The ICRP's Biokinetic Model for Cesium

ICRP Webinar

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Cesium (Cs) is an alkali metal that follows the alkali metal potassium (K) in the body

- The ICRP's current model for systemic cesium is based on a modeling scheme originally applied to potassium (Phys Med Biol, 1986)
- The potassium model was built around a blood flow model with parameter values based on blood flow rates, tissue-specific rates of extraction from blood, and the steady-state distribution of potassium
- The same approach was applied to the alkali metal rubidium (Rb) (Health Phys, 1988) and later to cesium (Sci Total Environ, 2003)
- Modified versions of these three models were adopted for use in the ICRP's OIR and EIR series

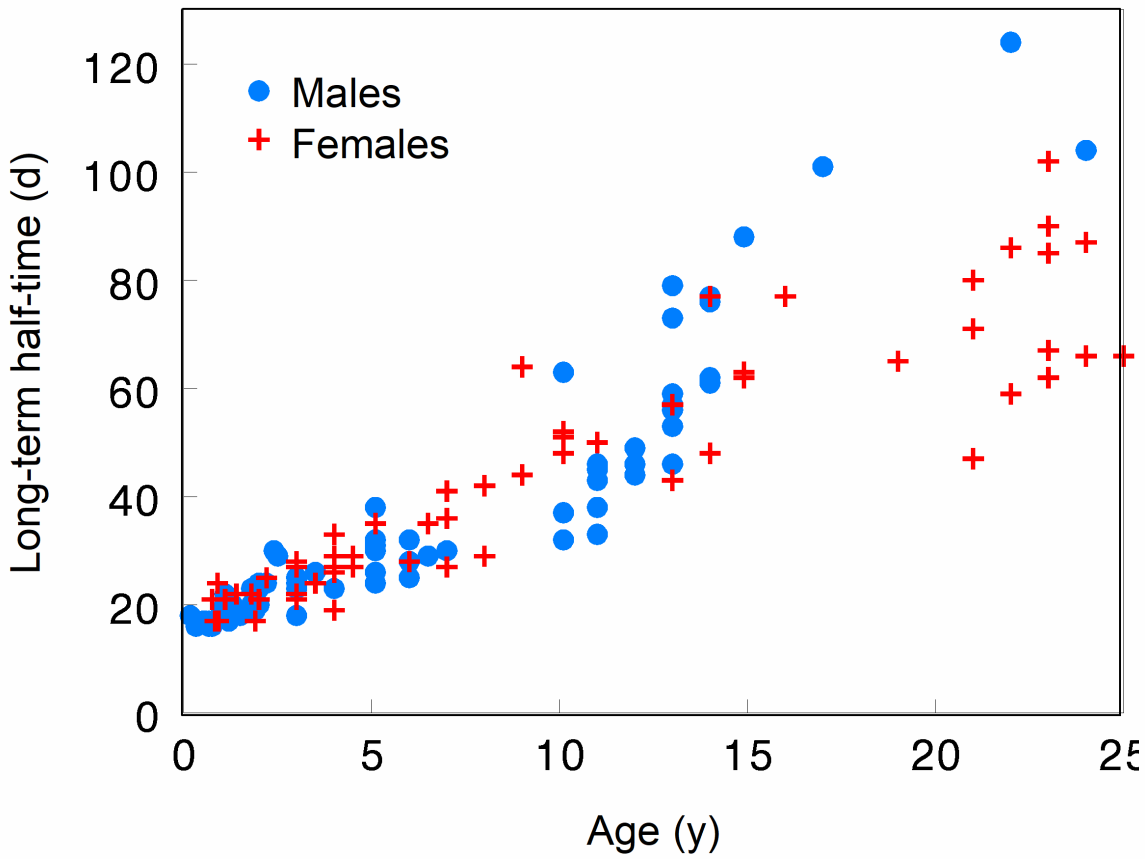
Early physiological comparisons of K, Rb, and Cs

