Internal Dosimetry
from Radionuclides Intakes

Christian Hurtgen

6 June 2005

Content I

- Dose (some definitions)
- Biokinetics (Compartment model)
- HRTM
- HAT
- Wound model
- Monitoring Internal contamination
- From measurements to Intake

Content II

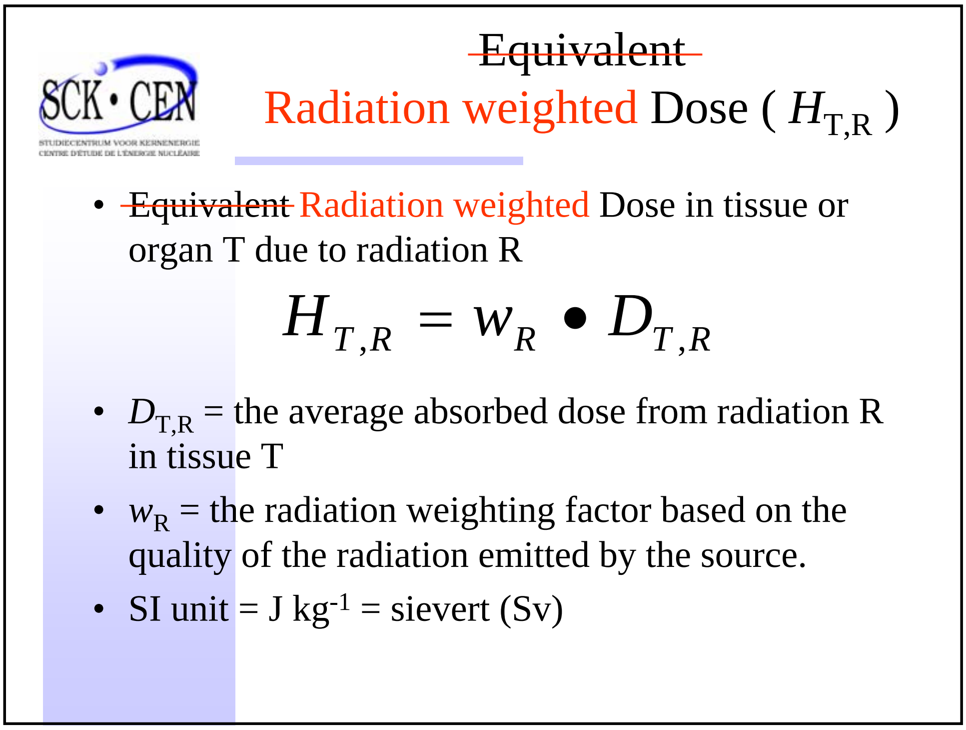
- General Guidelines for the Assessment of Internal Dose from monitoring Data. (project IDEAS)
- Examples
  - Acute Inhalation of ^{60}Co
  - Acute Inhalation of fission products: ^{90}Sr
  - Acute Inhalation of Plutonium

Absorbed Dose

- The physical dose quantity given by

$$D = \frac{d\,\bar{\varepsilon}}{d\,m}$$

- dε = mean energy imparted by ionisation radiation to the matter in a volume element
- dm = the mass of the matter in this volume element
- SI unit is joule per kilogram (J kg^{-1}) = gray (Gy)

