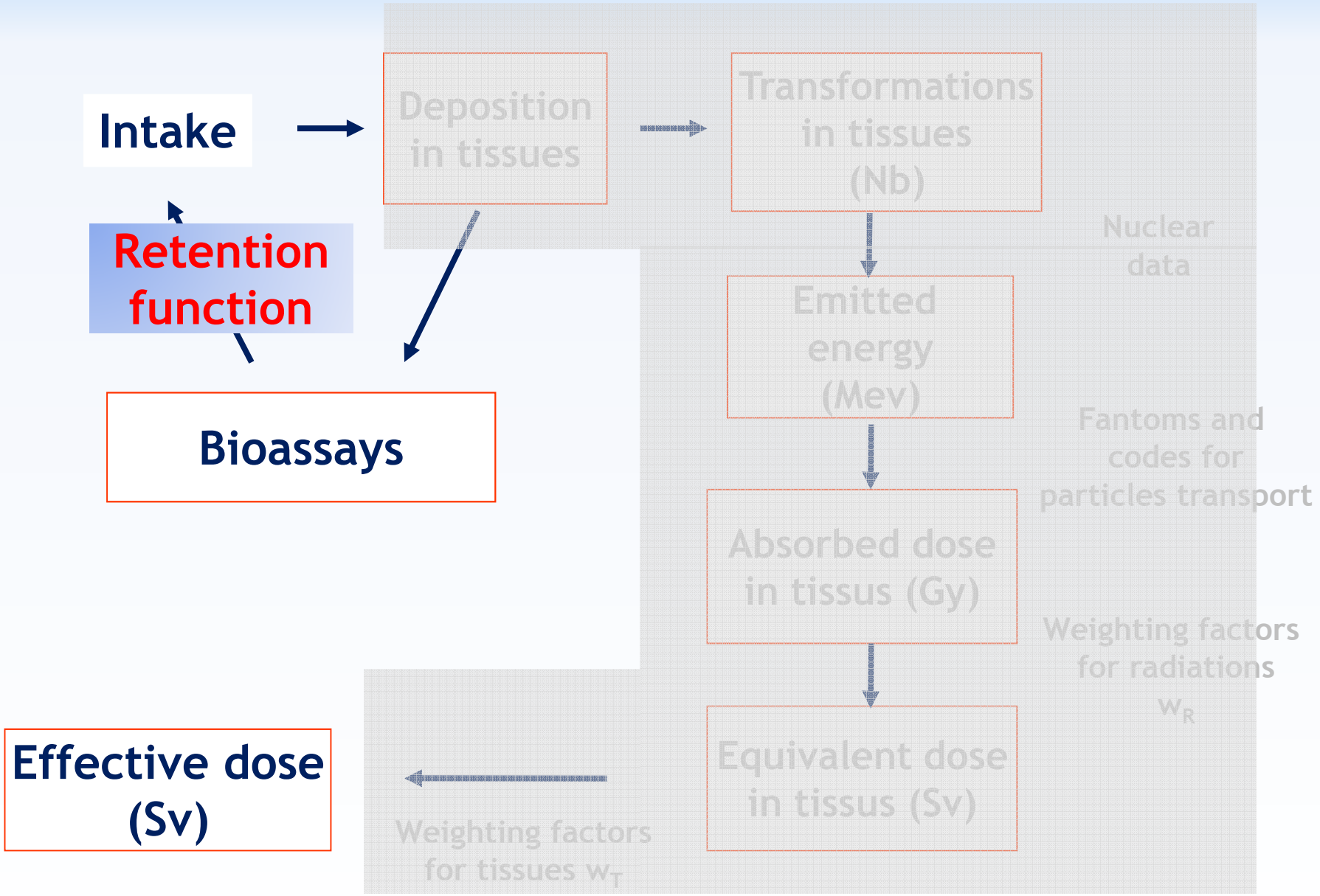
Nuclide	$t_{1/2}$	Effective dose coefficients (Sv Bq^{-1})					
		Inhalation, $e_{inh}(50)$				Ingestion	
		Type	f_1	1 μm AMAD	5 μm AMAD	f_1	$e_{ing}(50)$
Ca-47	4.53d	M	0.300	1.8E-09	2.1E-09	0.300	1.6E-09
Scandium							
Sc-43	3.89h	S	1.0E-04	1.2E-10	1.8E-10	1.0E-04	1.9E-10
Sc-44	3.93h	S	1.0E-04	1.9E-10	3.0E-10	1.0E-04	3.5E-10
Sc-44m	2.44d	S	1.0E-04	1.5E-09	2.0E-09	1.0E-04	2.4E-09
Sc-46	83.8d	S	1.0E-04	6.4E-09	4.8E-09	1.0E-04	1.5E-09
Sc-47	3.35d	S	1.0E-04	7.0E-10	7.3E-10	1.0E-04	5.4E-10
Sc-48	1.82d	S	1.0E-04	1.1E-09	1.6E-09	1.0E-04	1.7E-09
Sc-49	0.956h	S	1.0E-04	4.1E-11	6.1E-11	1.0E-04	8.2E-11
Titanium							
Ti-44	47.3y	F	0.010	6.1E-08	7.2E-08	0.010	5.8E-09
		M	0.010	4.0E-08	2.7E-08		
		S	0.010	1.2E-07	6.2E-08		
Ti-45	3.08h	F	0.010	4.6E-11	8.3E-11	0.010	1.5E-10
		M	0.010	9.1E-11	1.4E-10		
		S	0.010	9.6E-11	1.5E-10		