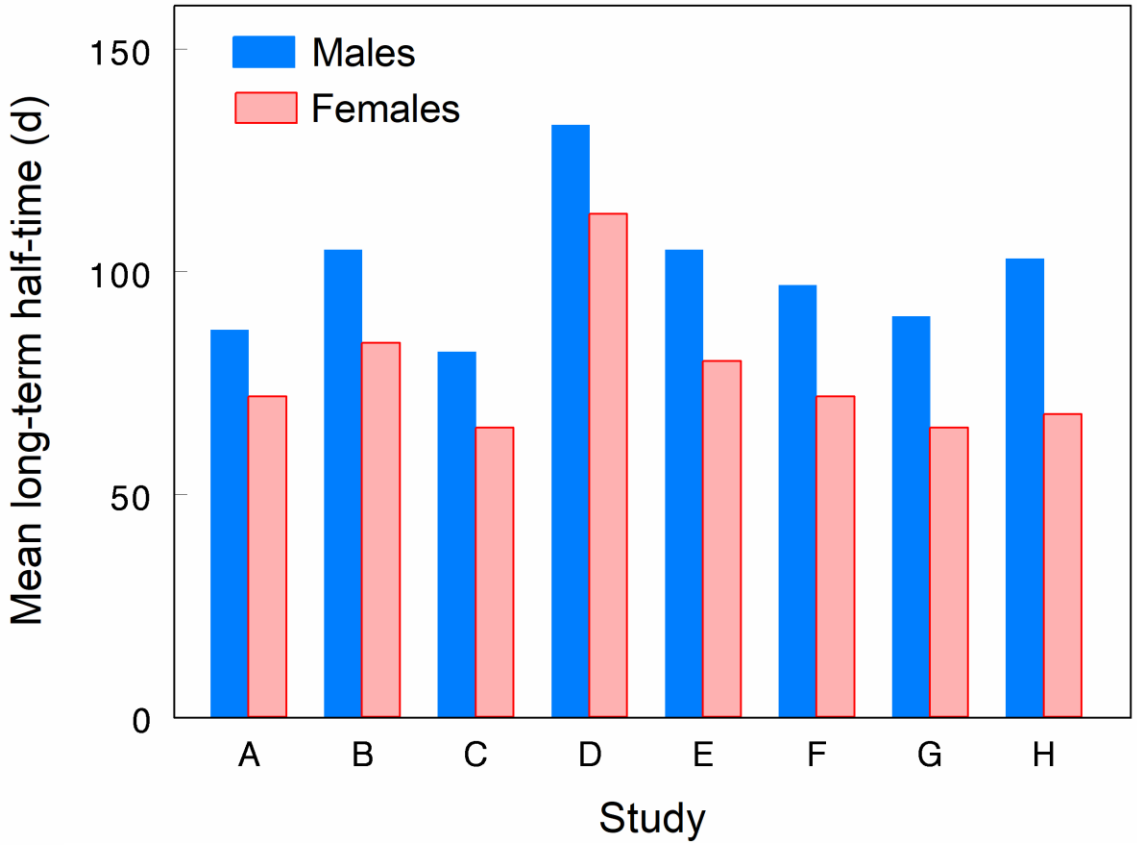
- In the 1880s Sydney Ringer tested whether Rb or Cs could substitute for K in maintaining beats of the isolated frog heart
- Rb substituted well for K over many hours
- Cs maintained heart beats but changed the rhythm and worked for at most 20 minutes
- Over the years, K, Rb, & Cs have been used extensively to study structures of ionic channels and discrimination between chemically similar elements

Comparative mobility of K, Rb, & Cs in the body

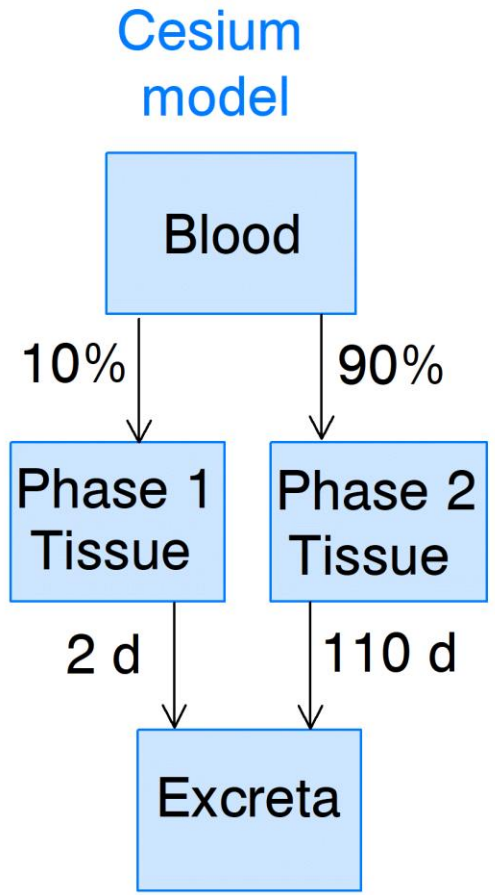
- **Rb and Cs compete with K for transport in all studied K transport systems including**
  - Active transport into cells via the sodium pump
  - passive transport out of cells along concentration gradients
- **Typically, K is chosen over Rb by about a 4:3 ratio and K over Cs by about a 5:1 ratio**
- **For example, for Cs and K atoms carried in blood, the extraction fraction for K when passing through a tissue in blood is on the order of 5 times the extraction fraction for Cs**

