Risks from Internal Emitters - misuse of equivalent and effective dose

EU Scientific Seminar,
Luxembourg, November 2010

John Harrison

Science / policy / regulations

UNSCEAR Reports on doses and effects
Science

ICRP Recommendations
Policy

UN, EU Basic Safety Standards
Regulations

Cancer risks from external radiation

- Hiroshima and Nagasaki 'A' bomb survivors

  44, 635 individuals, 11% solid cancer attributable

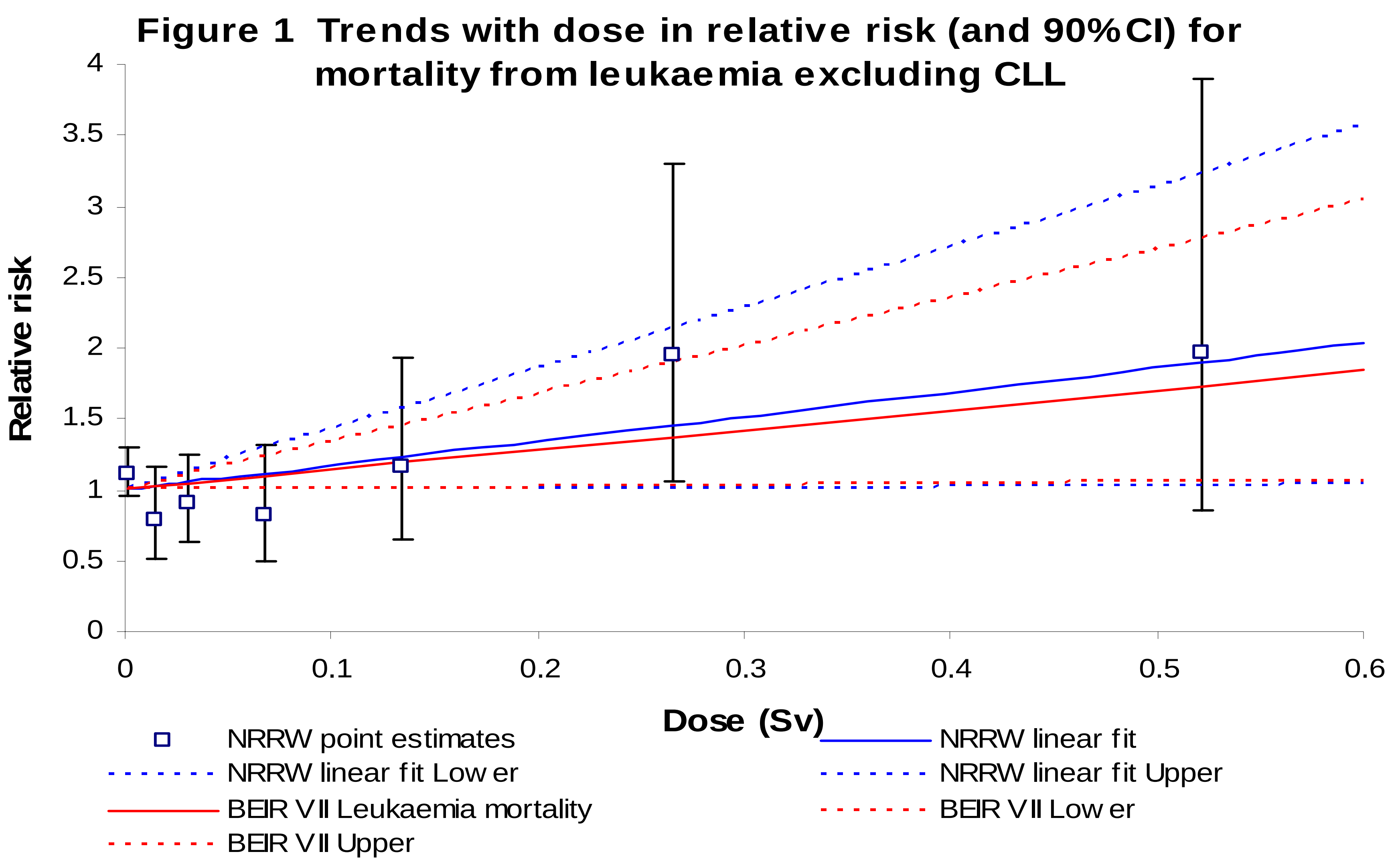
  Preston et al Radiation Research 2007

- UK National Registry of Radiation Workers (NRRW)