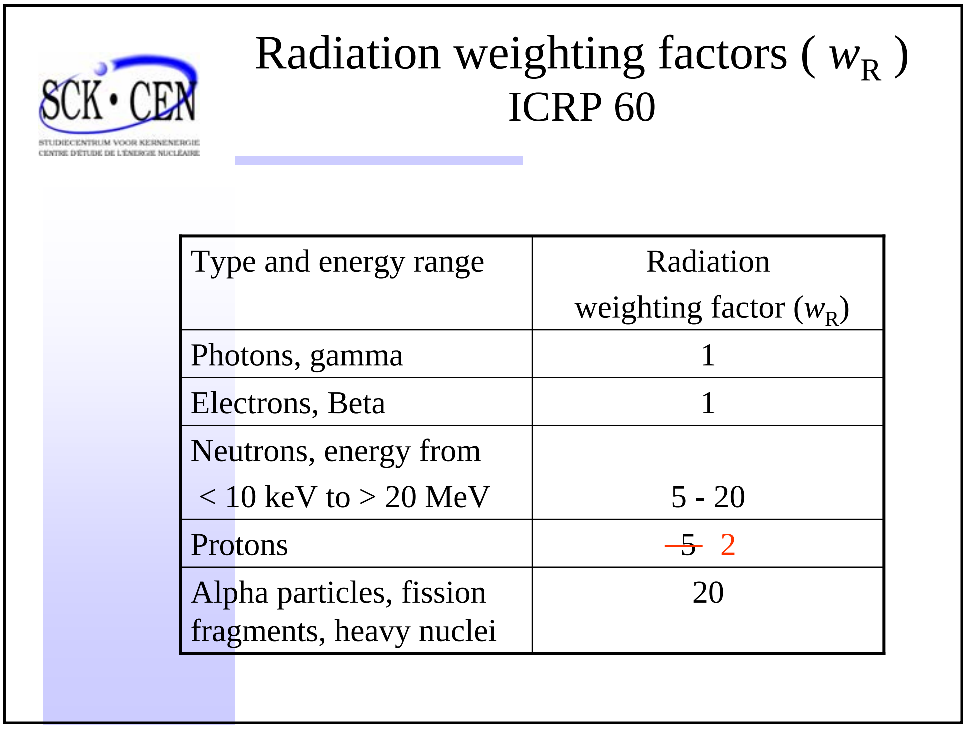


~~Equivalent~~ Radiation weighted Dose ($H_{T,R}$)

- ~~Equivalent~~ Radiation weighted Dose in tissue or organ T due to radiation R

$$H_{T,R} = w_R \bullet D_{T,R}$$

- $D_{T,R}$ = the average absorbed dose from radiation R in tissue T
- w_R = the radiation weighting factor based on the quality of the radiation emitted by the source.
- SI unit = J kg^{-1} = sievert (Sv)



Radiation weighting factors (w_R) ICRP 60

Type and energy range	Radiation weighting factor (w_R)
Photons, gamma	1
Electrons, Beta	1
Neutrons, energy from < 10 keV to > 20 MeV	5 - 20
Protons	~~5~~ 2
Alpha particles, fission fragments, heavy nuclei	20

Total ~~equivalent~~ Radiation weighted Dose (H_T)

- The sum of $H_{T,R}$ over all radiation types

$$H_T = \sum_R H_{T,R}$$

Effective Dose (*E*)

- The sum of the weighted radiation weighted ~~equivalent~~ doses in all tissues and organs of the body.

$$E = \sum_T w_T \bullet H_T$$

- w_T = tissue weighting factor
- H_T = ~~equivalent~~ radiation weighted dose for tissue or organ T

Tissue weighting factor

Organ or Tissue (T)	Tissue weighting factor (w_T)
Gonads	~~0.20~~ 0.05
Bone marrow (red), Colon, Lung, Stomach, Breast	0.12
Bladder, ~~Breast~~, Liver, Oesophagus, Thyroid	0.05
Skin, Bone surface, Brain, Kidney, Salivary glands	0.01
Remainder	~~0.05~~ 0.10

Committed equivalent dose ($H_T(\tau)$)

- The time integral of the equivalent dose rate in a particular tissue or organ that will be received by an individual following intake of radioactive material into the body, where t is the integration time in years following the intake.

$$H_T(\tau) = \int_{t_0}^{t_0+\tau} H_T(t)\,dt$$

- For adults, the integration time is 50 year

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Committed equivalent dose ($H_T(50)$)

$$H_T(50) = \sum_S U_S(50) \bullet SEE(T \leftarrow S)$$

- $U_S(50)$ = number of nuclear transformations (Bq s) in 50 y in source S following acute intake
- $SEE(T \leftarrow S)$ = Specific Effective Energy, equivalent dose in T per transformation in S expressed as (Sv(Bq s)$^{-1}$)

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Specific Effective Energy

$$SEE(T \leftarrow S) = \sum_R \frac{Y_R\, E_R\, w_R\, AF(T \leftarrow S)_R}{m_T}$$

- Y_R = yield of radiation R per nuclear transformation
- E_R = energy of radiation R (J)
- w_R = radiation weighting factor for radiation R
- $AF(T \leftarrow S)_R$ = absorbed fraction in T per transformation in S for radiation R
- m_T = mass of the target tissue, T (kg)

Committed Effective Dose

- The sum of the product of the committed equivalent doses in organs or tissues and the appropriate organ or tissues weighing factor (w_T) where τ is the integration time in time following the intake.
- $$E(\tau) = \sum_T w_T \bullet H_T(\tau)$$
- For adults, the integration time is 50 year

Dose coefficient

- $h_T(\tau)$ = committed tissue equivalent dose per unit acute intake
- $e(\tau)$ = committed effective dose per unit acute intake
- Where τ is the time period in years over which the dose is calculated
- Example : ^{239}Pu Type S, $e(50) = 8.3\ 10^{-6}$ Sv Bq^{-1}

Dose limits

- The occupational exposure of any worker shall be so controlled that the following limits be not exceeded:
  - an effective dose of 20 mSv per year averaged over five consecutive years;
  - an effective dose of 50 mSv in any single year;
  - an equivalent dose to the lens of the eye of 150 mSv in a year;
  - an equivalent dose to the extremities (hands and feet) or the skin of 500 mSv in a year.