Emergence of fission-produced Cs-137 led to much wider studies of Cs biokinetics





ICRP's previous systemic model for Cs (1980-2017)

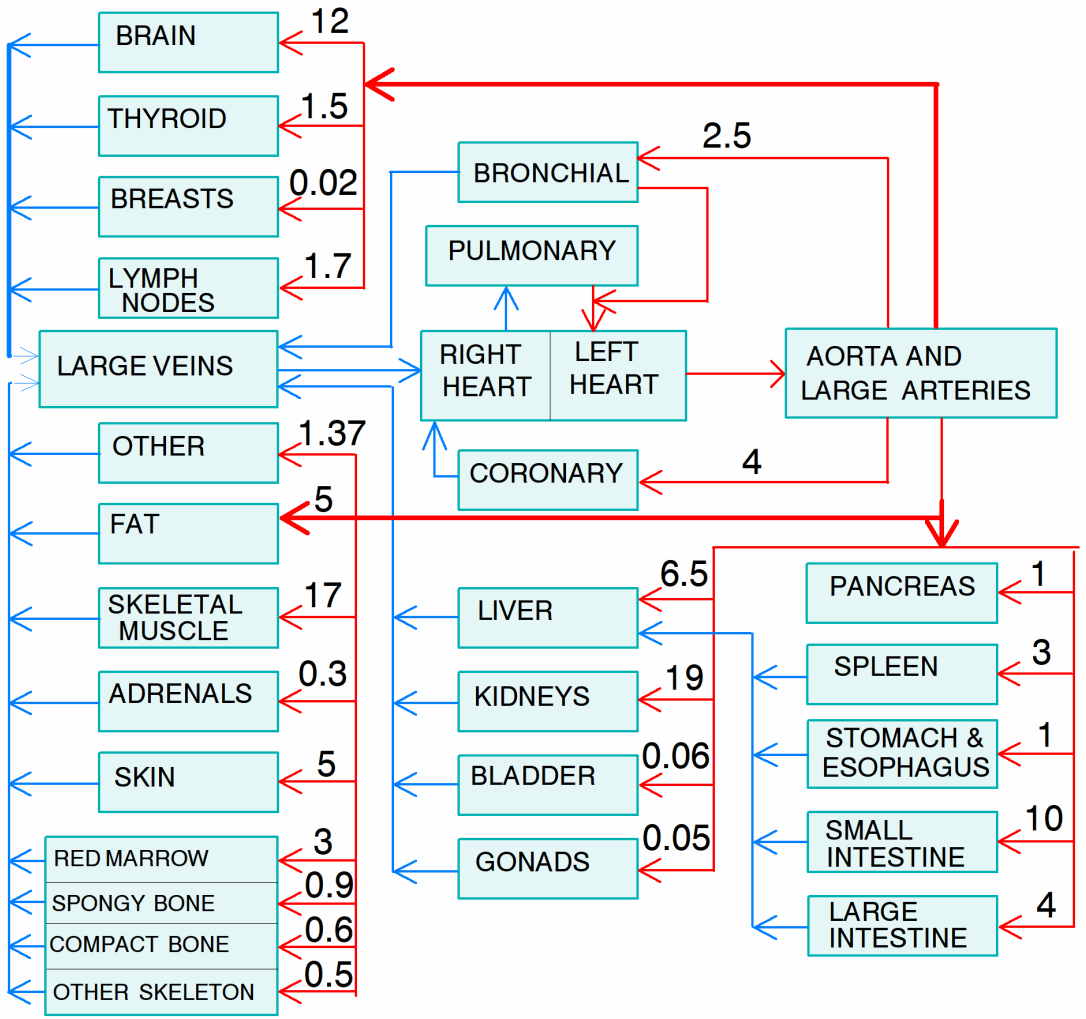


- **The same type of model was applied to K and Rb during the same period**
  - K retention half-time in adults assumed to be 30 days
  - Rb retention half-time in adults assumed to be 44 days

The current ICRP model for systemic Cs is based mainly on three types of information

1. **Blood flow data (condensed into a blood flow model)**
2. **Tissue-specific extraction fractions**
3. **The equilibrium distribution of stable Cs**

Blood flow model underlying current ICRP models for Cs, Rb, K



Reference equilibrium distributions of K, Rb, Cs in adult male (% total body content)