From ICRP 68, 1994

General procedures for assessing doses



General procedures for assessing doses



In this case, intake = Bq measured x 10^5

Retention functions

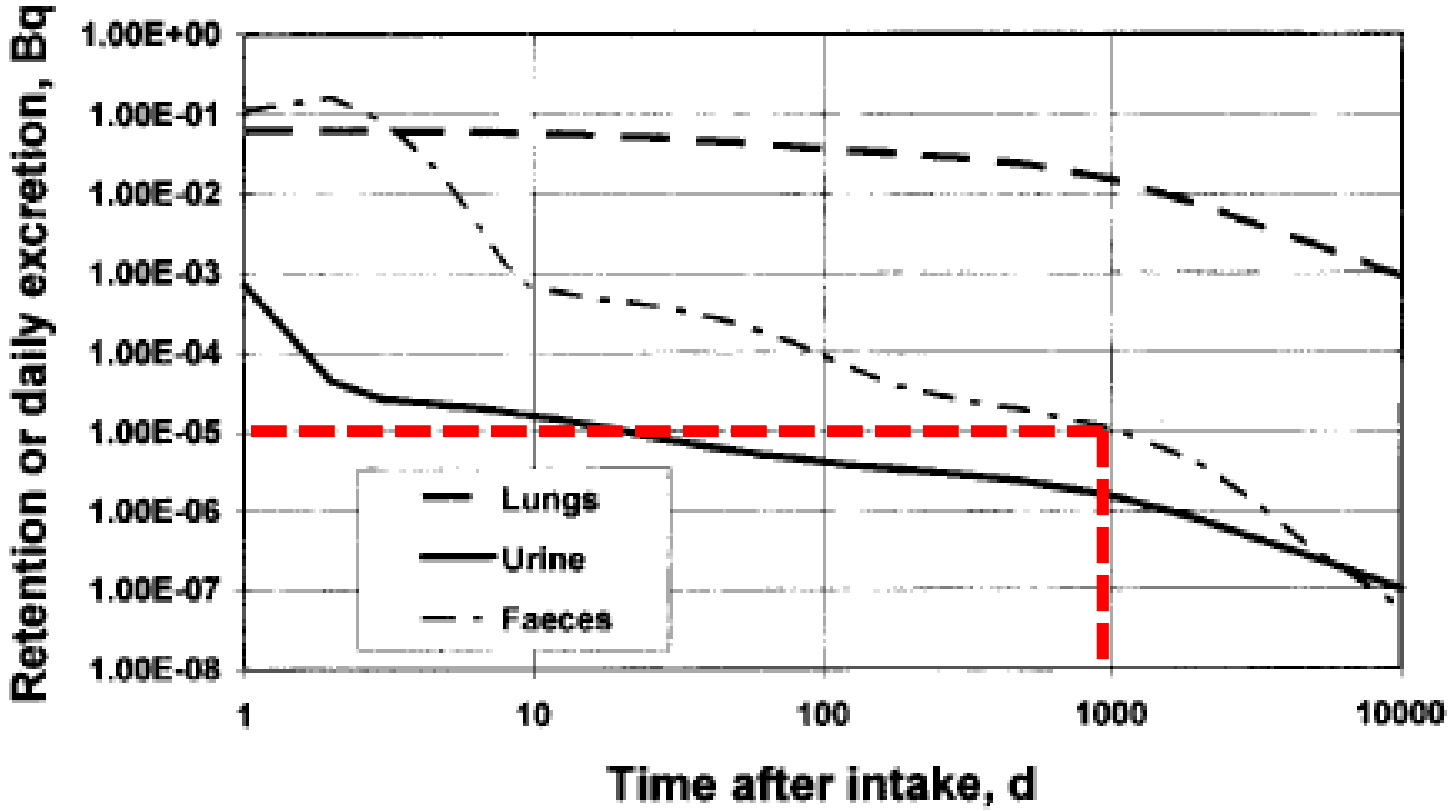
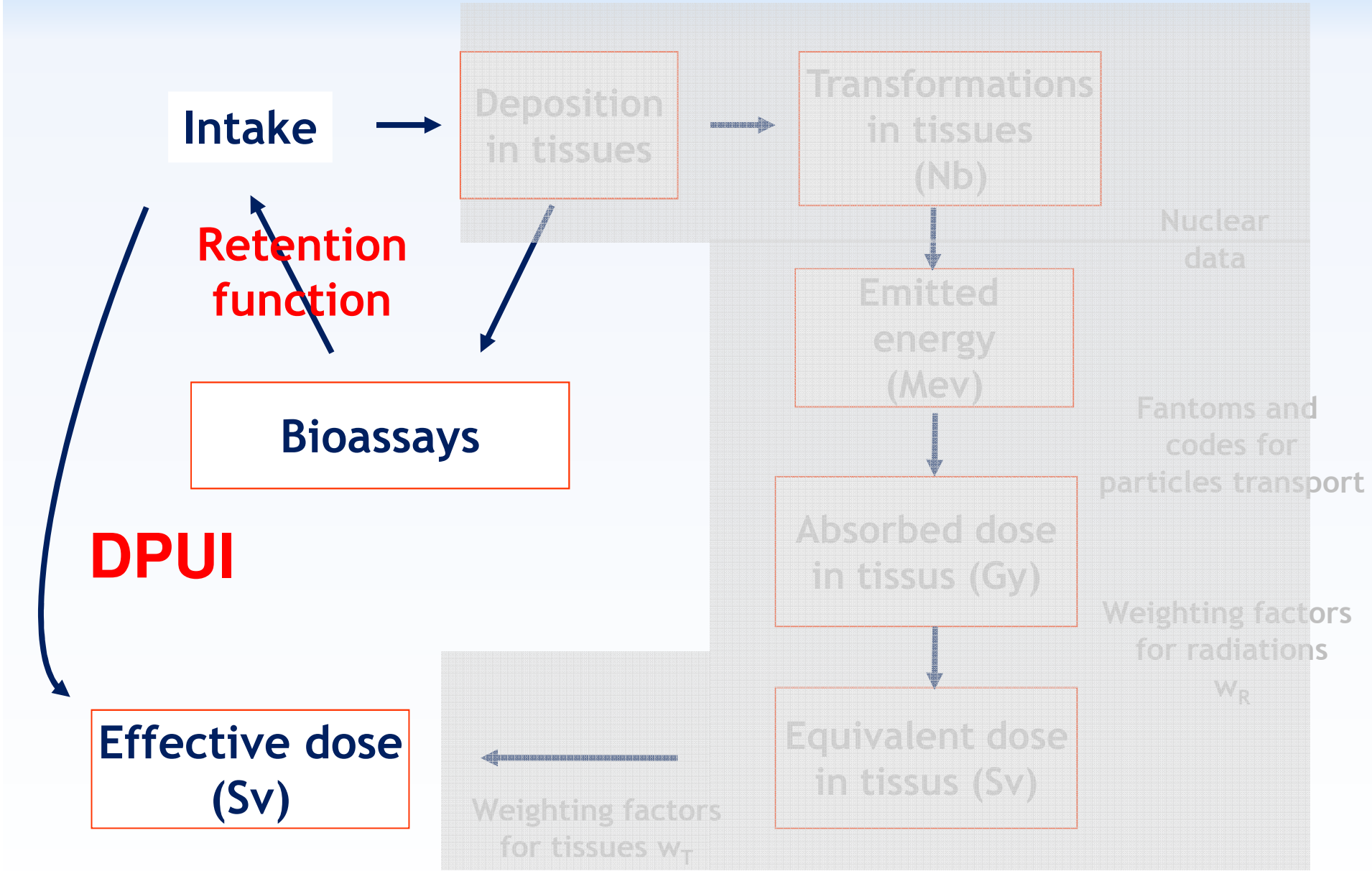


Fig. A.10.3. ^{234}U Inhalation Type S: predicted values (Bq per Bq intake) following acute intake.