Biokinetics
Introduction to compartment models

Biokinetic behaviour

- Route of intake (ingestion, inhalation, injection …)
- Accumulation of activity in specific organs
- Retention of radionuclides in those organs
- Transport of radionuclides between organs
- Removal, by excretion and radioactive decay, of activity from the body

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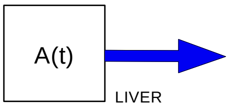
Transport out of a compartment



$$A(t) = A_0\, e^{-\alpha t}$$

Uptake

- Material which is absorbed from the respiratory tract or the gastro-intestinal tract first enter the blood or lymph (body fluids) and is then available for uptake by organs.

Compartment model for uptake

- From the transfer compartment with half-time 6 hours (for most radionuclides)
- 30 % to Organ 1, 70 % to Organ 2

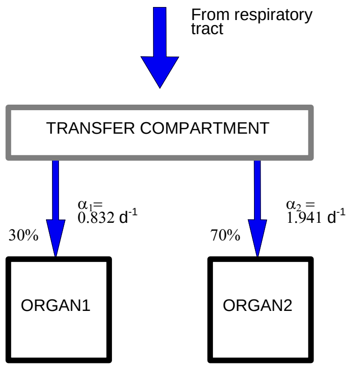
$$\frac{\alpha_1}{\alpha_2} = \frac{3}{7}$$