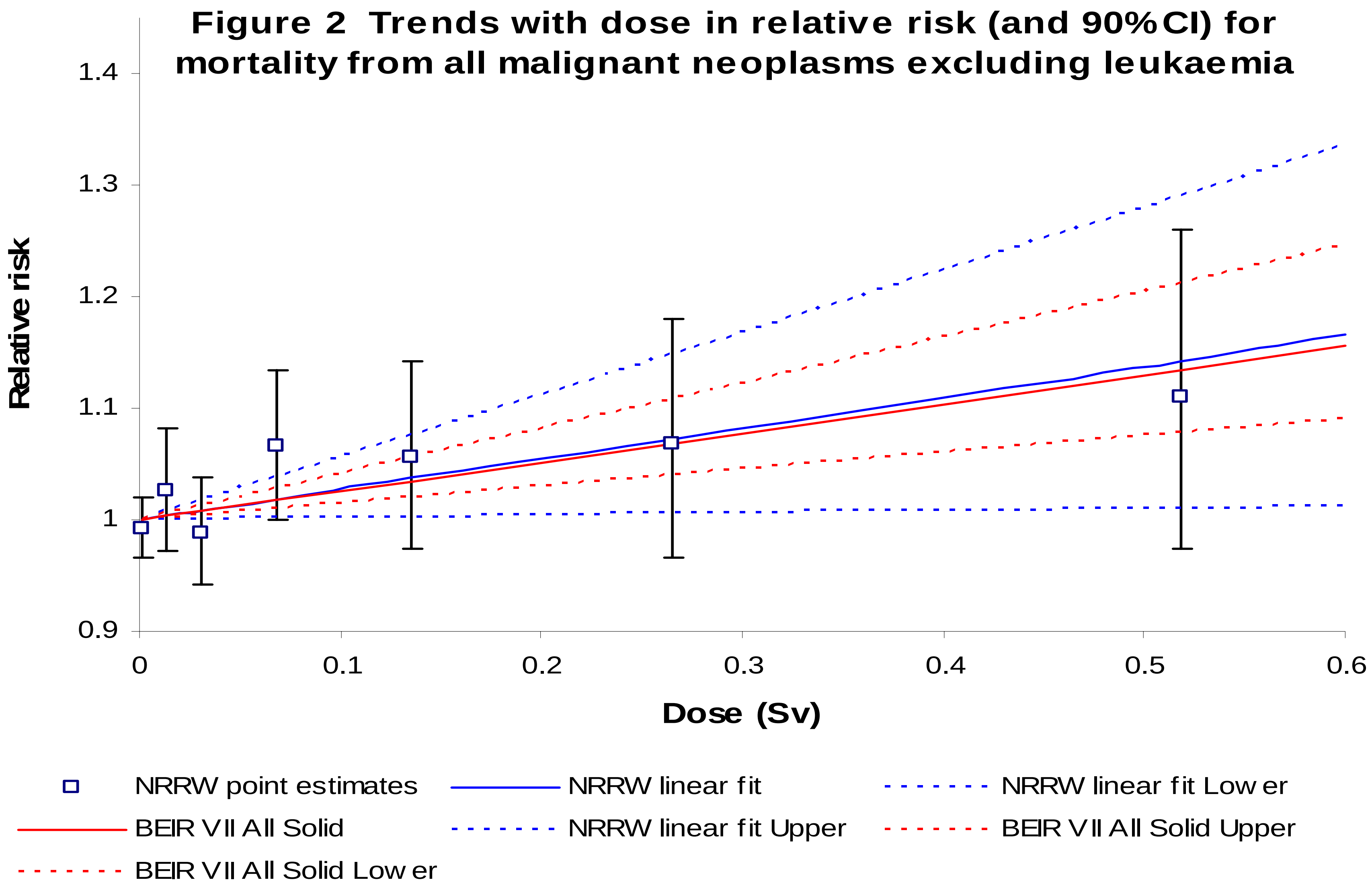
  174, 541 individuals

  Muirhead et al Brit J Cancer 2008

Leukaemia in the NRRW & 'A' bomb survivors



Solid cancers in the NRRW & 'A' bomb survivors

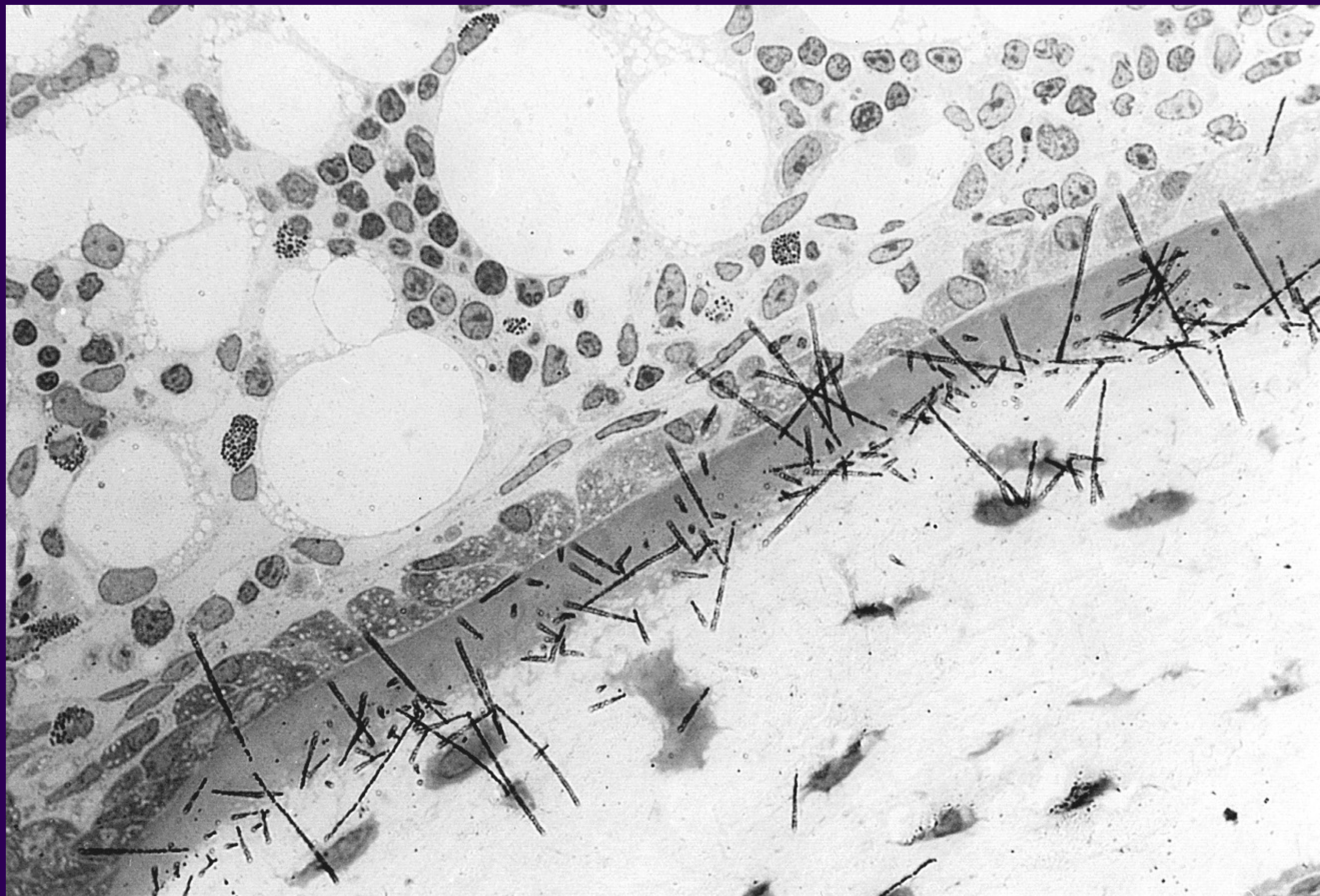


Internal cf External exposures

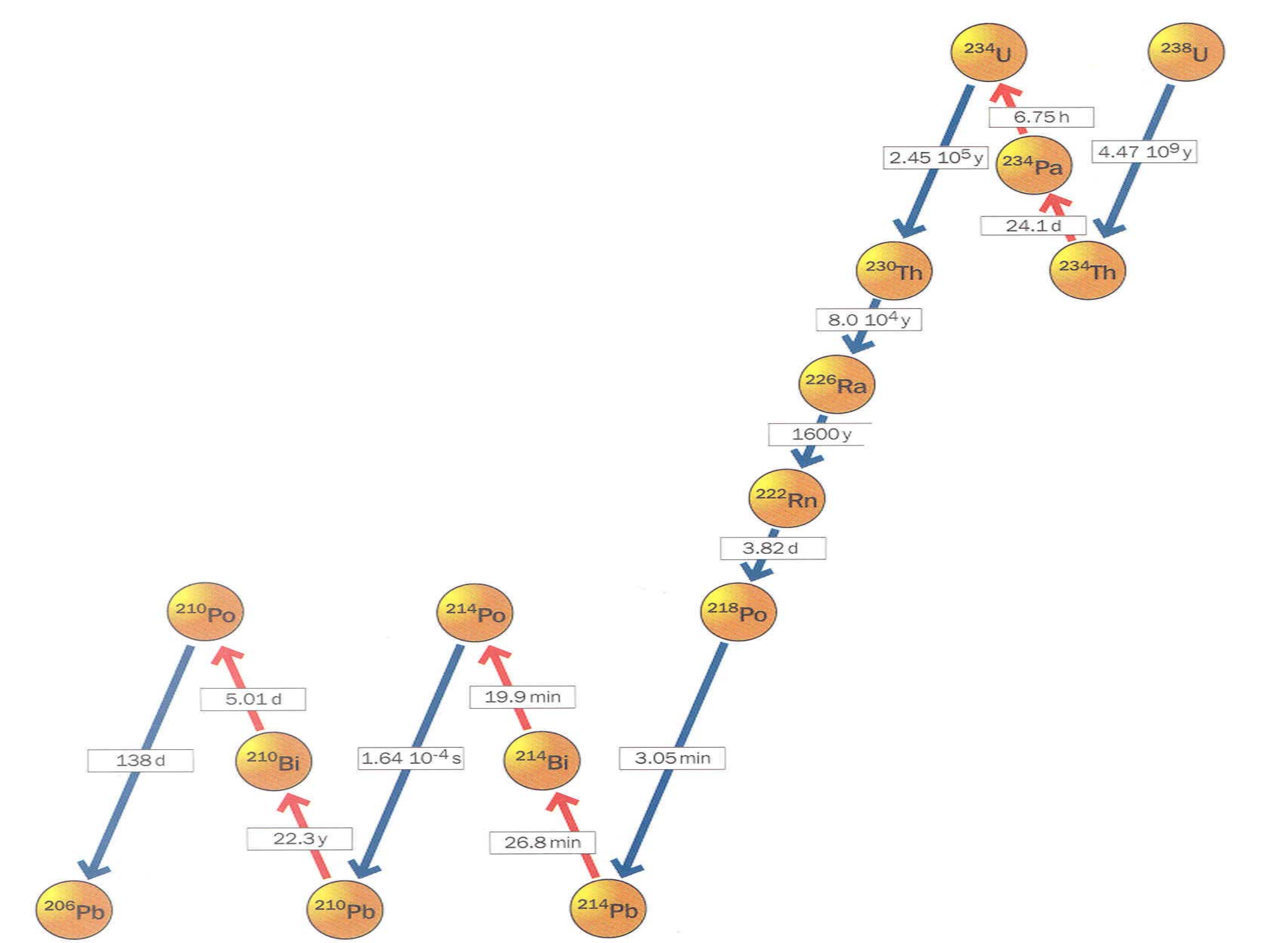
Can risks from external exposure be applied to internal exposures ?

- Chronic not acute delivery of dose
- Uptake in specific organs / tissues / cells / organelles
- Short range emissions
- Density of ionisation / RBE
- Dose averaging

Alpha emitter on bone surface



Radon-222 in the Uranium-238 decay chain



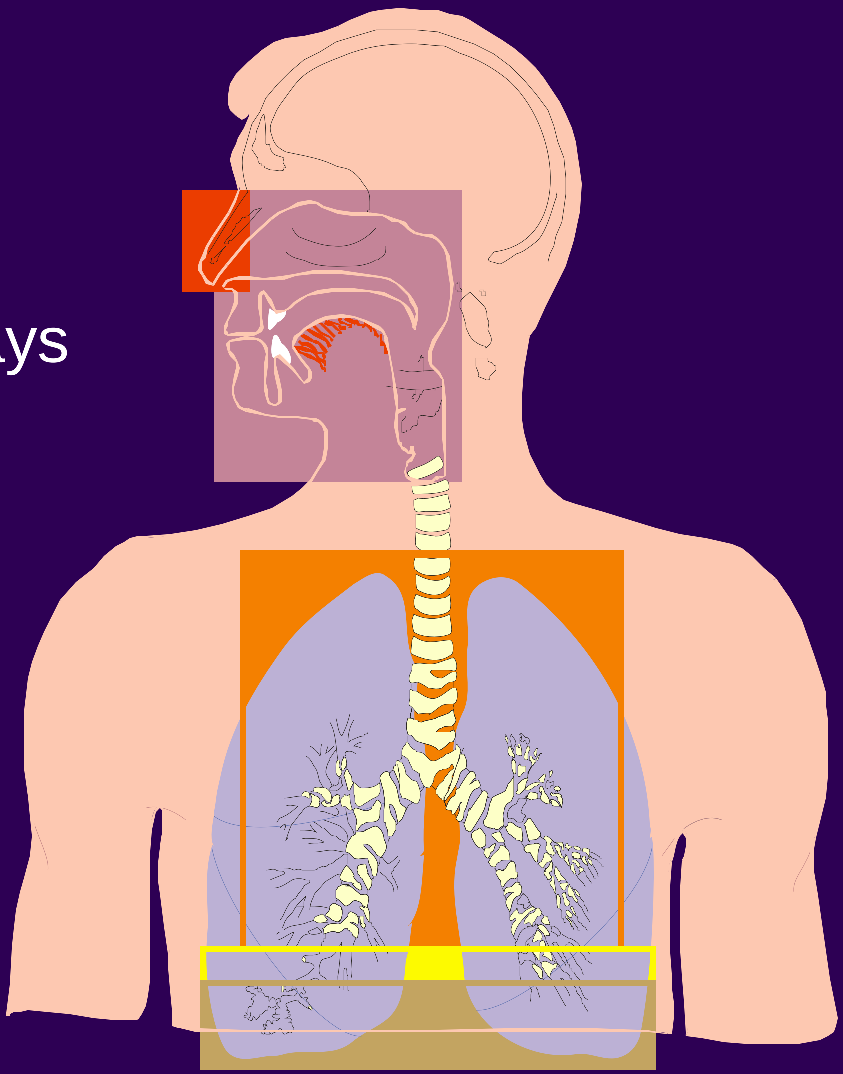
Human Respiratory Tract Model, ICRP (1994)