Tissue or fluid	Potassium (%)	Rubidium (%)	Cesium (%)
Blood plasma	0.36	0.30	0.20
Heart	0.57	0.50	0.35
Kidneys	0.43	0.60	0.40
Liver	3.4	4.6	2.0
Muscle	68	67	80
Spleen	0.43	0.40	0.20
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Examples of extraction fractions for Cs

Tissue	Reference extraction fraction
Kidneys	0.2
Liver	0.05
Brain	0.002
Muscle	0.1

Example of derivation of transfer coefficients (TC_{IN}) from blood plasma to tissues

For Cs in the adult male, TC_{IN} from plasma to skeletal muscle is

$$TC_{IN} = 0.1 \bullet 0.17 \bullet 1766\ d^{-1} = 30.02\ d^{-1}$$

where

- **0.1 is the reference Cs extraction fraction for muscle**
- **0.17 is the reference fraction of cardiac output going to muscle**
- **1766 d^{-1} is the reference cardiac output (plasma volumes d^{-1})**

Example of derivation of transfer coefficient TC_{OUT} from tissue to blood plasma

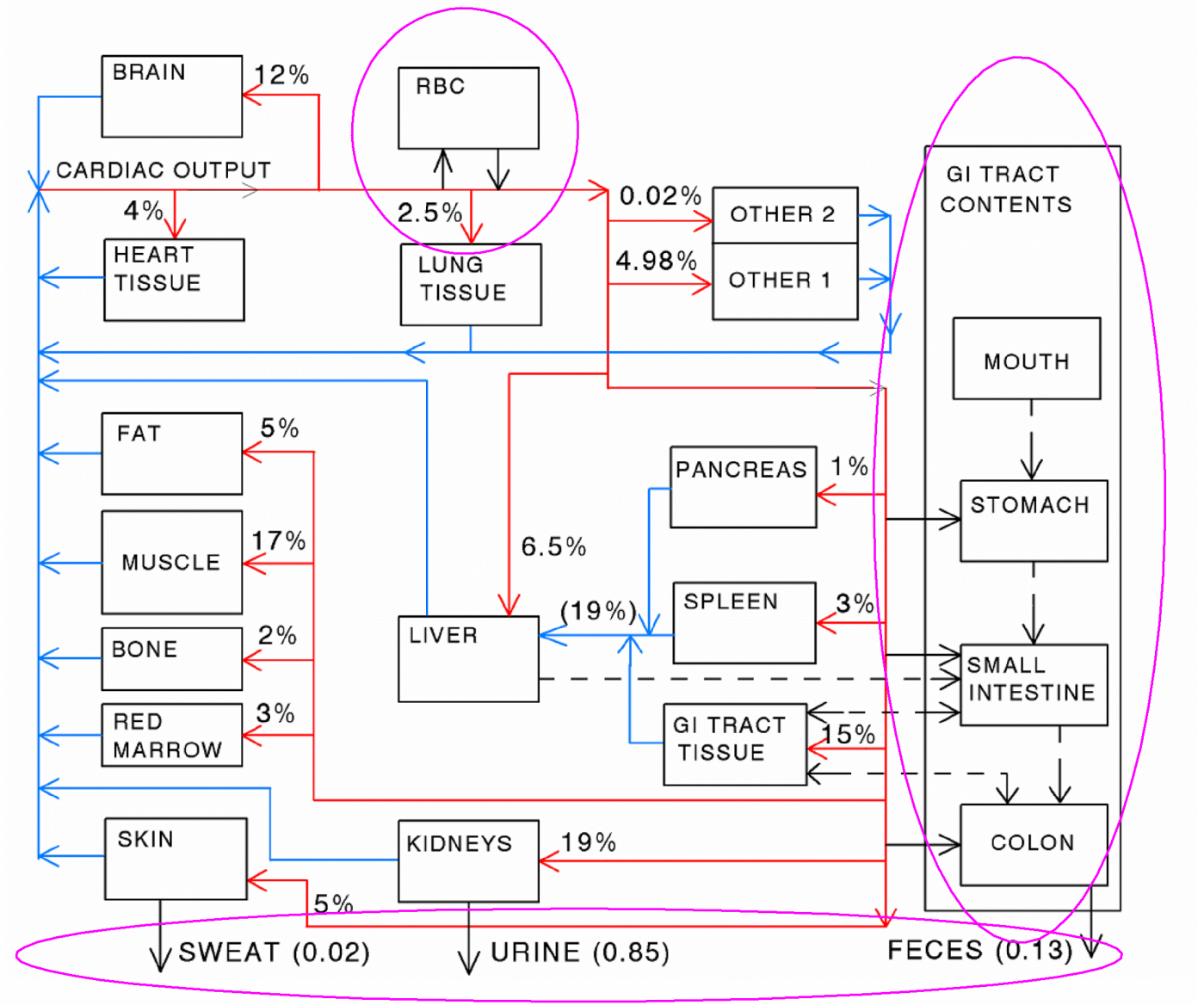
Continuing from the previous example, the transfer coefficient TC_{OUT} from muscle to plasma is calculated from the equilibrium equation :