$$\alpha_1 + \alpha_2 = \frac{\ln(2)}{0.25} \quad (d^{-1})$$

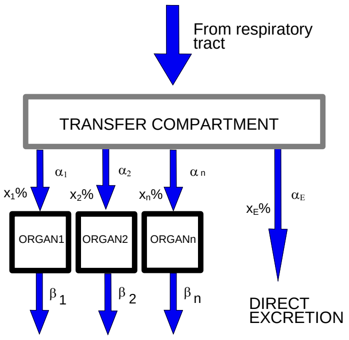
$$\alpha_1 = 0.832 \quad (d^{-1})$$

$$\alpha_2 = 1.941 \quad (d^{-1})$$

Compartment model for uptake

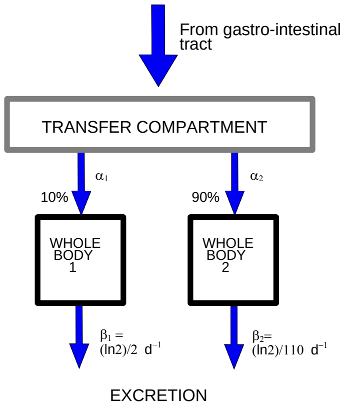


Compartment model for retention



$$R(t) = \frac{A(t)}{A_0} = e^{-\alpha t}$$

Model for caesium retention



From gastro-intestinal tract

TRANSFER COMPARTMENT

α_1 10%

α_2 90%

WHOLE BODY 1

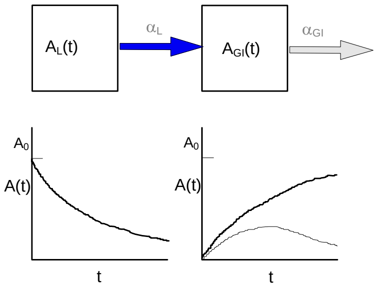
WHOLE BODY 2

$\beta_1 = (\ln 2)/2\ d^{-1}$

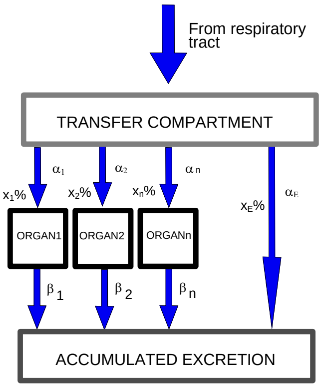
$\beta_2 = (\ln 2)/110\ d^{-1}$

EXCRETION

Model for transport between organs



Model for excretion



From respiratory tract

TRANSFER COMPARTMENT

α_1 α_2 α_n α_E

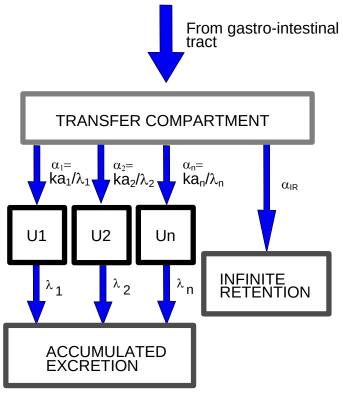
x_1% x_2% x_n% x_E%

ORGAN1 ORGAN2 ORGANn

β_1 β_2 β_n

ACCUMULATED EXCRETION

Model for an excretion function



From gastro-intestinal tract

TRANSFER COMPARTMENT

α_1= ka_1/λ_1 α_2= ka_2/λ_2 α_n= ka_n/λ_n α_{IR}

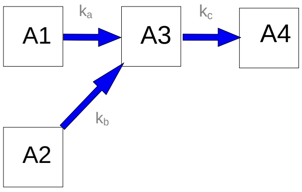
U1 U2 Un

INFINITE RETENTION

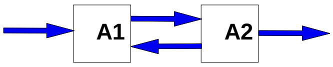
λ_1 λ_2 λ_n

ACCUMULATED EXCRETION

Multiple path compartment model


A1
k_a
A3
k_c
A4
k_b
A2

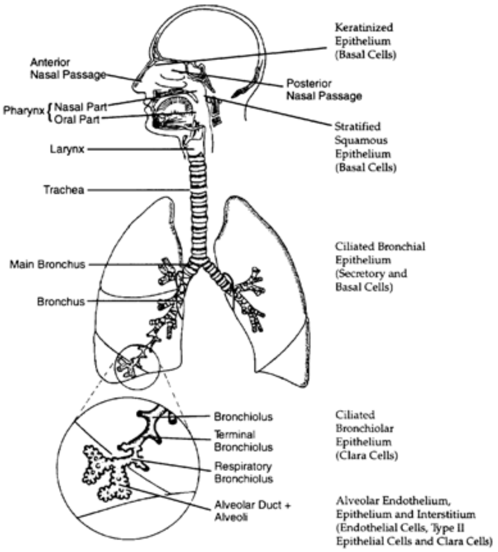
Recycling compartment model


A1
A2

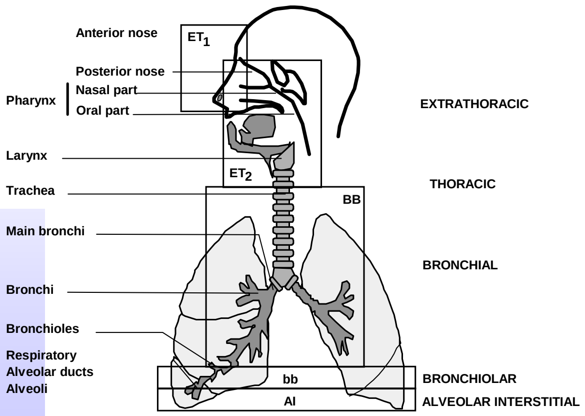
Human Respiratory Tract Model

ICRP Publication 66

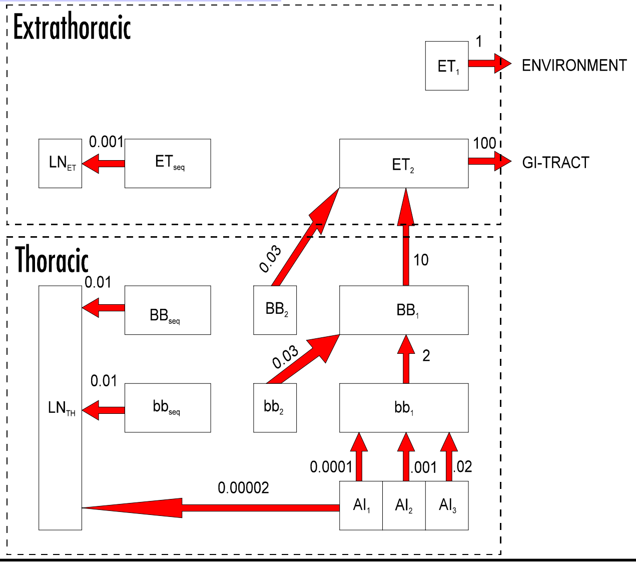
Human Respiratory Tract



Human Respiratory Tract



Particle transport in the human respiratory tract



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Deposition (I)

- Deposition model evaluates fractional deposition of the aerosol in each region for all particle sizes of practical interest (0.0006 – 100 µm)
- Aerosols:
  Activity Median Aerodynamic Diameter = AMAD
  - Lognormal particle size distribution
  - Geometric standard deviation (σ_g) function of the median particle size
    - = 1.0 at 0.0006 µm
    - = 2.5 at 1 µm and above

Deposition (II)

- Exposure : Occupational or environmental
- Male or Female, adult or child or infant or baby
- Activities
  - Sleep
  - Sitting
  - Light exercises
  - Heavy exercises
- Nose and/or mouth breather

Deposition (III)

- Standard worker (ventilation rate = 1.200 m³/h)

➢ Sleep	0 %
➢ Sitting	31.3 %
➢ Light exercises	68.8 %
➢ Heavy exercises	0 %

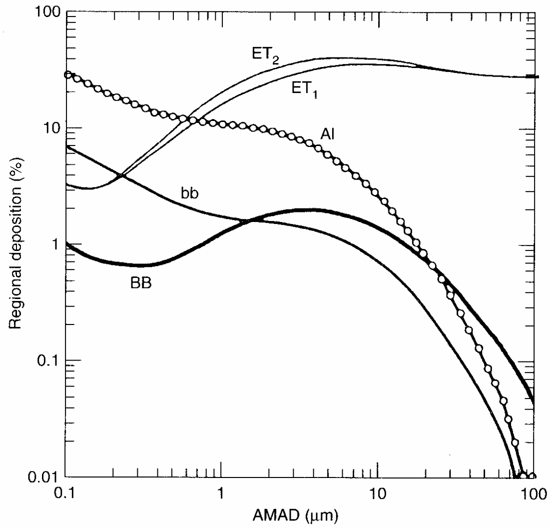
- Heavy worker (ventilation rate = 1.688 m³/h)