General procedures for assessing doses



Main ICRP publications on these topics

For workers

Publication 30 **(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 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

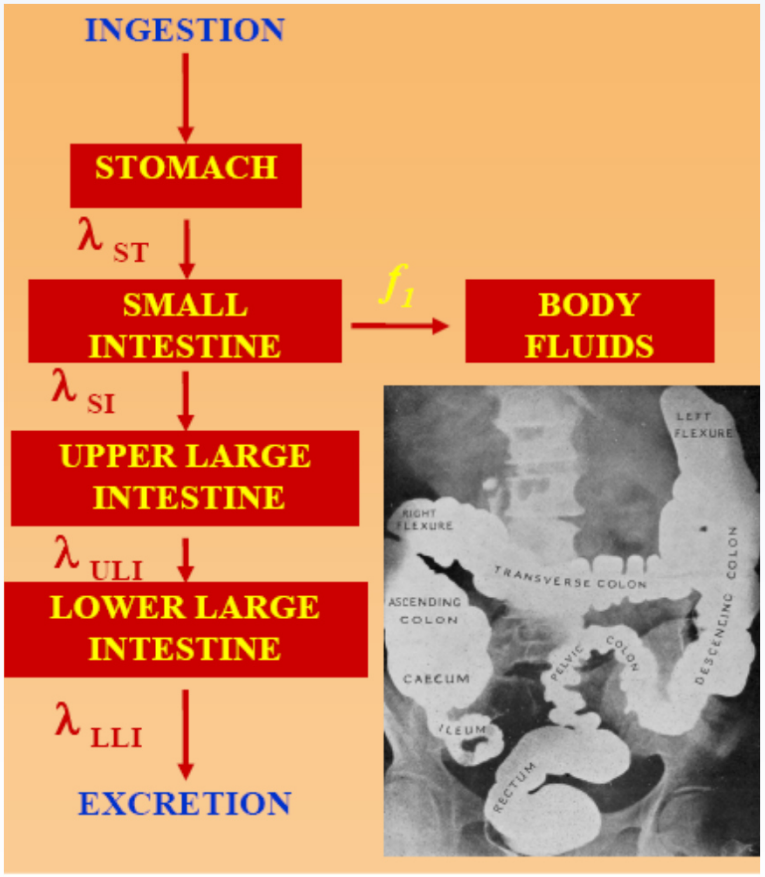
Progress and changes made during this period

In physiology and biokinetic models

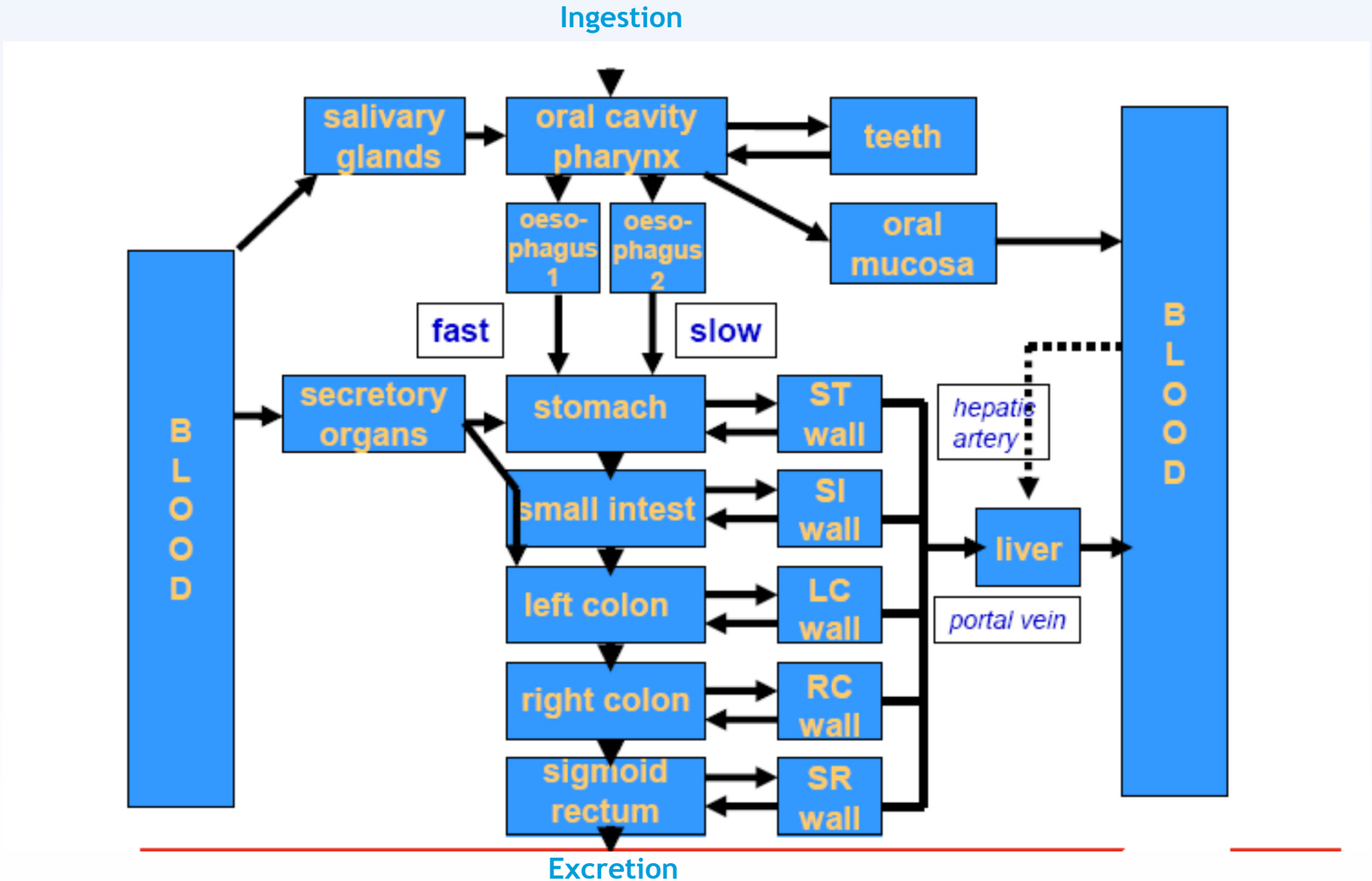
- New data on Reference man (ICRP 89, 2002)
- Human Alimentary Tract Model (ICRP 100, 2006)