Extrathoracic airways

Bronchial

Bronchiolar

Alveolar interstitial



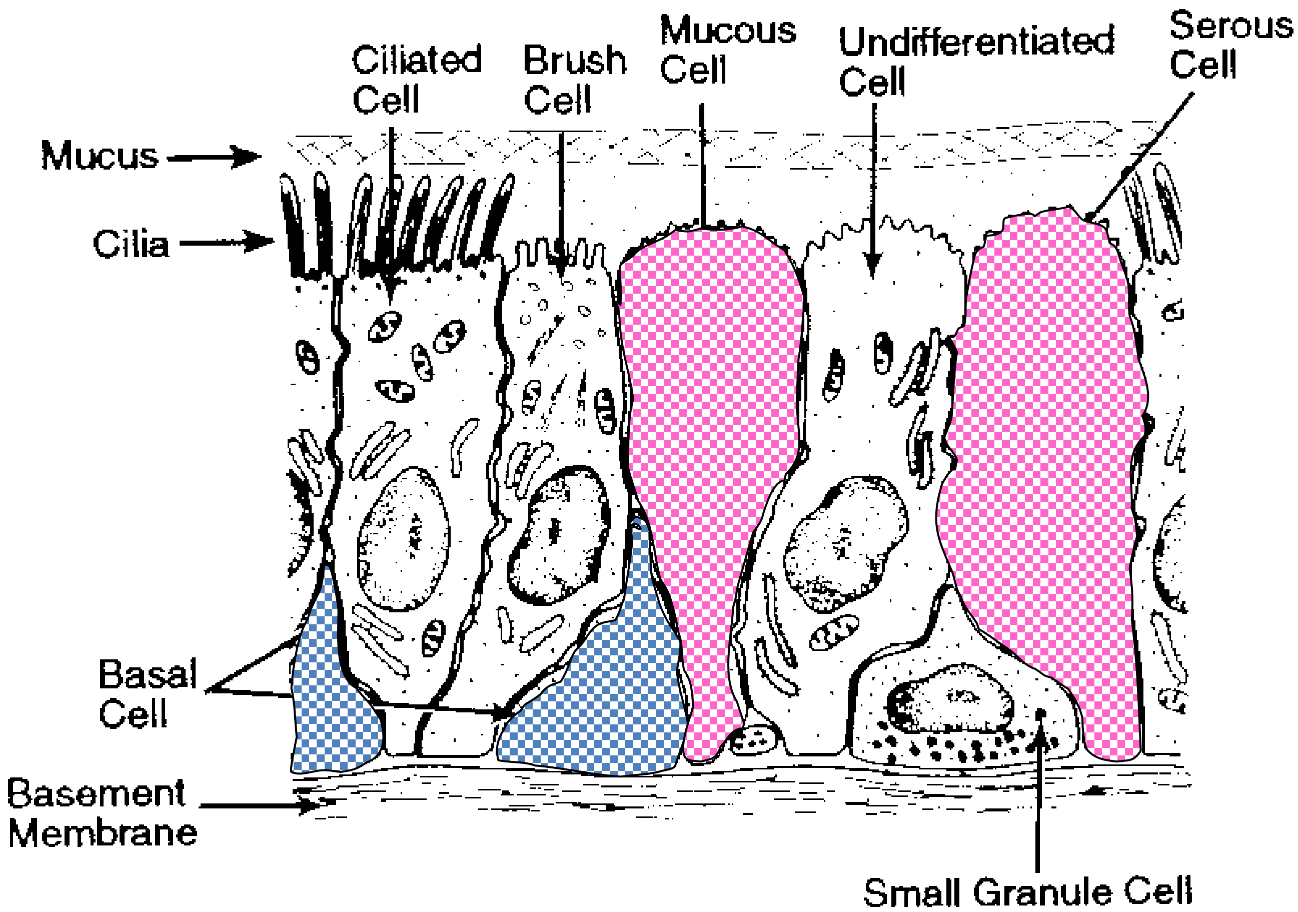
ET_1

ET_2

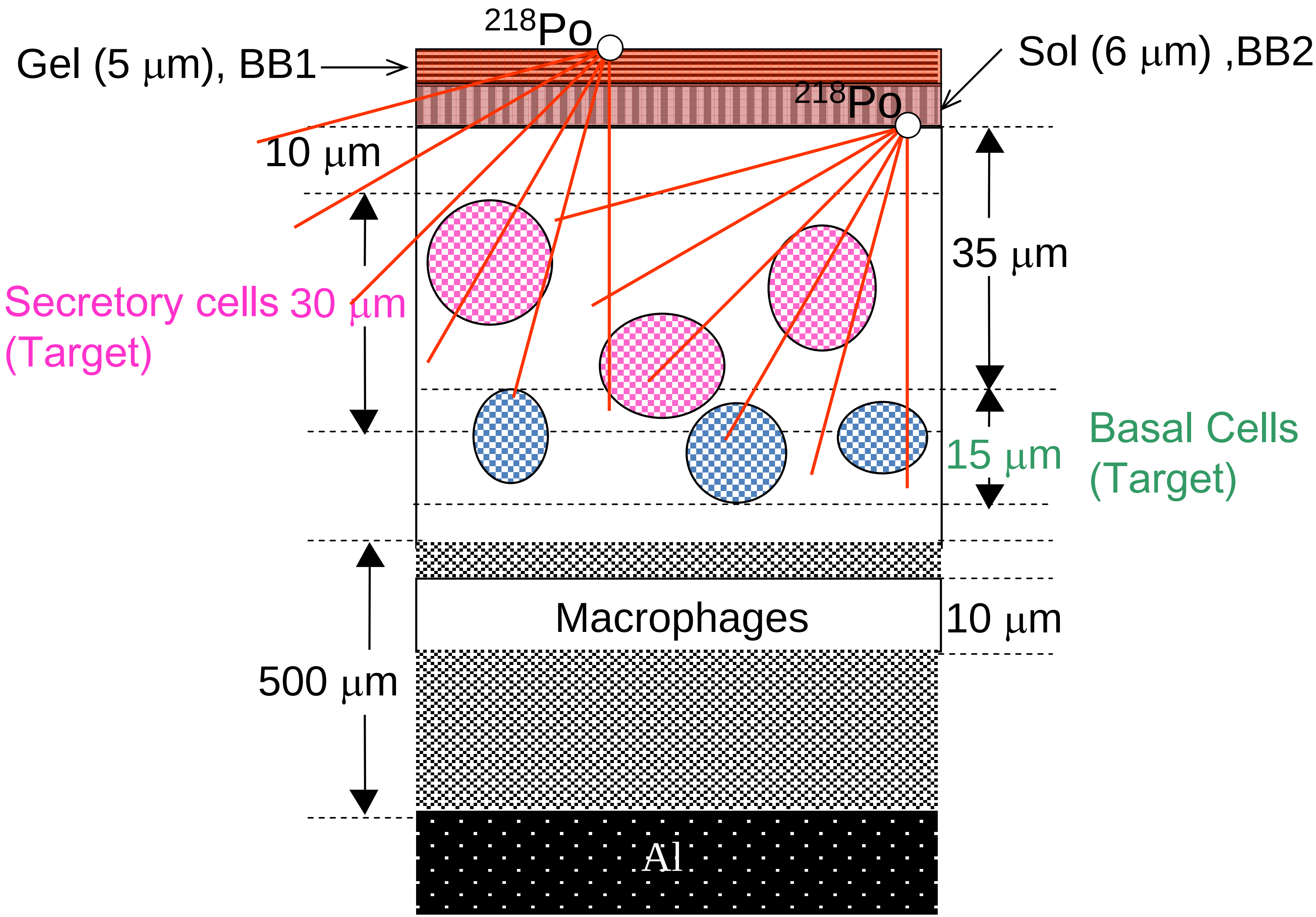
BB

bb

AI



Epithelium of trachea and bronchi



^{218}Po
Gel (5 μm), BB1
Sol (6 μm) ,BB2
^{218}Po
10 μm
35 μm
Secretory cells 30 μm
(Target)
15 μm
Basal Cells
(Target)
Macrophages
10 μm
500 μm
Al

Epidemiology

Radon induced lung cancer

- *Mines*
- *Homes*

Study poolings : *USA*

Europe

China

Exposure → Dose conversion

ICRP Pub 65 (1993) dose conversion convention

Compare lung cancer risk in miners

2.83×10^{-4} per WLM

with total detriment from cancer and hereditary effects from Pub 60 (1991):

Workers	5.6×10^{-2} per Sv	5 mSv per WLM
Public	7.3×10^{-2} per Sv	4 mSv per WLM

Exposure → Dose conversion

Updating the ICRP Pub 65 (1993) dose conversion

Compare lung cancer risk in miners

5×10^{-4} per WLM

with total detriment from cancer and hereditary effects from Pub 103 (2007):

Workers	4.2×10^{-2} per Sv	12 mSv per WLM
Public	5.7×10^{-2} per Sv	9 mSv per WLM

Exposure → Dose calculation

Dosimetry for exposure conditions in a typical mine:

12 mSv per WLM

So: Epidemiological conversion = Dosimetric calculation

Alternatively:

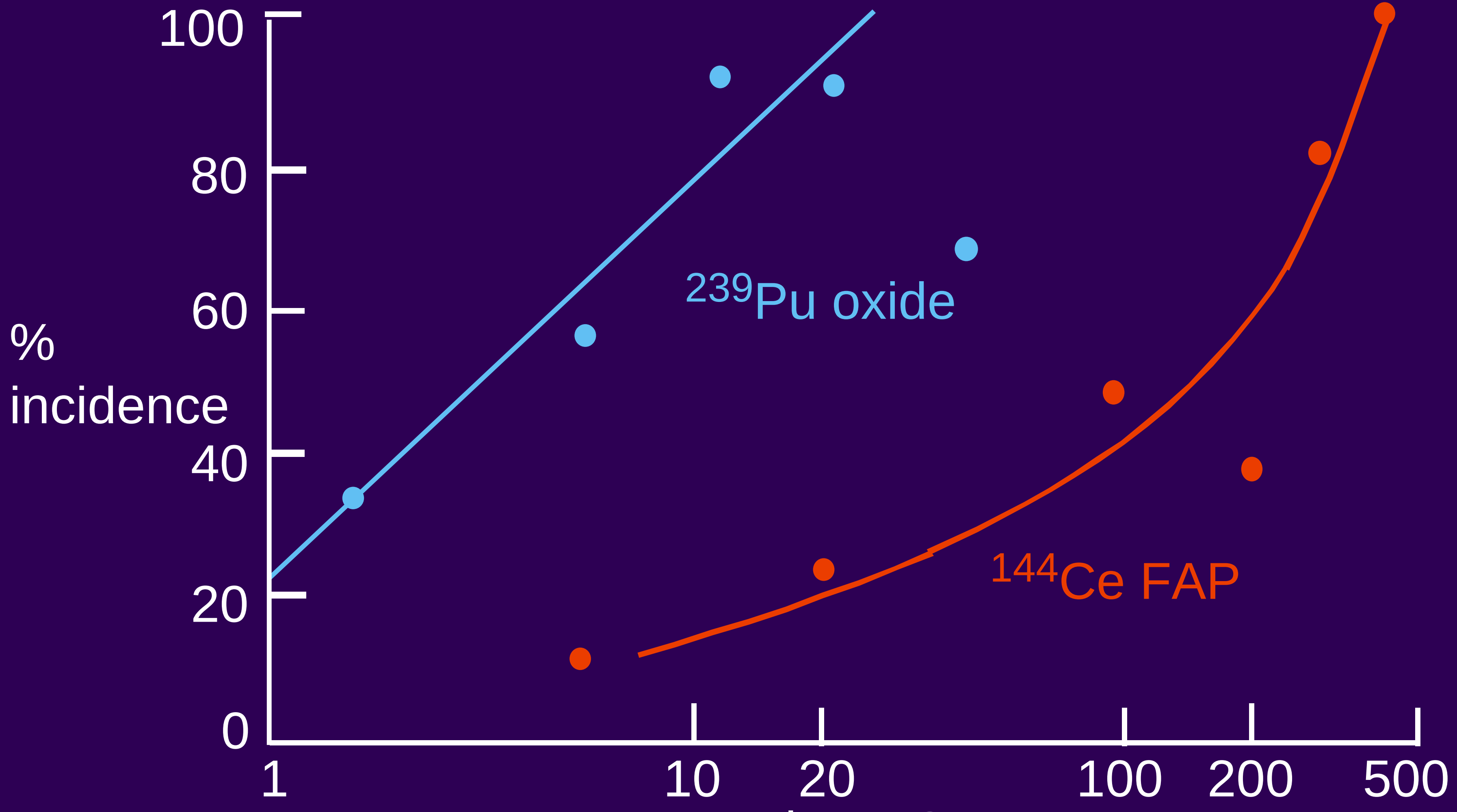
Risk per Sv for radon induced lung cancer corresponds to *risk per Sv* for lung cancer derived from the A bomb data

Cancer risk estimates for alpha emitters

• Radon	Lung cancer
• Thorotrast	Liver cancer & Leukaemia
• Radium isotopes	Bone cancer
• Plutonium-239	Lung (liver & bone cancer)

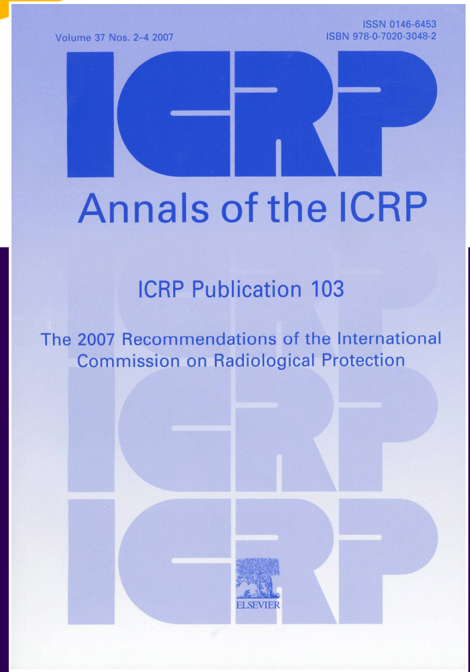
Harrison and Muirhead J. Radiat. Biol. **79**, 1-13 (2003)

Lung Tumours in Dogs



Hahn et al., 1999

ICRP 2007 recommendations
➔ what's new ?



- Revised nominal risk factors
- Changes to radiation and tissue weighting factors, w_R and w_T
- Adoption of defined phantoms
- Sex-averaging in calculation of effective dose
- Clarity on intended use of ICRP quantities

ICRP 2007 recommendations
➔ what's next ?

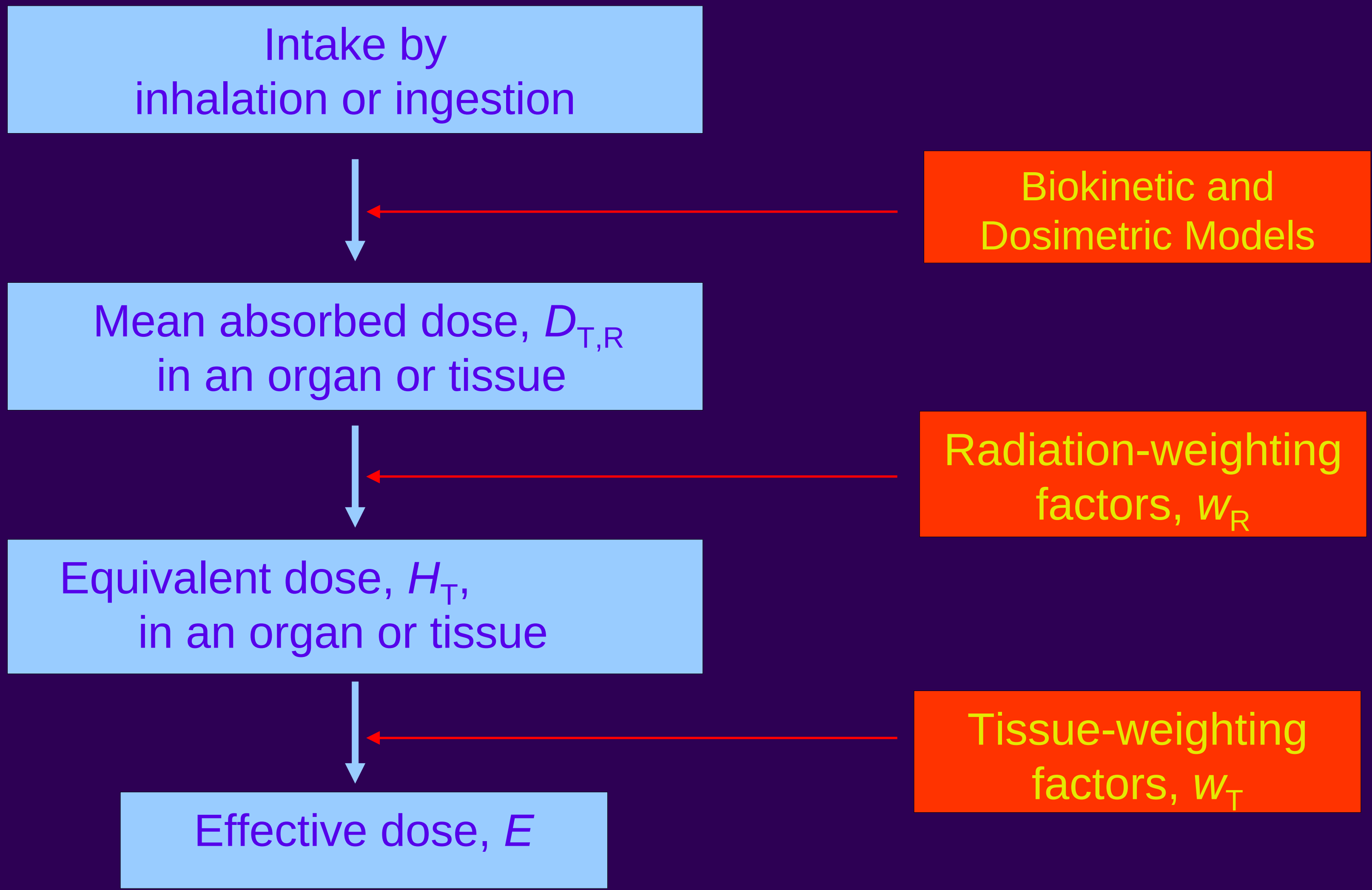
New dose coefficients

- external and internal
- workers and public

Using :