➢ Sleep	0 %
➢ Sitting	0 %
➢ Light exercises	87.5 %
➢ Heavy exercises	12.5 %

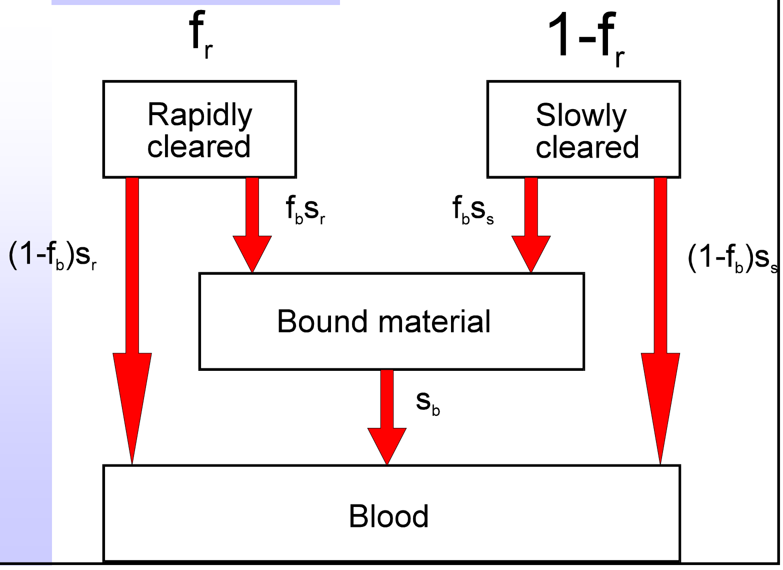
Deposition of inhaled aerosols

Region	AMAD 1 µm	AMAD 5 µm
ET_1	16.5	33.9
ET_2	21.1	39.9
BB	1.24	1.78
bb	1.65	1.10
AI	10.7	5.3
Total	51.2	82.0

Regional deposition % in function of AMAD



Compartmental representation of absorption to blood (I)



f_r

$1-f_r$

Rapidly cleared

Slowly cleared

$f_b s_r$

$f_b s_s$

$(1-f_b)s_r$

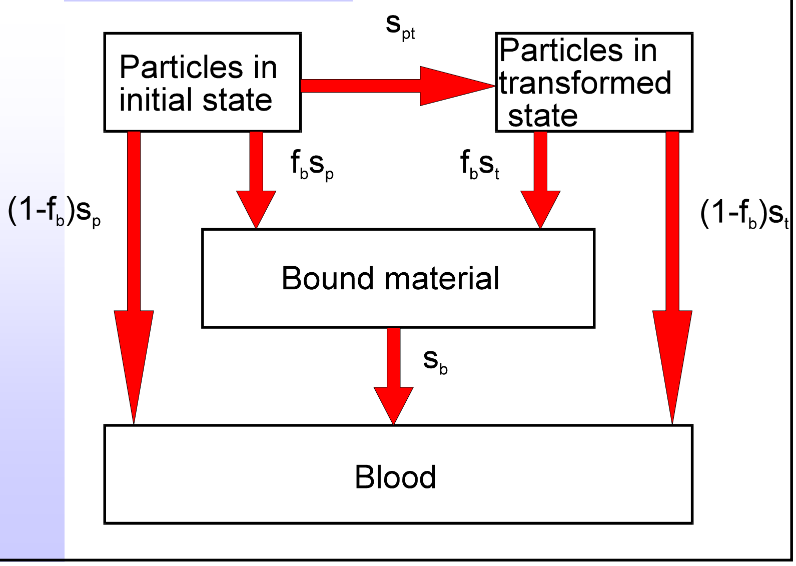
$(1-f_b)s_s$

Bound material

s_b

Blood

Compartmental representation of absorption to blood (II)



s_{pt}

Particles in initial state

Particles in transformed state

$f_b s_p$

$f_b s_t$

$(1-f_b)s_p$

$(1-f_b)s_t$

Bound material

s_b

Blood

Absorption rate

- If known used absorption rate for specific coumpound
- Default values for three material
  - Type F (fast)
  - Type M (moderate)
  - Type S (slow)

Type F (fast)

- 100 % absorbed with a half-time of 10 minutes.
- There is rapid absorption of almost all material deposited in BB, bb, and AI,
- and 50% of material deposited in ET_2 is clear to the GI tract by particle transport.
- Example: all compounds of Cs and I

Type M (moderate)

- 10% aborbed with a half-life of 10 minutes and 90% with a half-life of 140 d.
- There is rapid absorption of about 10% of the deposit in BB and bb; and 5% of material deposited in ET2.
- About 70% of the deposit in AI eventually reaches the body fluids.