The Human alimentary tract model

The former model



The Human alimentary tract model

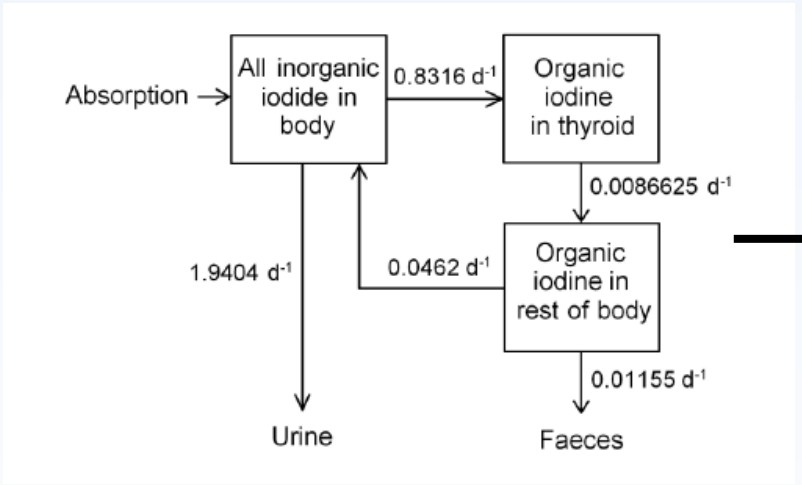


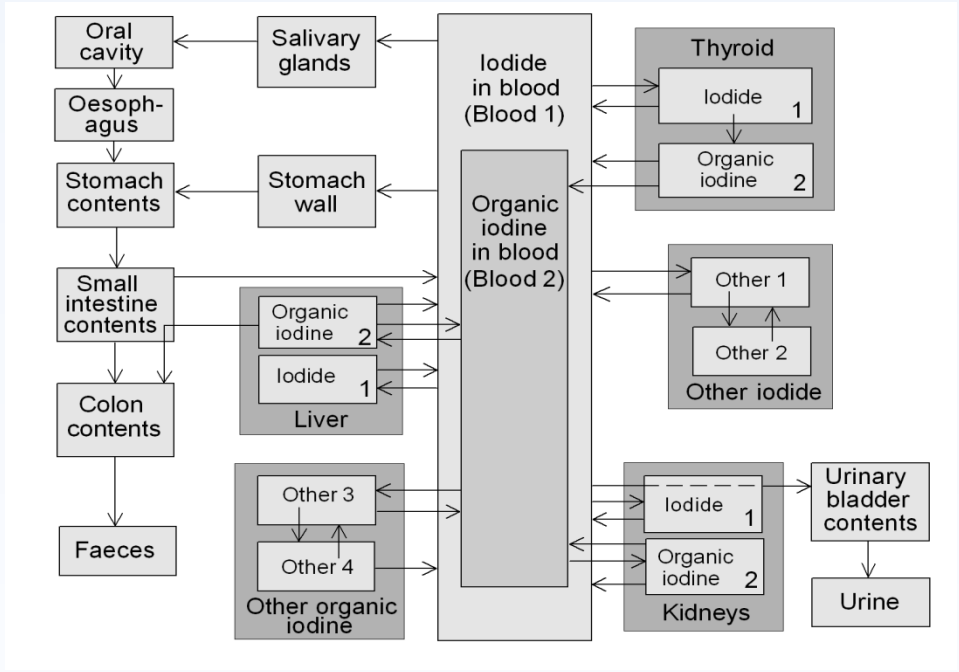
Progress and changes made during this period

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

Three subsystems:

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

Systemic model for Strontium

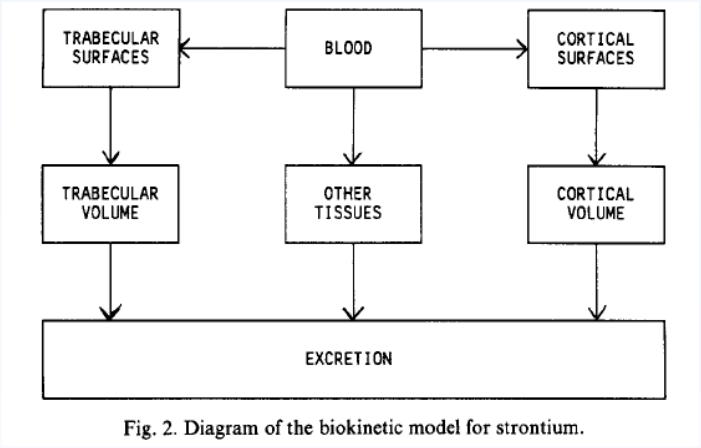


Fig. 2. Diagram of the biokinetic model for strontium.

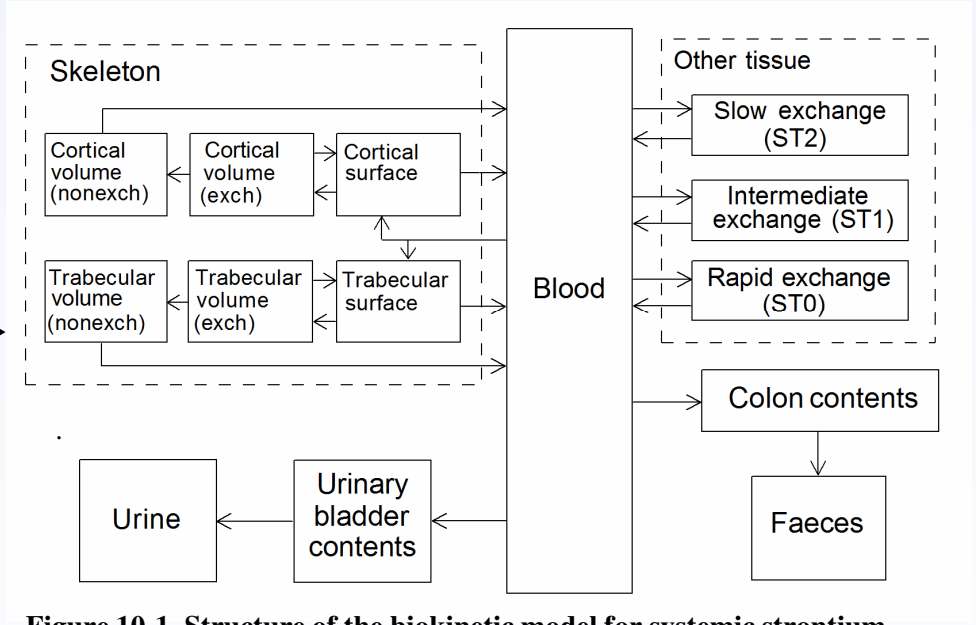


Figure 10-1. Structure of the biokinetic model for systemic strontium.
Abbreviations: exch = exchangeable, nonexch = non-exchangeable

The former model (ICRP 1989)