$$TC_{OUT} \bullet 0.8 = TC_{IN} \bullet 0.002$$

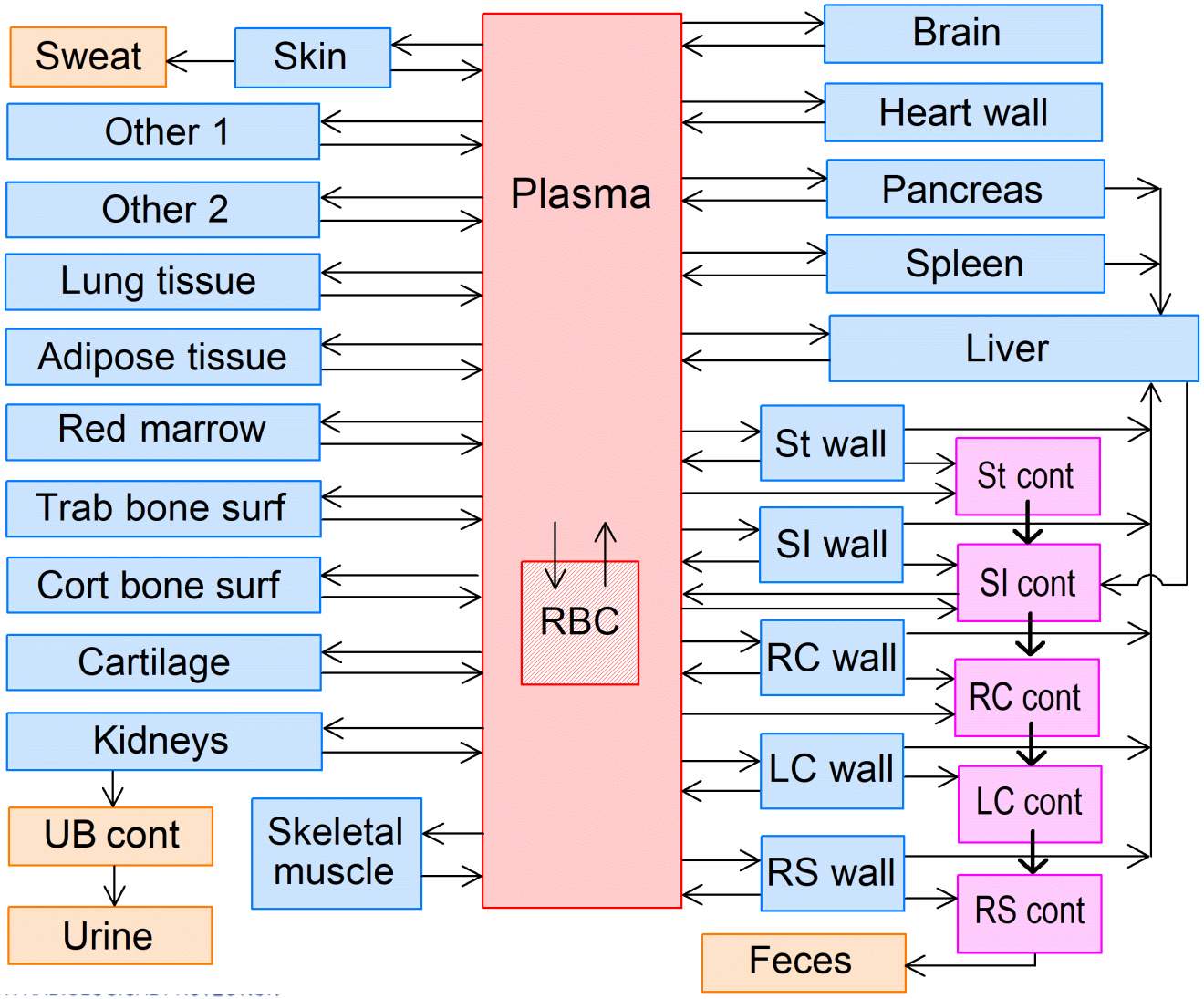
- 0.8 is the fraction of total-body Cs in muscle at equilibrium
- 0.002 is the fraction of total-body Cs in plasma at equilibrium
- TC_{IN} is the transfer coefficient from blood plasma to muscle (30.02 d^{-1} from the previous slide)