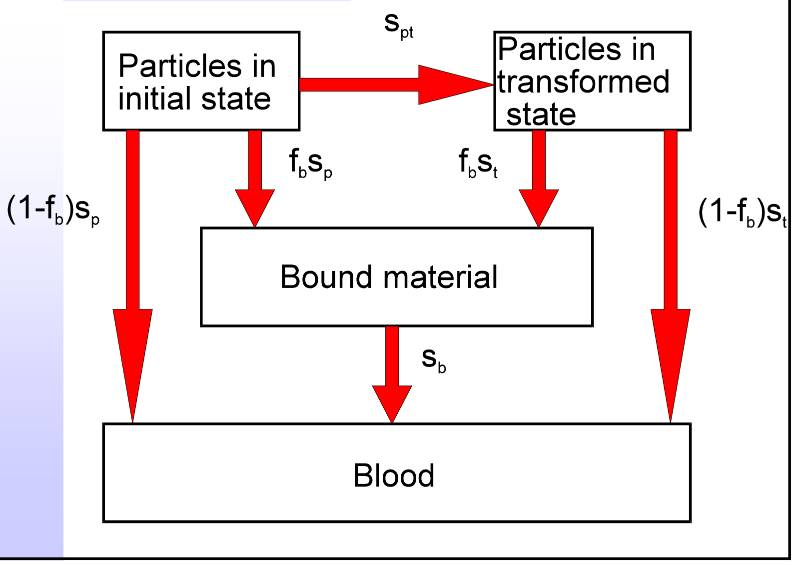
- Example: all compounds of Ra and Am

Type S (slow)

- 0.1% absorbed with a half-life of 10 minutes and 99.9% with a half-life of 7000 d.
- There is little absorption from ET, BB, or bb;
- about 10% of the deposit in AI eventually reaches the body fluids.

- Examples: all insoluble compounds of U and Pu

Compartmental representation of absorption to blood (II)



Particles in initial state

s_{pt}

Particles in transformed state

$f_b s_p$

$f_b s_t$

$(1-f_b)s_p$

$(1-f_b)s_t$

Bound material

s_b

Blood

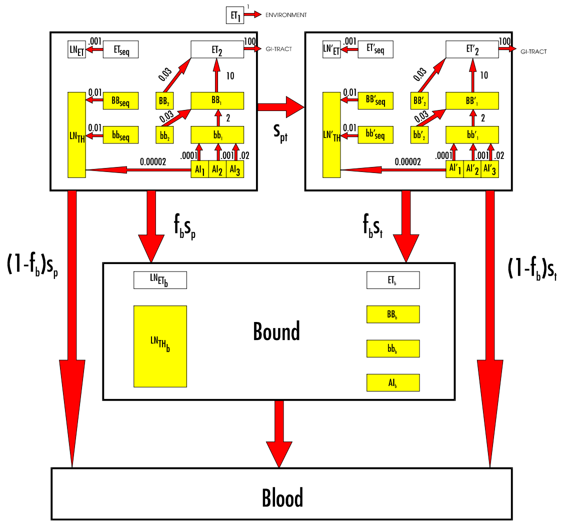
Default absorption parameters

Model parameters (d^{-1})	Type F	Type M	Type S
S_p	100	10	0.1
S_{pt}	0	90	100
S_t	-	0.005	0.0001

Absorption parameters for gas and vapour

- Absorptions Type F or V (Very rapid absorption)
- Class SR-0: Insoluble and non-reactive
  negligible deposition
  - ➢ ^{41}Ar, ^{85}Kr, ^{133}Xe
- Class SR-1: Soluble or reactive
  deposition may occur
  - ➢ Tritium (g), ^{14}CO, ^{131}I vapour, ^{195}Hg vapour
- Class SR-2: Highly soluble or reactive
  complete deposition in ET_2
  for calculation = directly injected in blood
  - ➢ ^{3}H organic compounds and tritiated water

Full compartmental representation of absorption to blood



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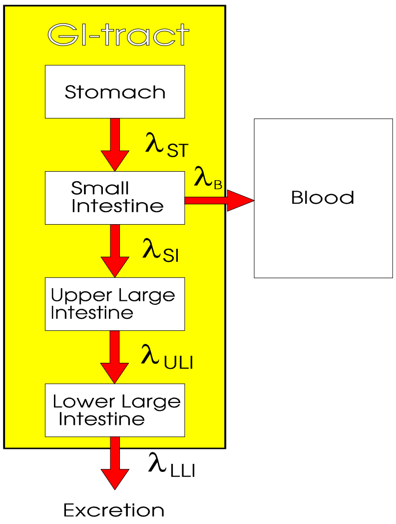
Gastro-Intestinal Tract Model

ICRP Publication 30

GI Tract (ICRP 30)