The new model

Systemic model for Radon

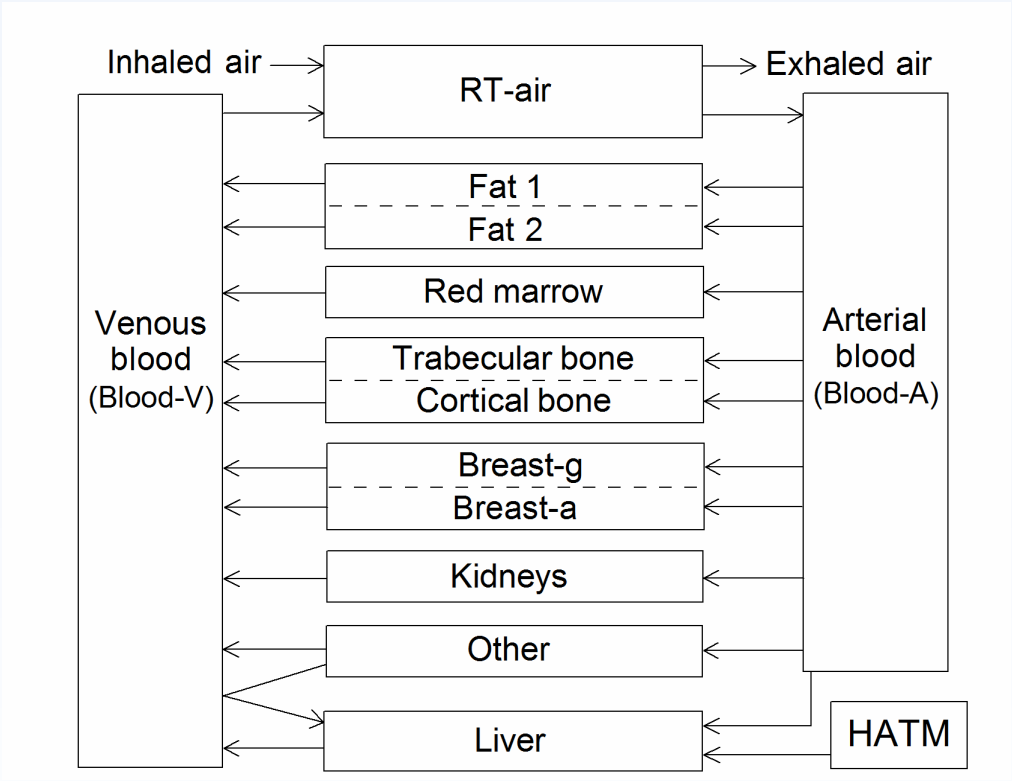


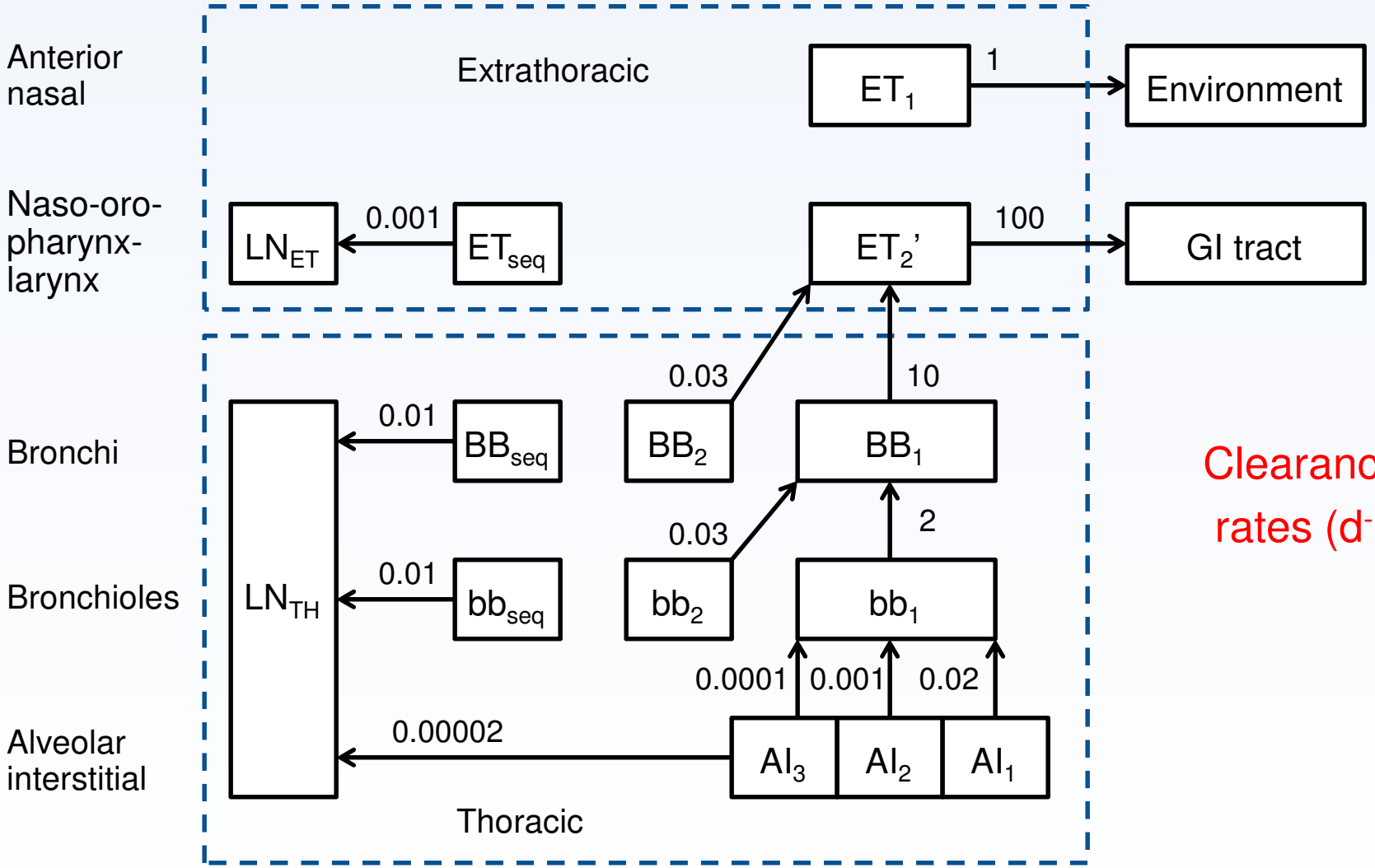
Figure 12.6. Structure of the biokinetic model for systemic radon.
Abbreviations: RT-air = respiratory tract air; Blood-A = arterial blood; Blood-V = venous blood; Breast-g = glandular breast tissue; Breast-a = adipose tissue in breast; HATM = Human Alimentary Tract Model (ICRP, 2006).