$$TC_{OUT} = 30.02\ d^{-1} \bullet 0.002 / 0.8 = 0.0751\ d^{-1}$$

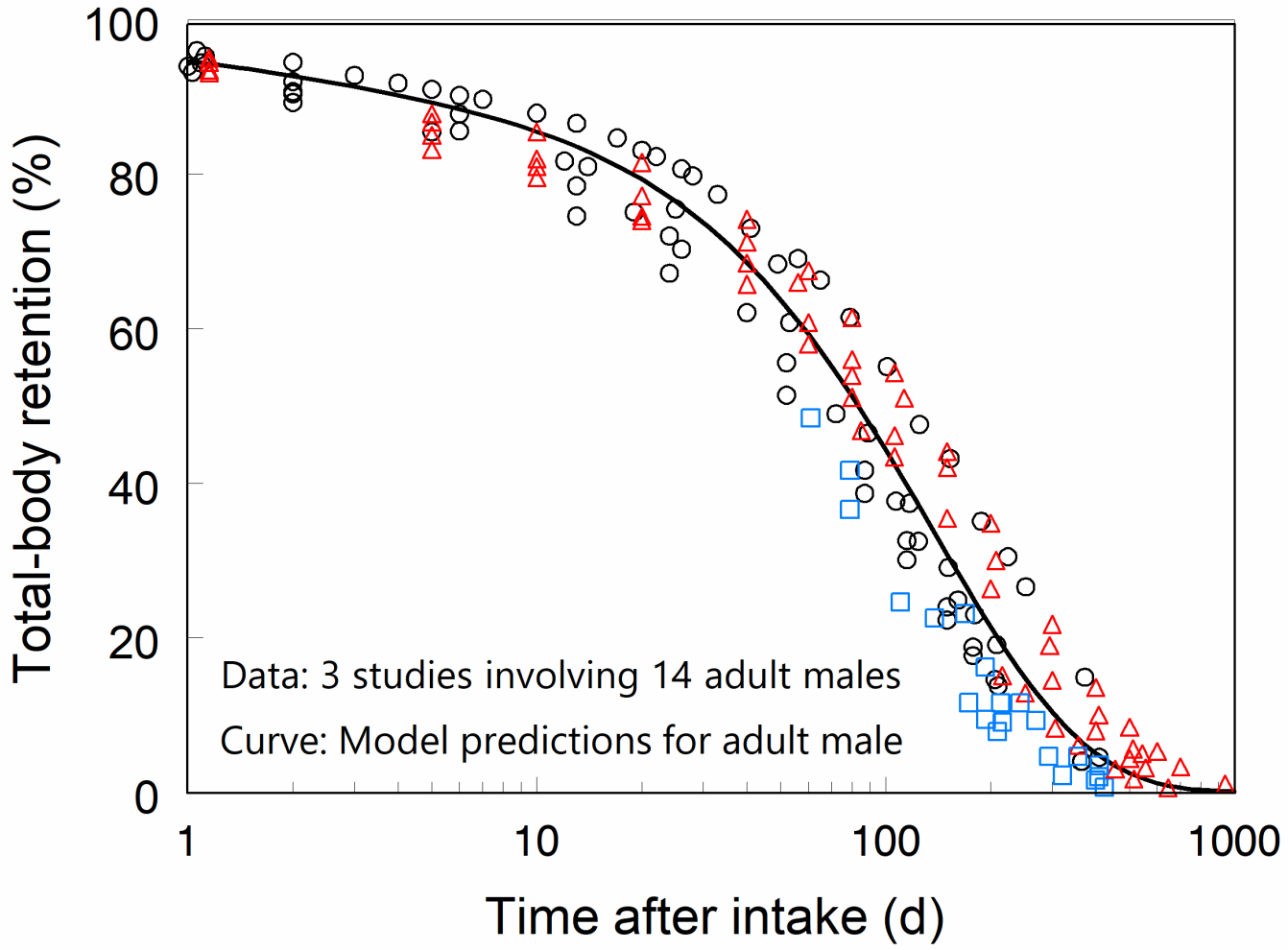
Original structure of the model for Cs, built mainly around blood-tissue exchange but addressing remaining kinetics