GI-tract
Stomach
λ_{ST}
Small Intestine
λ_B
Blood
λ_{SI}
Upper Large Intestine
λ_{ULI}
Lower Large Intestine
λ_{LLI}
Excretion

GI Tract compartments

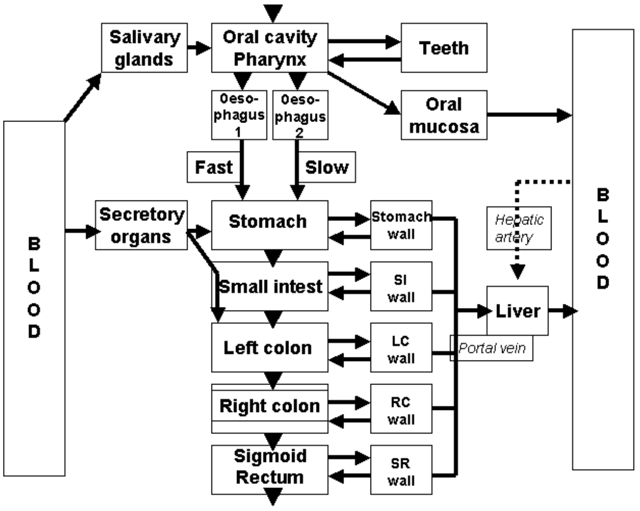
- Stomach
  - Mean residence time = 1 hour
- Small Intestine
  - Mean residence time = 4 hours
  - Absorption to blood
  - Fraction of material reaching body fluids
  - SI is alkaline
- Upper large intestine
  - Mean residence time = 13 hours
- Lower large intestine
  - Mean residence time = 24 hours

$$f_1 = \frac{\lambda_B}{\lambda_B + \lambda_{SI}}$$

Human Alimentary Tract Model

ICRP Publication ?? 2005

HAT
Human Alimentary Tract



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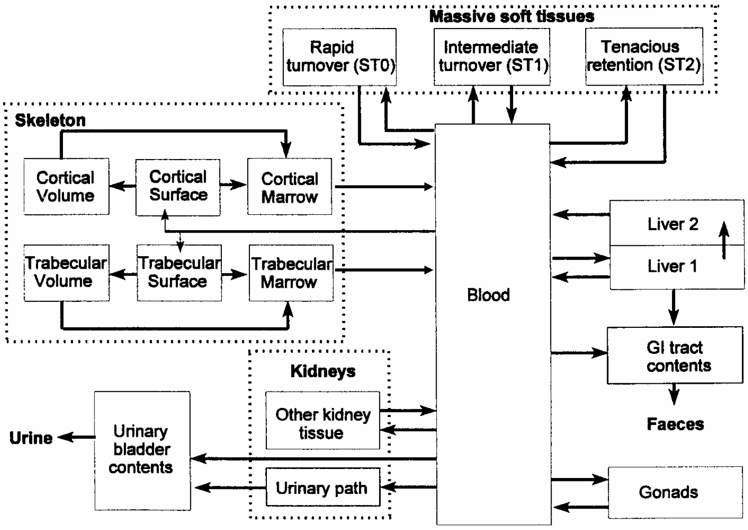
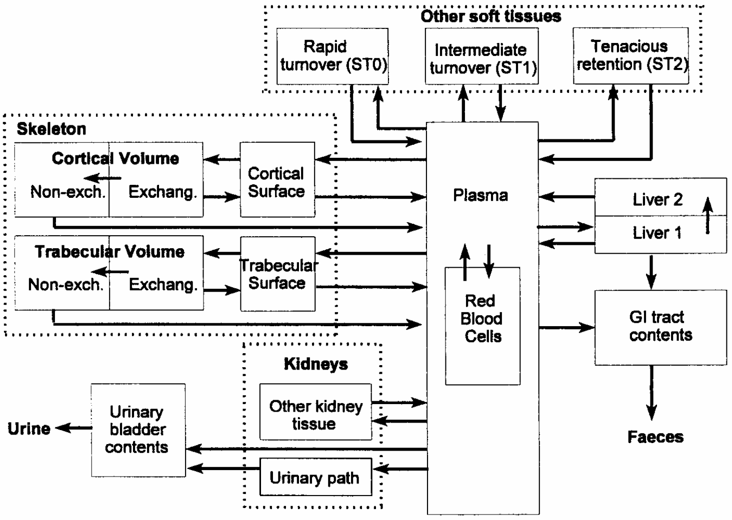
Some biokinetic models