Progress and changes made during this period

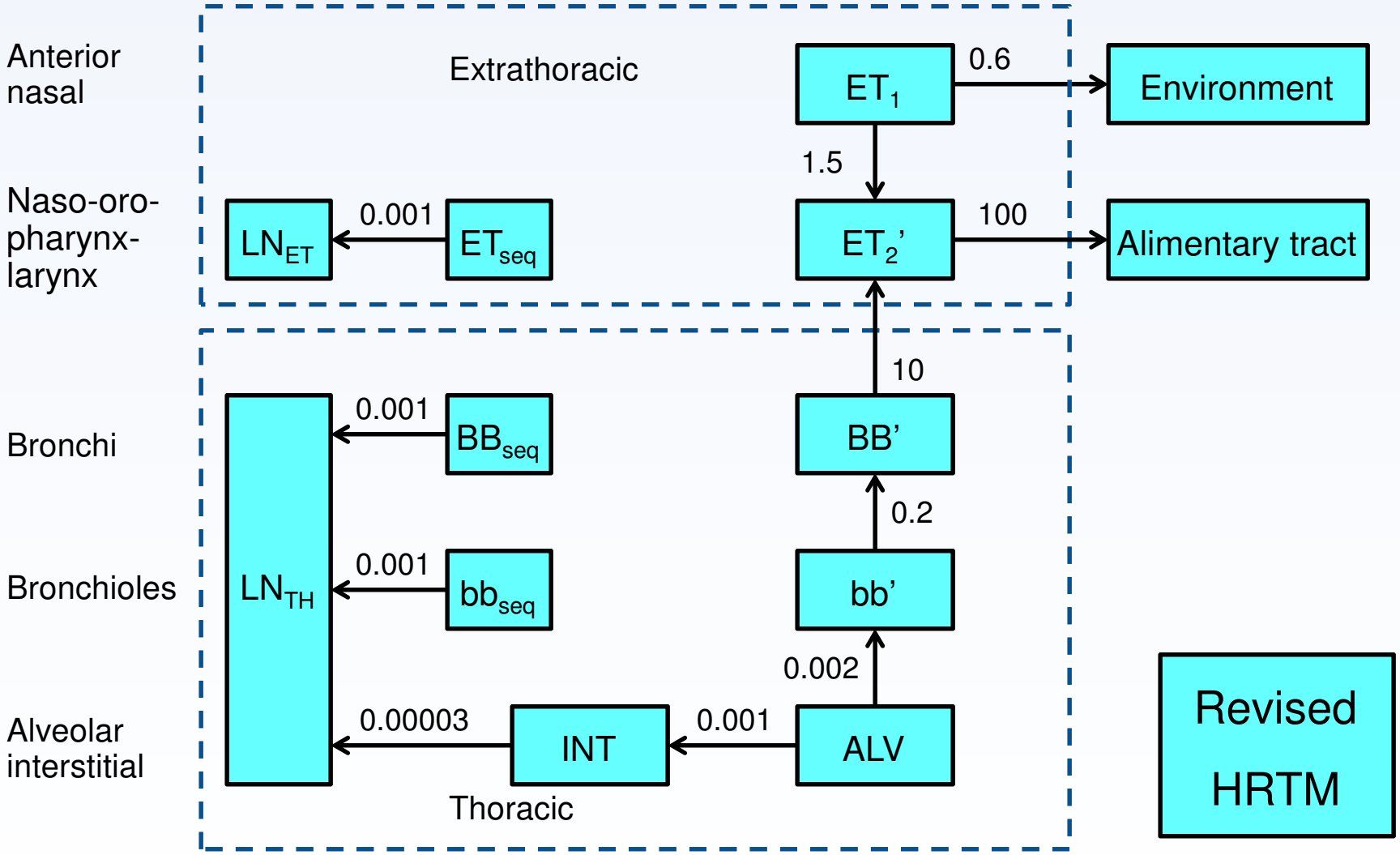
In physiology and biokinetic models

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



Uranium absorption

Compound	Absorption parameter values			Type
	f_r	s_r (d^{-1})	s_s (d^{-1})	
Default Type F	***1.0***	***100***		

Element-specific values for f_r, s_r and s_s

Uranium absorption

Compound	Absorption parameter values			Type
	f_r	s_r (d^{-1})	s_s (d^{-1})	
Default Type F	***1.0***	***100***		
Uranyl nitrate, $UO_2(NO_3)_2$	0.9	3	0.005	(F)
U-Tri-butyl-phosphate	0.97	12	0.002	(F)
Uranium peroxide hydrate	0.9	0.9	0.024	(F)

Element-specific values for f_r, s_r and s_s

Uranium absorption

Compound	Absorption parameter values			Type
	f_r	s_r (d^{-1})	s_s (d^{-1})	
Default Type F	***1.0***	***100***		
Uranyl nitrate, $UO_2(NO_3)_2$	0.9	3	0.005	(F)
U-Tri-butyl-phosphate	0.97	12	0.002	(F)
Uranium peroxide hydrate	0.9	0.9	0.024	(F)
Default Type M	***0.1***	***100***	***0.005***	

Element-specific values for f_r, s_r and s_s

Uranium absorption

Compound	Absorption parameter values			Type
	f_r	s_r (d^{-1})	s_s (d^{-1})	
Default Type F	***1.0***	***100***		
Uranyl nitrate, $UO_2(NO_3)_2$	0.9	3	0.005	(F)
U-Tri-butyl-phosphate	0.97	12	0.002	(F)
Uranium peroxide hydrate	0.9	0.9	0.024	(F)
Default Type M	***0.1***	***100***	***0.005***	
Ammonium diuranate, ADU	0.8	0.7	0.02	(M)
Uranium tetrafluoride	0.6	0.15	0.005	(M)
Uranium trioxide	0.8	1	0.01	(M)
U_3O_8	0.04	1	0.004	(M)

Element-specific values for f_r, s_r and s_s

Uranium absorption

Compound	Absorption parameter values			Type
	f_r	s_r (d^{-1})	s_s (d^{-1})	
Default Type F	***1.0***	***100***		
Uranyl nitrate, $UO_2(NO_3)_2$	0.9	3	0.005	(F)
U-Tri-butyl-phosphate	0.97	12	0.002	(F)
Uranium peroxide hydrate	0.9	0.9	0.024	(F)
Default Type M	***0.1***	***100***	***0.005***	
Ammonium diuranate, ADU	0.8	0.7	0.02	(M)
Uranium tetrafluoride	0.6	0.15	0.005	(M)
Uranium trioxide	0.8	1	0.01	(M)
U_3O_8	0.04	1	0.004	(M)
Default Type S	***0.001***	***100***	***0.0001***	
Uranium dioxide	0.015	1	0.0005	(S)

Element-specific values for f_r, s_r and s_s

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*

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)

Progress and changes made during this period

In physiology and biokinetic models

- New data on Reference man (ICRP 89, 2002)
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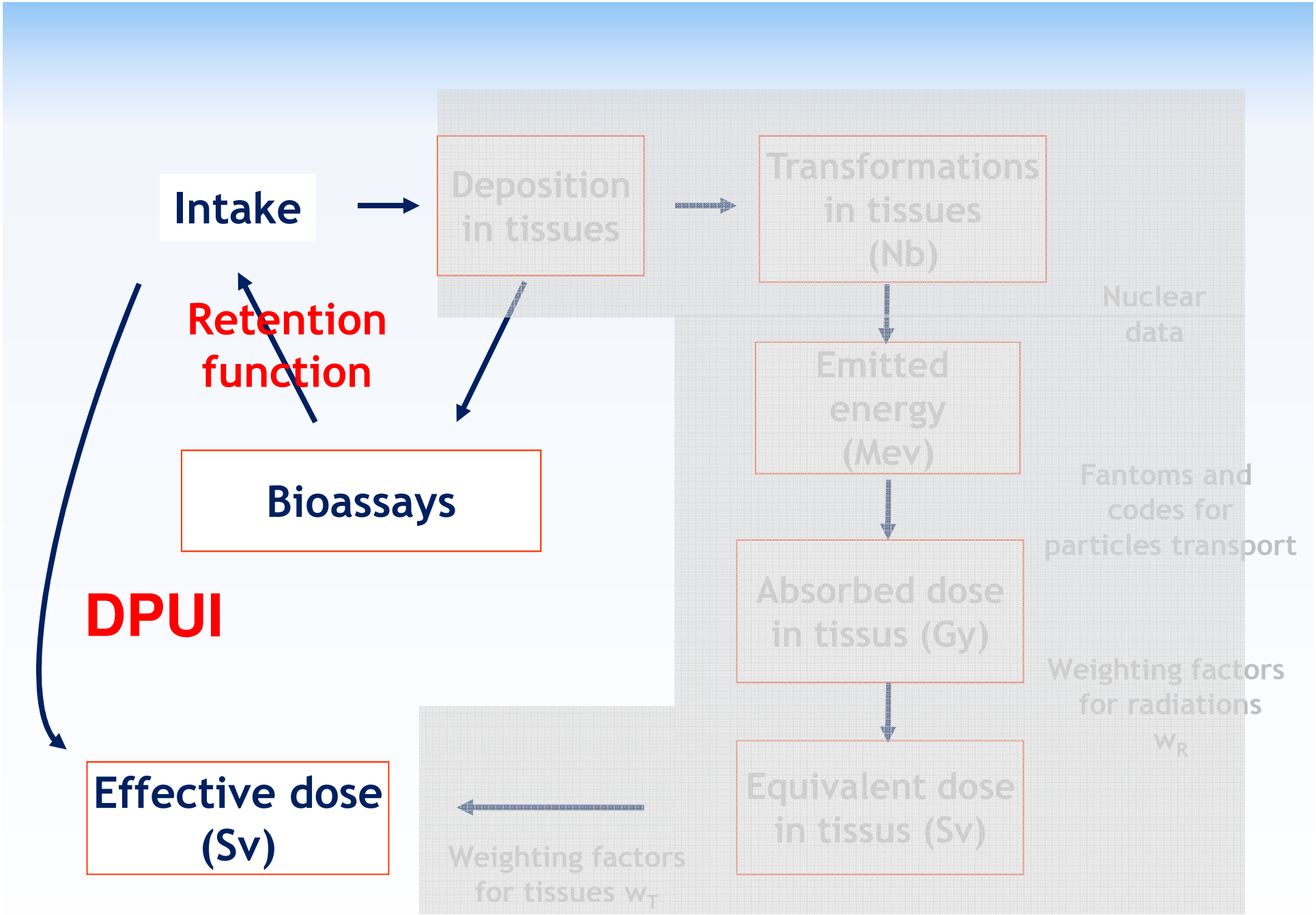
In dosimetry and monitoring