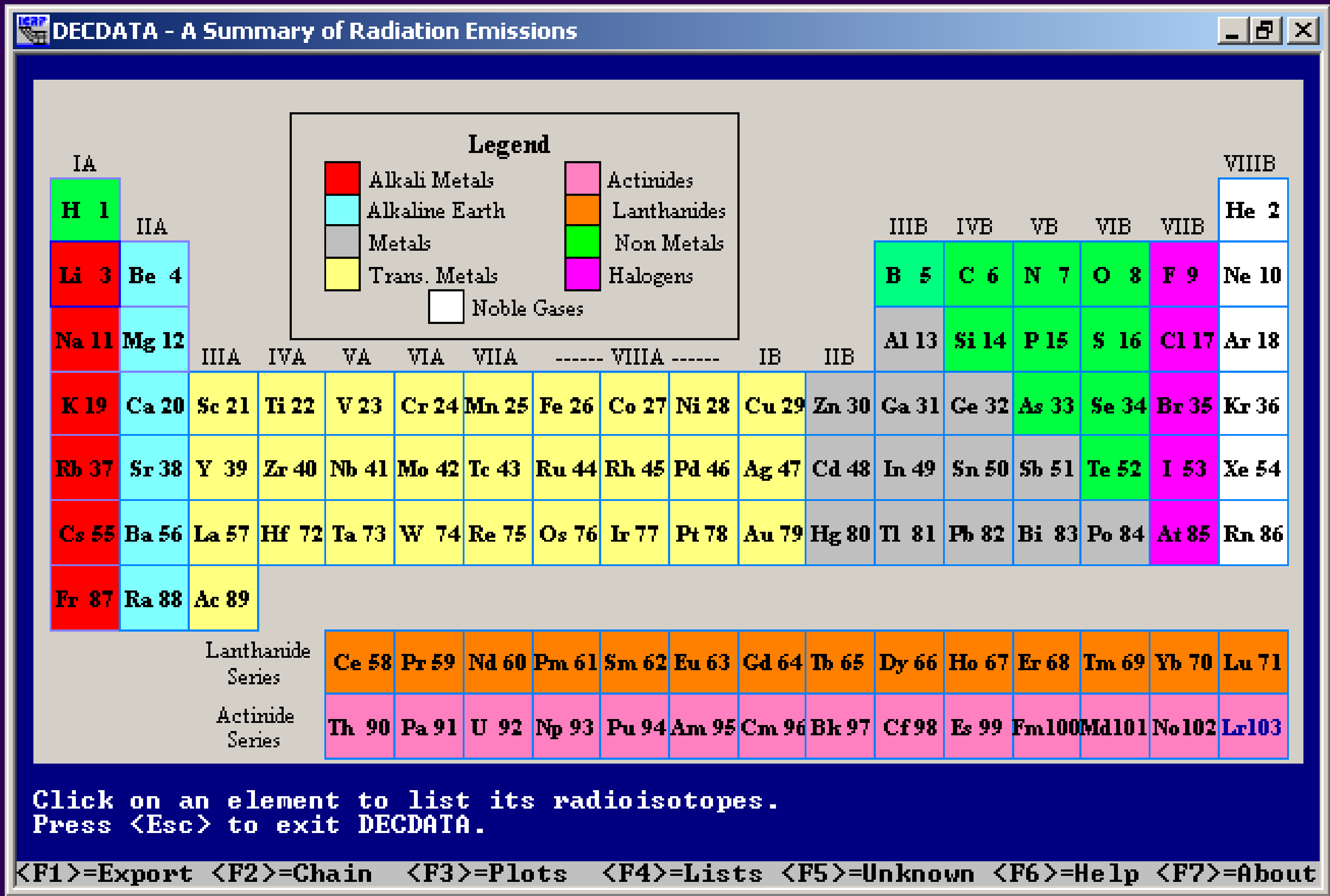
- Revised radionuclide decay data
- Reference anatomical models
- New / revised biokinetic and dosimetric models

Calculation of equivalent and effective dose



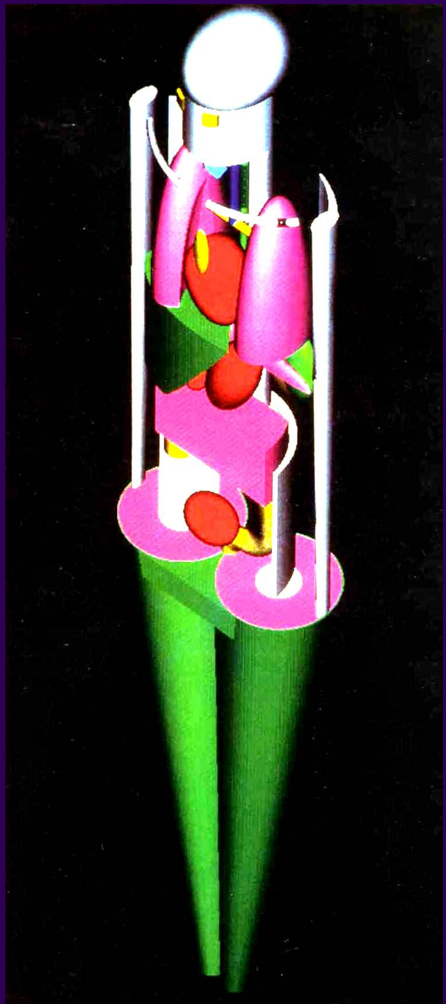
Radionuclide decay data
ICRP Publication 107

Health Protection Agency



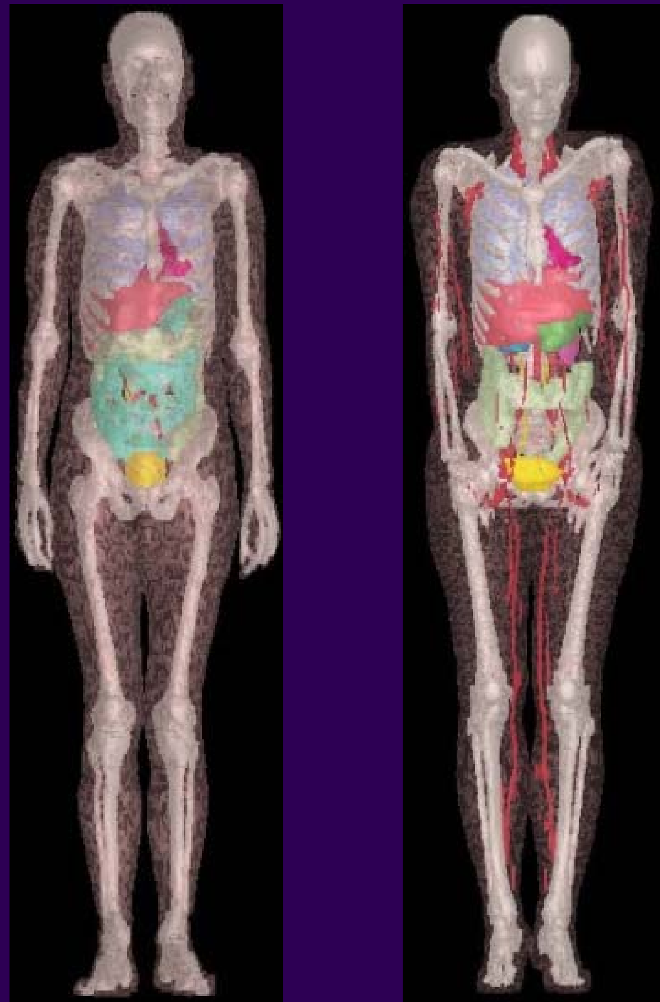
Reference Anatomical Models
Publication 110