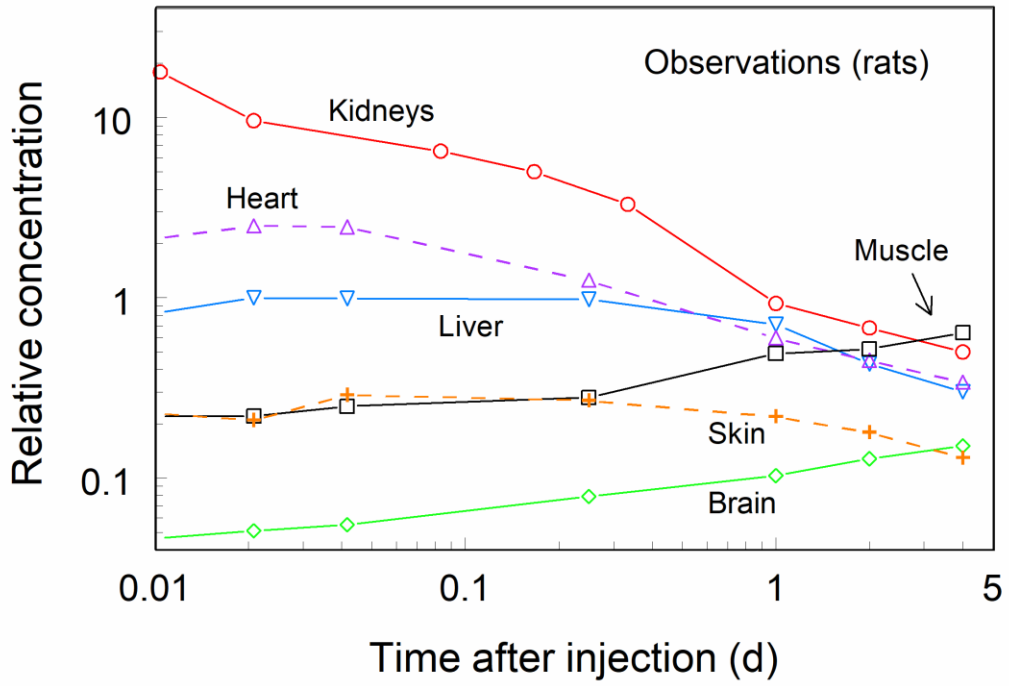
The structure of the Cs model was modified for use in the OIR & EIR series

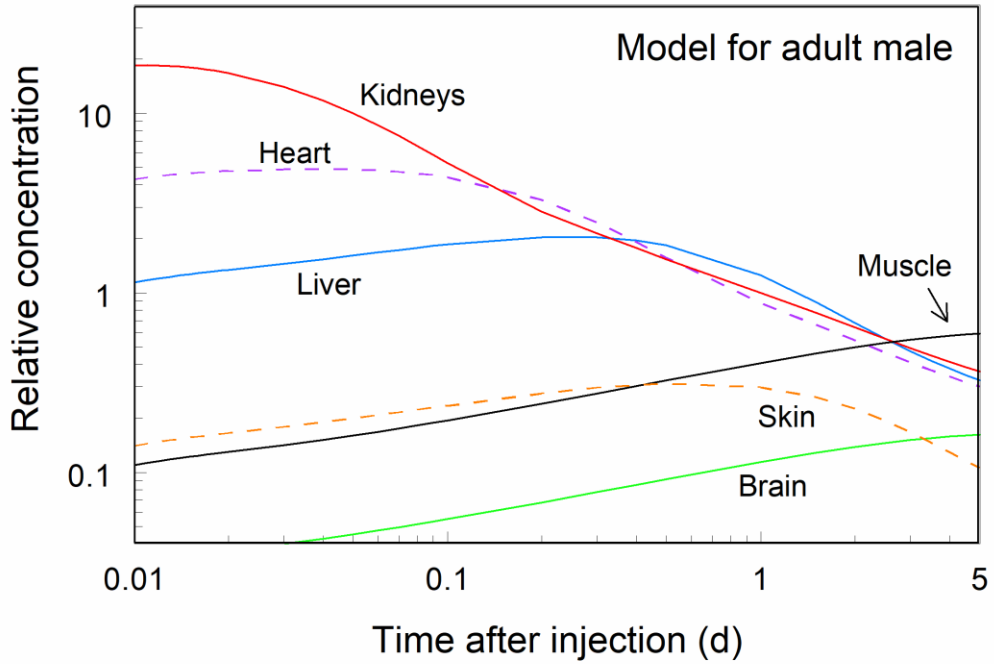


Model predictions for Cs retention in adult males compared with observations for 14 adult males