- 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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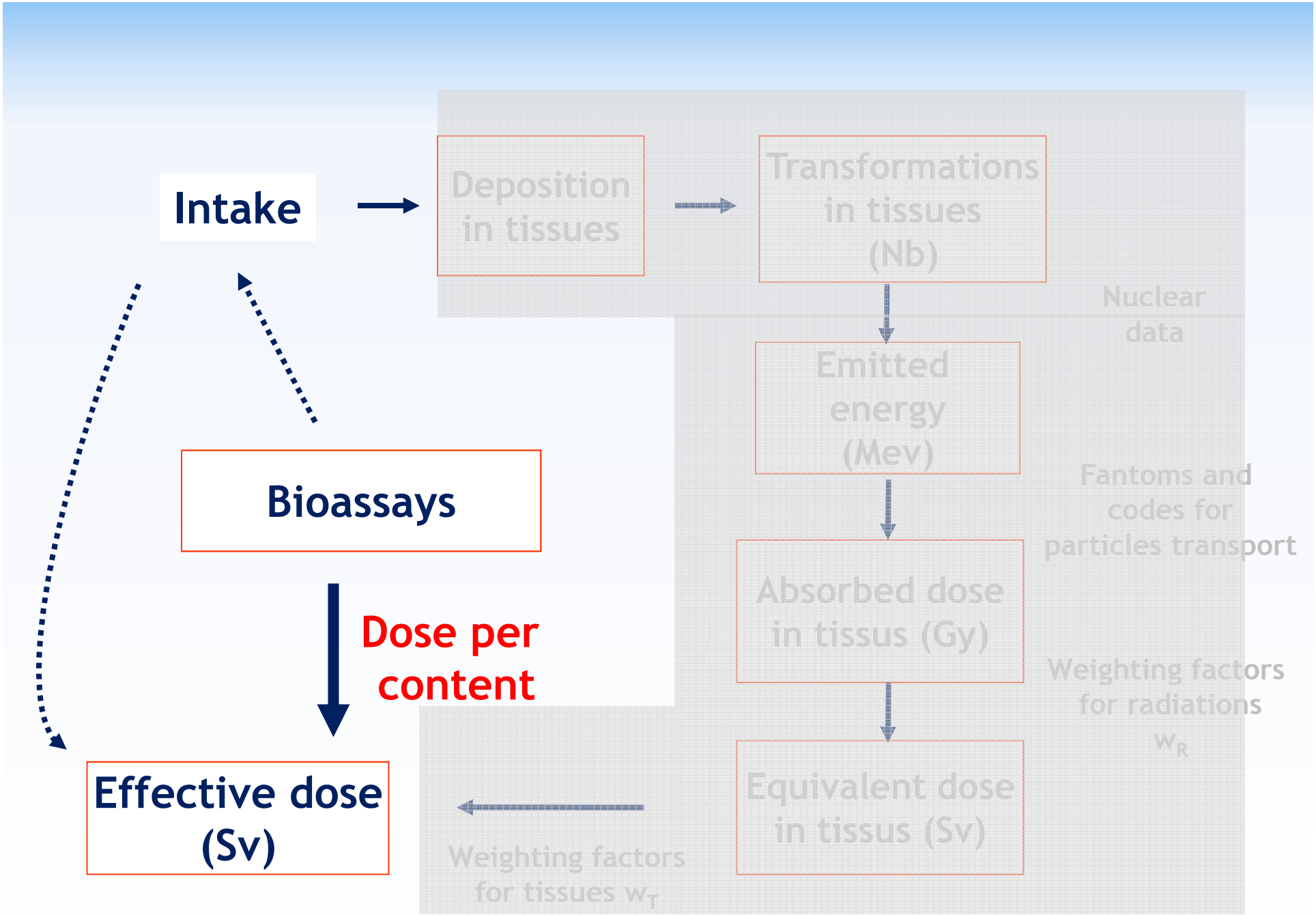
Transformations in tissues (Nb)
Nuclear data
Retention function
Emitted energy (Mev)
Bioassays
Fantoms and codes for particles transport
DPUI
Absorbed dose in tissus (Gy)
Weighting factors for radiations w_R
Effective dose (Sv)
Equivalent dose in tissus (Sv)
Weighting factors for tissues w_T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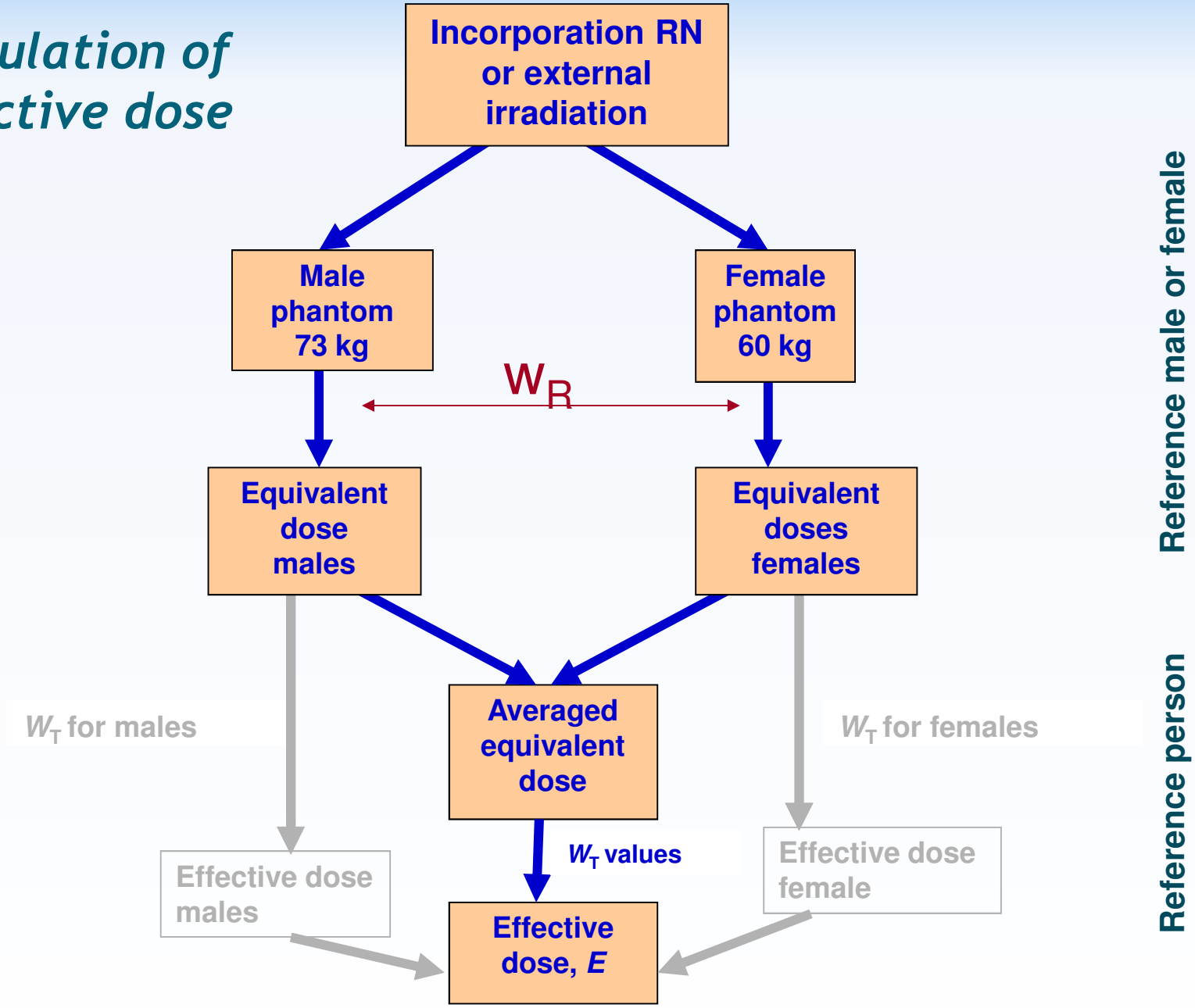
Dose per content
Weighting factors for radiations w_R
Equivalent dose in tissus (Sv)
Effective dose (Sv)
Weighting factors for tissues w_T