Health Protection Agency

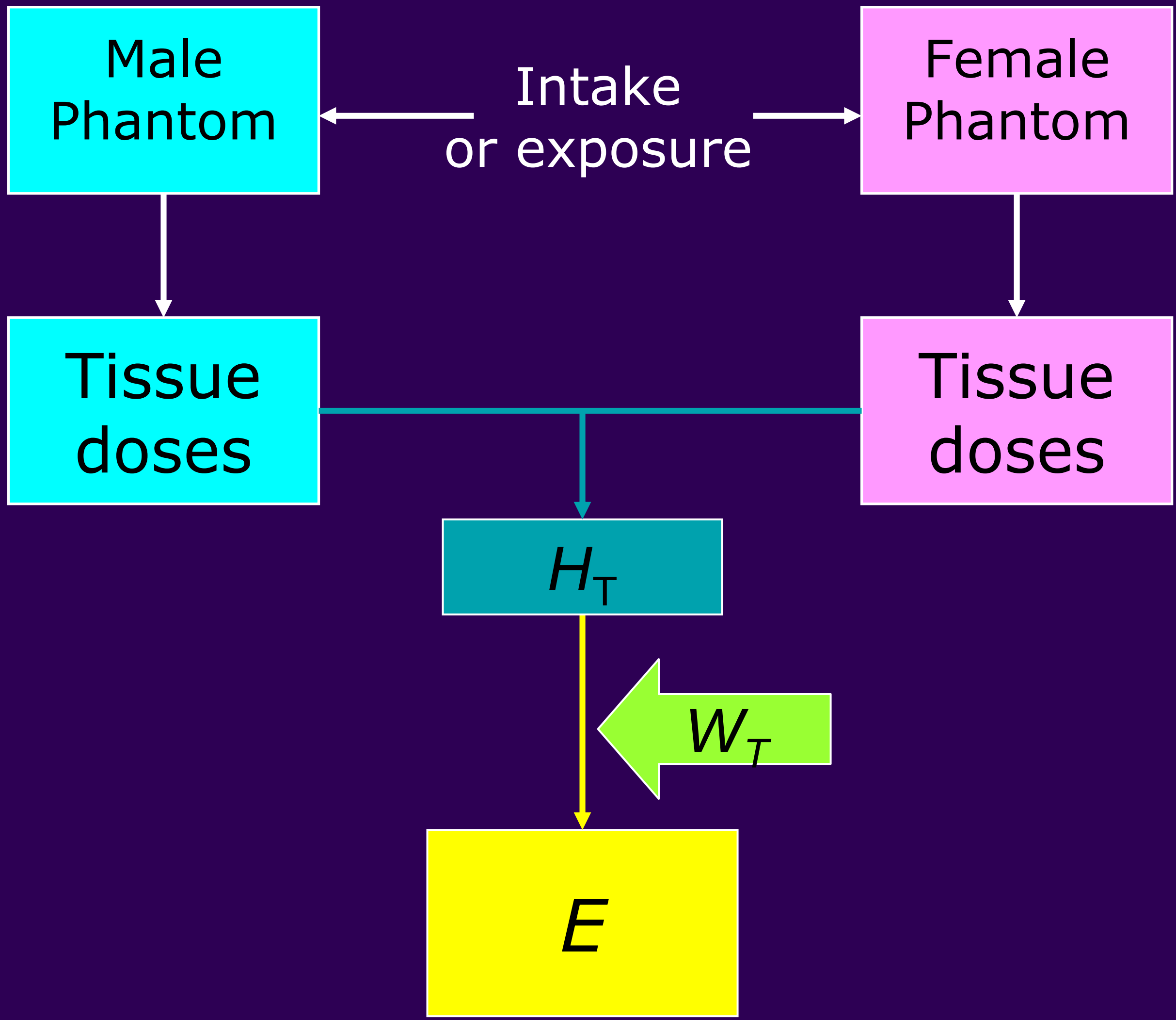


MIRD

VOXEL



Sex averaging in calculation of Effective Dose



RBE values for alpha particles

- Data consistent with assumption of RBE of 10 - 20 for liver and lung cancer
- Low RBE of around 1 for leukaemia and < 10 for bone cancer
- Threshold may apply to specific cancer types

BUT *use single radiation weighting factor of 20 for alpha particles compared with single value of 1 for low LET radiations – to calculate ICRP equivalent dose*

Age-specific cancer risks

- life-time attributable risk for U.S. population

Cases per 10^6 exposed to a single dose of 10 mGy (BEIR VII)

Cancer site	Age at exposure, years					
	Males			Females		
	0	20	60	0	20	60
Breast	-	-	-	1171	429	31
Colon	336	173	94	220	114	62
Liver	61	30	14	28	14	7
Lung	314	149	89	733	346	201
Thyroid	115	21	0.3	634	113	1
Leukaemia	237	96	82	185	71	57
All cancers	2563	977	489	4777	1646	586

Tissue weighting factors

0.01	bone surface, skin, brain, salivary glands
0.04	bladder, liver, oesophagus, thyroid
0.08	gonads
0.12	bone marrow, colon, lung, stomach, breast, remainder

Use of effective dose

FOR → protection purposes

Sum doses from different radionuclides and external exposures

Limits, constraints, reference levels

Reference Persons

NOT FOR → best estimates of dose and risk

Uses of dosimetry beyond effective dose

Arguable that the effort involved in improving models and dose calculations in not warranted for the calculation of equivalent and effective dose

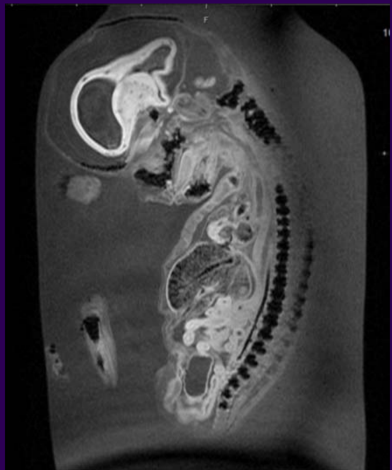
However :

- ICRP biokinetic and dosimetric models are also used for **:**
  - ➔ epidemiology
  - ➔ probability of cancer causation
- The methods used are subject to continuing scientific scrutiny

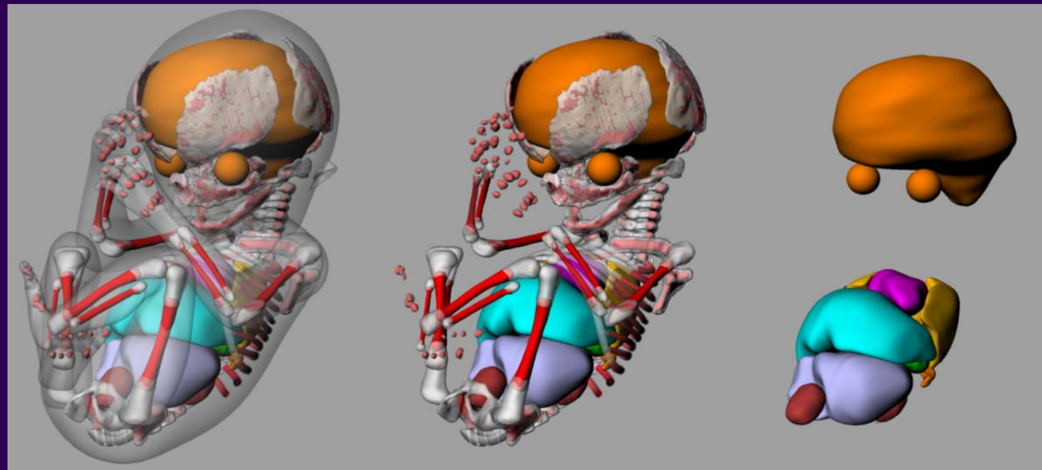
Phantoms for children

Health Protection Agency

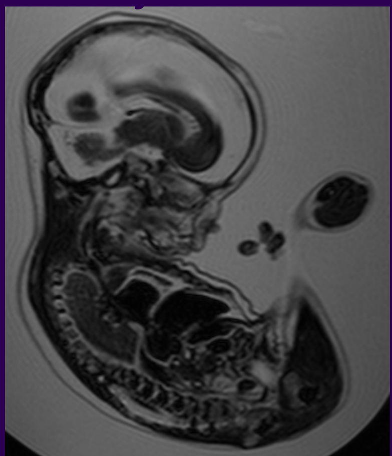
Fetal Model Development for Techa Dosimetry



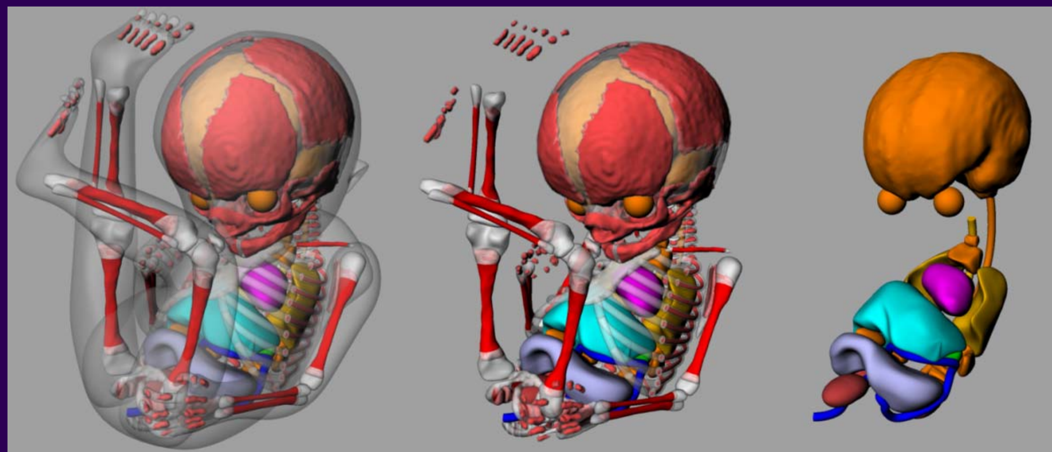
4.7 T NMR Image – 11.5 week



Two Specimen-Specific Fetal Models



1.5 T MR Image – 21 week



Bone dosimetry

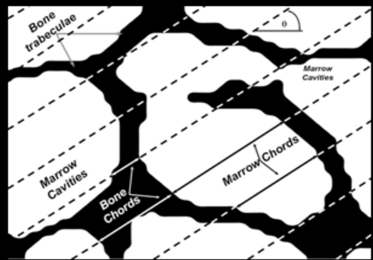
CBIST (Chord-Based Infinite Spongiosa Transport)

Macrostructure:

None
Infinite spongiosa

Microstructure:

Chord-length distributions



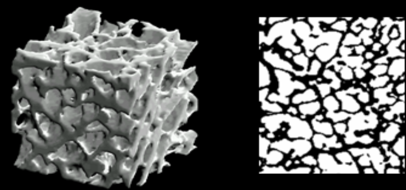
VBIST (Voxel-Based Infinite Spongiosa Transport)

Macrostructure:

None
Infinite spongiosa

Microstructure:

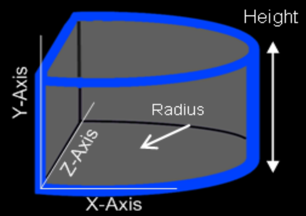
MicroCT imaging
3D image of skeletal spongiosa



VBRST (Voxel-Based Restricted Spongiosa Transport)