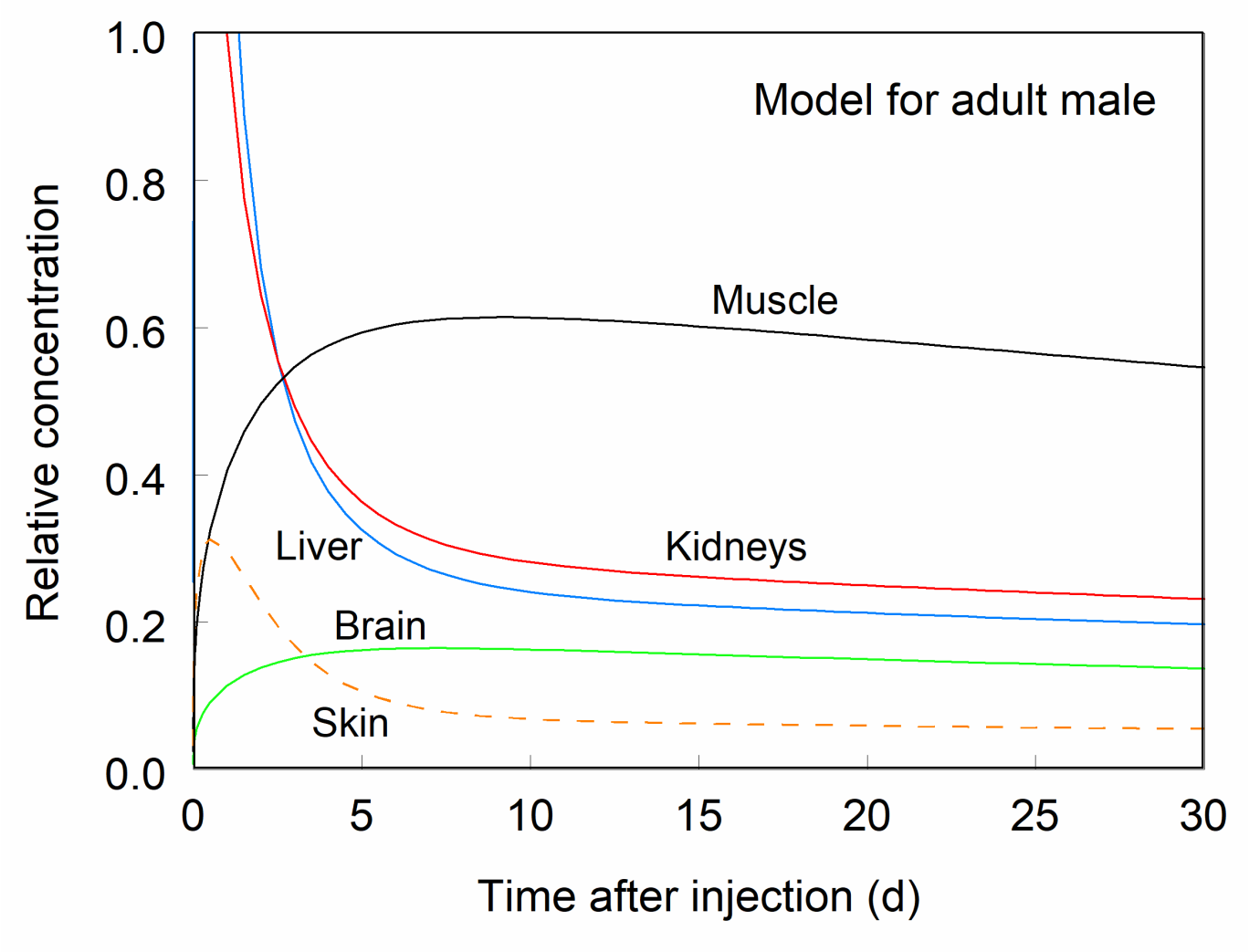


Comparison of modeled Cs concentrations in adult male with animal data





Model predictions of relative Cs concentrations in adult male tissues over 30 days



Ratios of adult male injection dose coefficients, OIR model : previous model

Tissue	Cs-130 (29.2 min)	Cs-134m (2.90 h)	Cs-134 (2.06 y)	Cs-137 (30.2 y)
Bone surface	1.0	2.3	0.8	1.9
Colon wall	7.4	5.0	0.8	1.4
Kidneys	25	9.5	0.9	0.9
Liver	3.0	2.9	0.8	0.9
Muscle	0.6	0.8	1.1	1.3
Spleen	6.4	4.8	0.9	0.9
Effective	3.2	2.3	0.80	0.87

Summary of ICRP's current model for systemic Cs

- **Based largely on blood flow model, Cs extraction fractions, and equilibrium distribution of Cs**
- **Model is most strongly supported for adult males but reasonably well supported for both sexes and all ages**
- **Empirical data for Cs are sufficient to check theoretical approach for both sexes and all ages**

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