Progress and changes made during this period (con't)

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)

Calculation of effective dose



Progress and changes made during this period (con't)

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)

- Need to provide dose coefficients for Radon (ICRP 2009)

Progress and changes made during this period (con't)

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 *(Age dependant series, Embryo and fetus, maternal transfer,..)***

The OIR series
5 volumes

OIR Part 1 (ICRP Publication 130)

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

To be published today!!

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

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

OIR Part 3

Ruthenium (Ru), Antimony (Sb), Tellurium (**2016** aesium (Cs), Barium (Ba), Iridium (Ir), Lead (Pb), Bismuth (Bi), Poloniu (Rn), Radium (Ra), Thorium (Th) and Uranium (U).

OIR Part 4

Lanthanides series, actinium (Ac), protactiniu **2017** 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

Uncertainty and variability in dose calculation

Uncertainty : lack of knowledge of a central value for a population

Variability : difference between members result from physiological or environmental factors

Variability may induce uncertainty !!

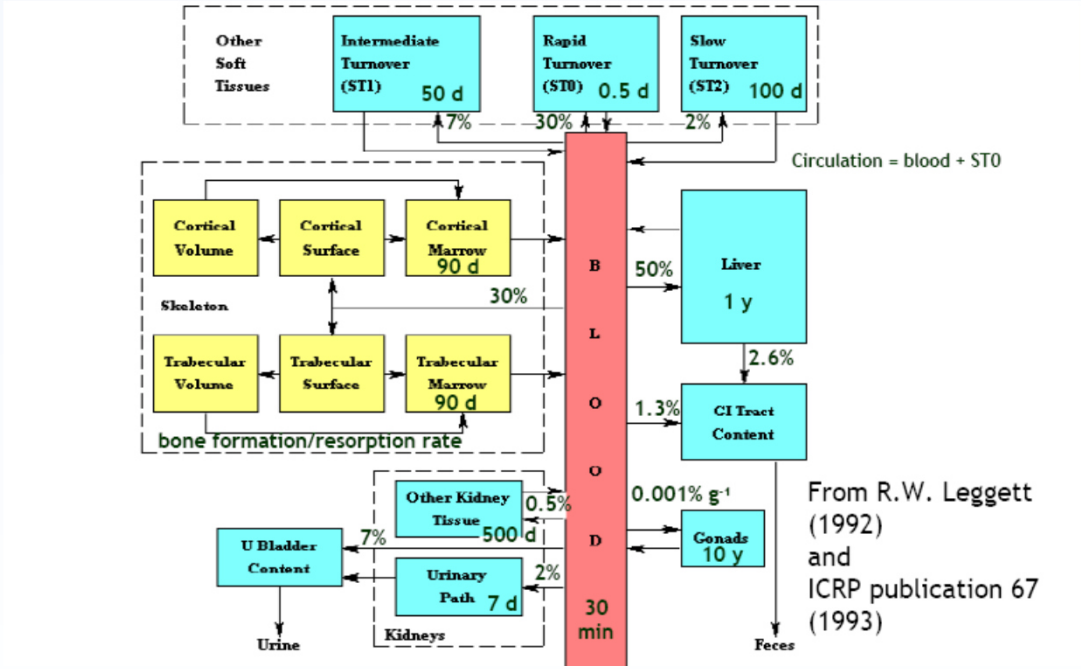
Uncertainty in dose calculation

Depends on uncertainties :

- **in measurement of activity**
- **in exposure scenario (route, time, RN, form,..)**
- **in biokinetic and dosimetric models**

Uncertainties in biokinetic models

on parameter values AND on model structure



Uncertainties in biokinetic models

Depends on available information to derive biokinetic models

- **Human data**

(available for Essent. elts + Cs, Pb, Ra, U, Am, Pu,..)

Uncertainties in biokinetic models

- Human data
- **Human data on chemically similar elements (Ln)**

Uncertainties in biokinetic models

- Human data
- **Human data on chemically similar elements (Ln)**

Ca, Sr, Ba, Ra chemically and physiologically similar.. but
Na and K chemically similar but physiologically different
Cs and K chemically similar but different kinetics

Uncertainties in biokinetic models

- Human data
- Human data on chemically similar elements
- **Animal data**

Need extrapolation

Uncertainties in biokinetic models

- Human data
- Human data on chemically similar elements
- Animal data
- **Animal data AND chemically similar elements**

There are many sources of uncertainty but :

Reference models and parameter values are fixed by convention and are not subject to uncertainty

They are intended to be used for optimisation and demonstration of compliance with dose limits

In case where models are used for other scientific purposes, uncertainties and variability may be taken into account.

Conclusions

Determination of internal doses is a complex procedure

Many tools available to directly assess dose from activity measurements

Based on the use of biokinetic and dosimetric models

No uncertainty for calculation of effective dose

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