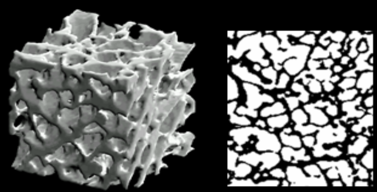
Macrostructure:

Stylized Model
Representation of cortical bone cortex



Microstructure:

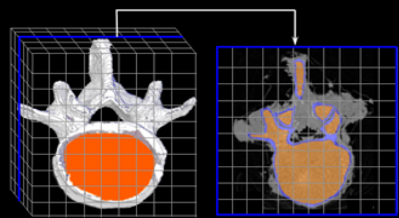
MicroCT imaging
3D image of skeletal spongiosa



PIRT (Paired-Image Radiation Transport)

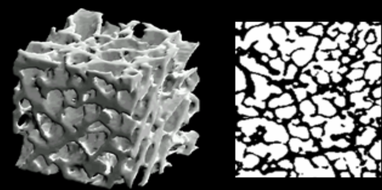
Macrostructure:

Ex-vivo CT imaging
Contour of true skeletal structure



Microstructure:

MicroCT imaging
3D image of skeletal spongiosa

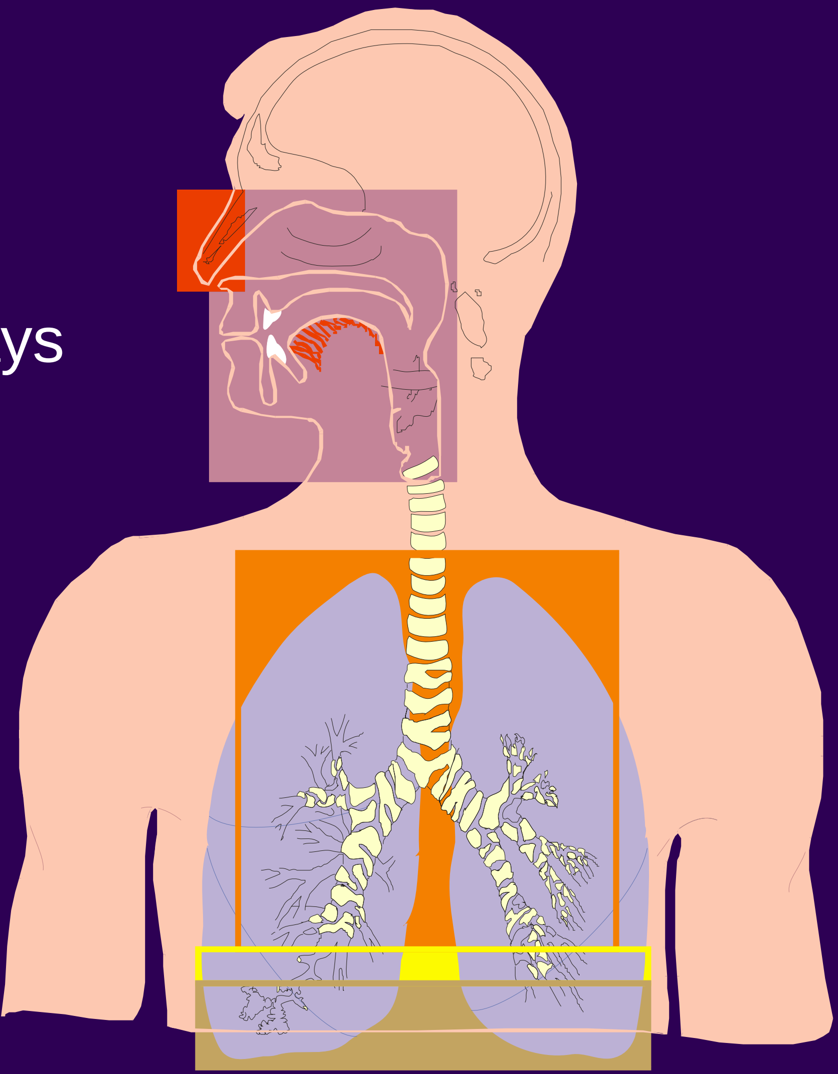


Biokinetic models

- Revisions to respiratory tract model
- New alimentary tract model
- New systemic models for some elements

Human Respiratory Tract Model, Pub 66 (1994)

Health Protection Agency



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Updates to HRTM

Particle transport

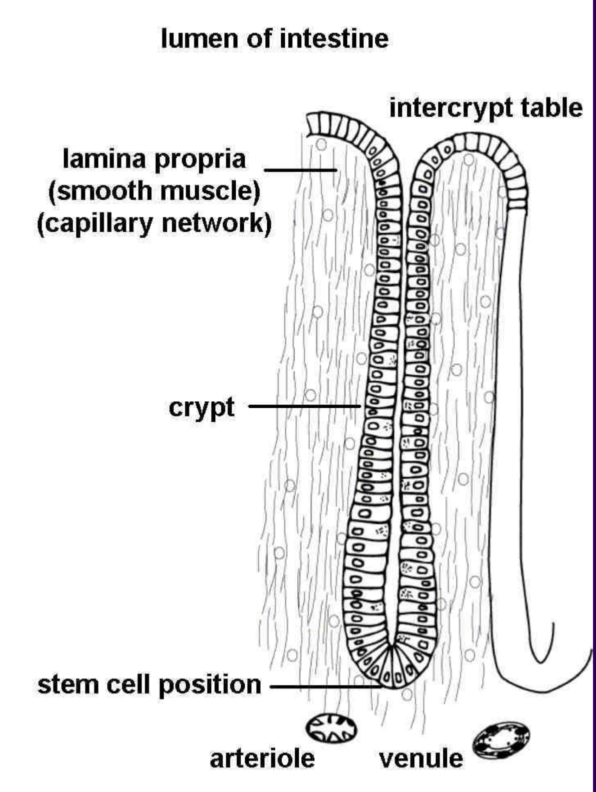
- Nasal passage
- Bronchial tree (slow phase)
- Alveolar region

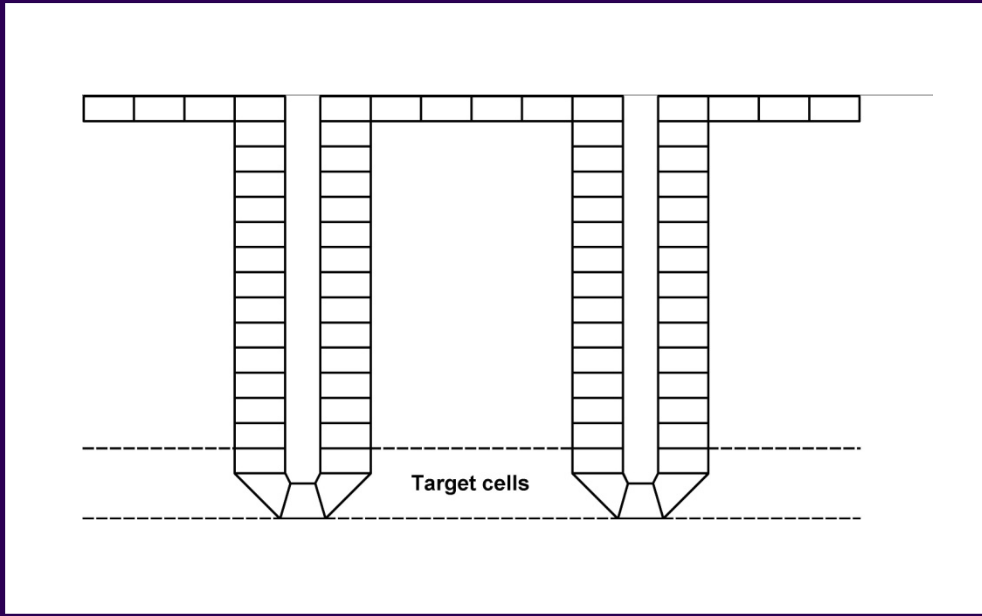
Absorption to blood

- Material specific parameter values for 20-30 materials (mainly H, Th, U, Pu, Am)
- Default Type F, M, S parameter values, based on experimental data
- Element-specific values of rapid dissolution

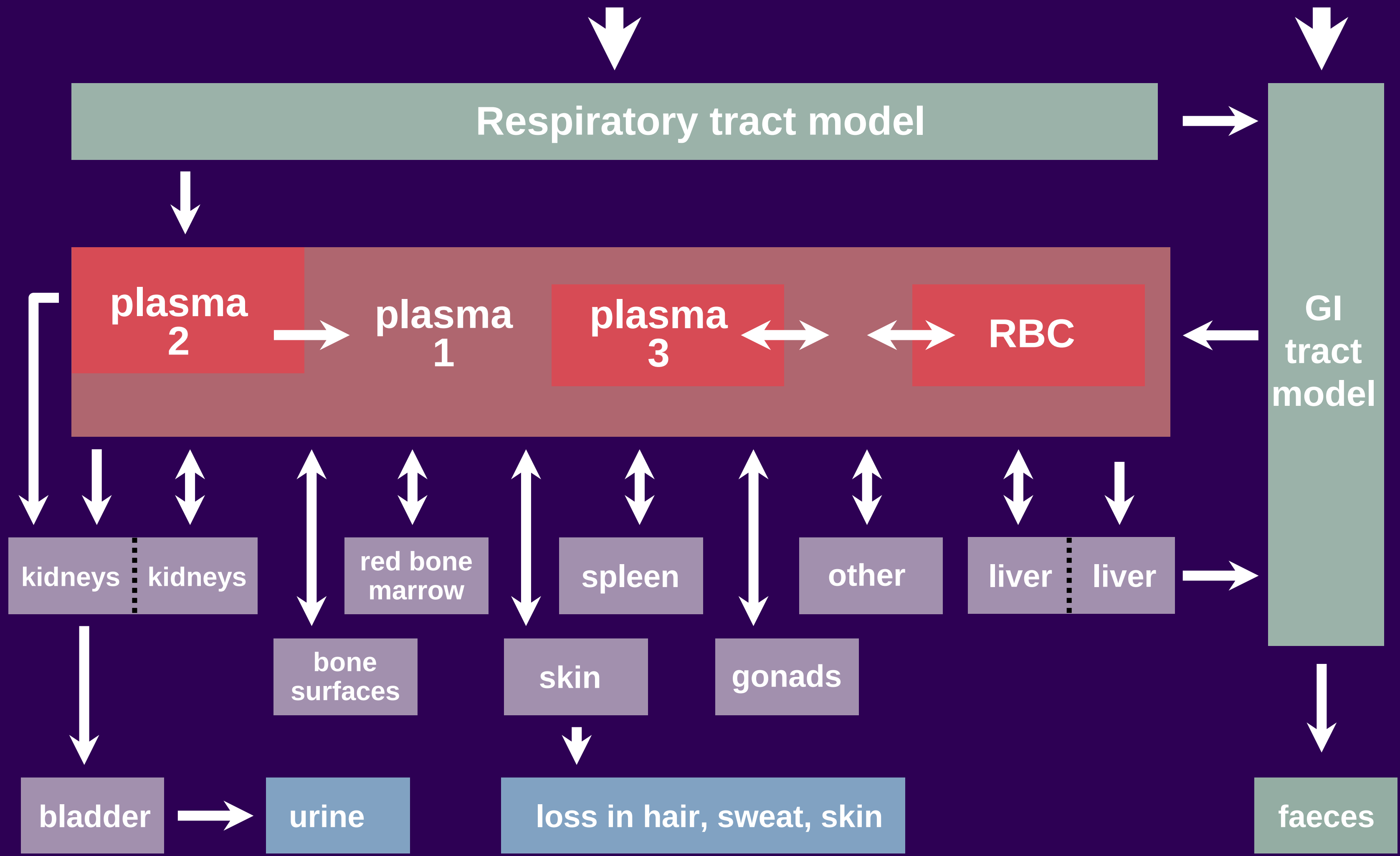
Target cells in the alimentary tract

Colon





Leggett and Eckerman (2000) systemic model for Po



Research priorities

Epidemiological studies

- *Occupational : Radon, Plutonium, Uranium, Tritium*
- *Environmental : Strontium, Iodine*

Experimental studies

- *RBE, biokinetics*
- *Target evaluation : stem cells, microenvironment, bystander effects*

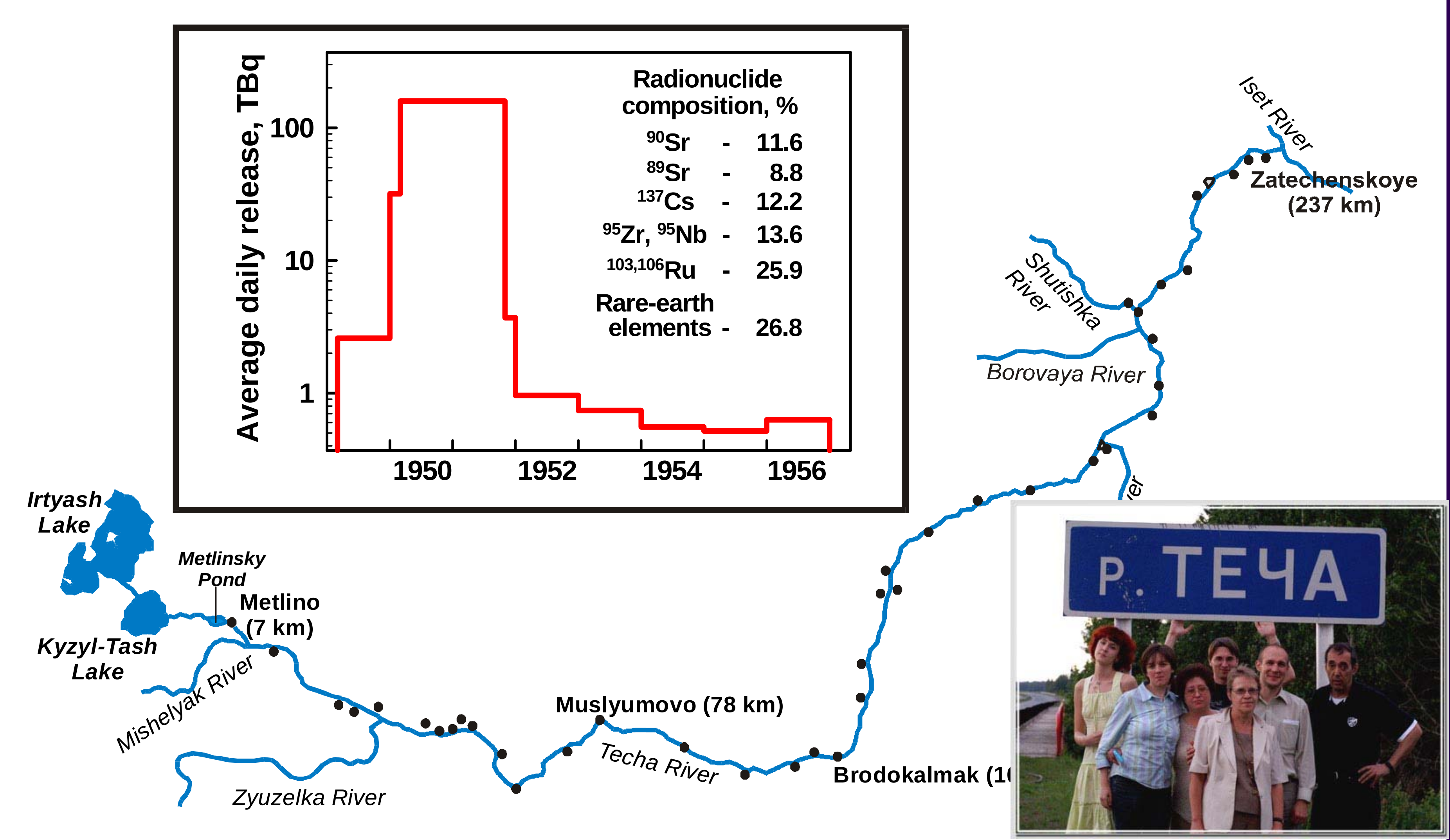
Model development

- *Physiologically based biokinetic models*
- *MRI / CT based anatomical models, macro- and micro-*

Uncertainties

Mayak Pu production

Techa River



Average daily release, TBq
100
10
1
1950
1952
1954
1956
Radionuclide composition, %
^{90}Sr - 11.6
^{89}Sr - 8.8
^{137}Cs - 12.2
^{95}Zr, ^{95}Nb - 13.6
$^{103,106}Ru$ - 25.9
Rare-earth elements - 26.8
Irtyash Lake
Metlinsky Pond
Metlino (7 km)
Kyzyl-Tash Lake
Mishelyak River
Zyuzelka River
Muslyumovo (78 km)
Techa River
Brodokalmak
Iset River
Zatechenskoye (237 km)
Shutishka River
Borovaya River
р. ТЕЧА

Mayak and Techa Cohorts

Mayak workers

- *Around 19,000 first employed between 1948 and 1972*
- *Lower doses to later employees*
- *Plutonium as well as external exposures*

Extended Techa River Cohort (ETRC)

- *Around 30,000 people born before 1950, resident at any time during 1950 – 1960*
- *Strontium as well as external exposures*

Techa River Offspring Cohort

- *Around 24,000 people born 1950 or later, having an ETRC parent; 6,000 exposed in utero*

SOLO

Solo

Health Protection Agency

Supported by the EC 7th Framework Programme (Euratom) 2010 – 2013

Total value 9 M€ - 5 M€ from the EC

Project Coordinator : John Harrison

Scientific Secretary : Richard Haylock

Administrative Officer : Svetlana Carr

Business Manager : Anne Dempsey

9 Contract Partners: HPA, SUBI (RF), URCRM (RF), Helmholtz Zentrum München (D), Univ Central Lancashire (UK), Danish Cancer Society, ISS (I), LUMC (NL), Univ Florida (USA)

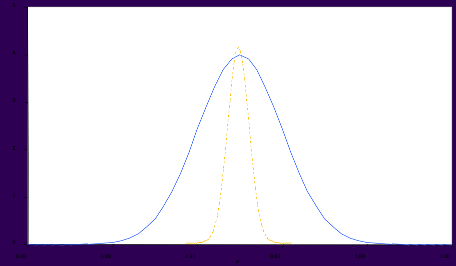
Uncertainties in dose estimates

ICRP dose coefficients

- *Reference values BUT*
- *Underlying data subject to uncertainty*
- *Important to understand the reliability of protection*

Epidemiological studies

- *Uncertainties on organ / tissue doses for individuals*



Implications for policy

- Evidence that current methodology of dose estimation for internal emitters provides adequate assessment of risk
- ICRP strong on model development for internal dosimetry
- ICRP protection quantities are not intended as best estimates of dose and risk BUT
- ICRP models are used for other purposes including individual risk estimation and epidemiological studies
- Future research findings will help in model development, strengthening the reliability of dose and risk estimation and of the ICRP quantities