Biokinetic model for the Actinides
ICRP 67

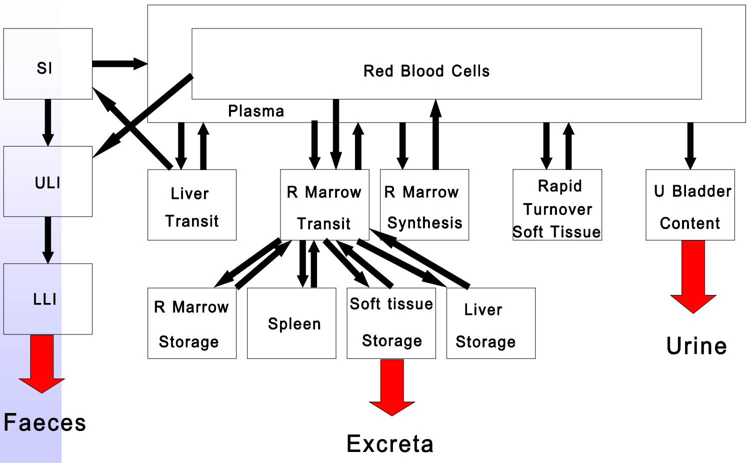


Biokinetic model for Alkaline earth, Pb & U
ICRP 67



Biokinetic model for Iron

ICRP 69



SI

ULI

LLI

Faeces

Red Blood Cells

Plasma

Liver Transit

R Marrow Transit

R Marrow Synthesis

Rapid Turnover Soft Tissue

U Bladder Content

Urine

R Marrow Storage

Spleen

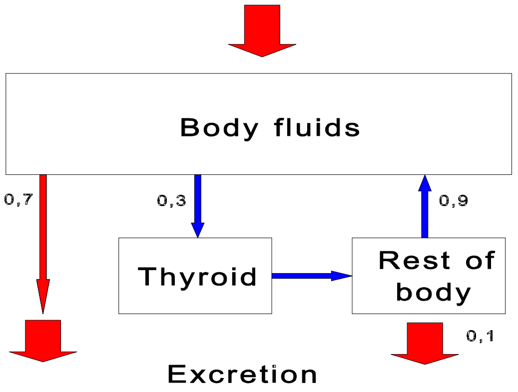
Soft tissue Storage

Liver Storage

Excreta

Biokinetic model for Iodine

ICRP 30



Body fluids

0,7

0,3

0,9

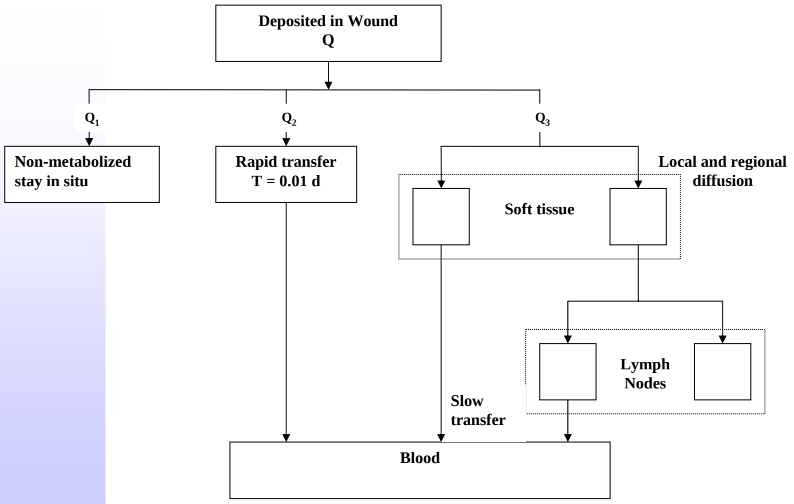
Thyroid

Rest of body

0,1

Excretion

Wound model (I)



Deposited in Wound
Q

Q_1

Q_2

Q_3

Non-metabolized stay in situ

Rapid transfer
T = 0.01 d

Local and regional diffusion

Soft tissue

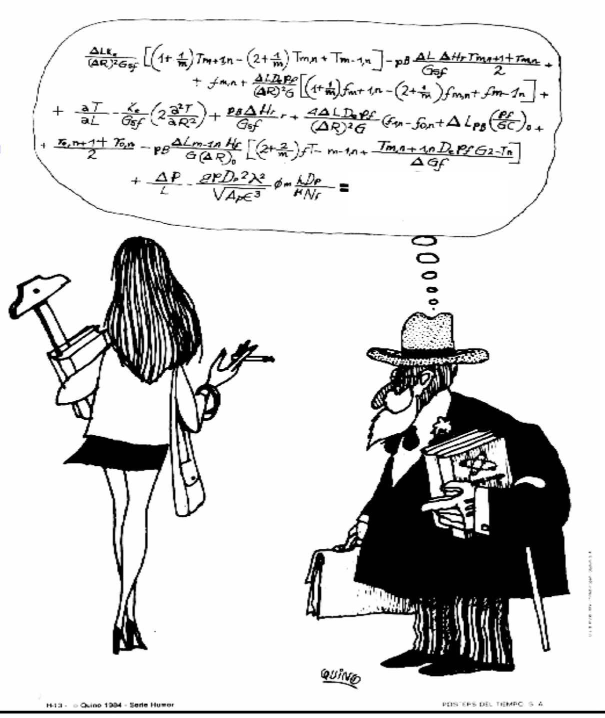
Lymph Nodes

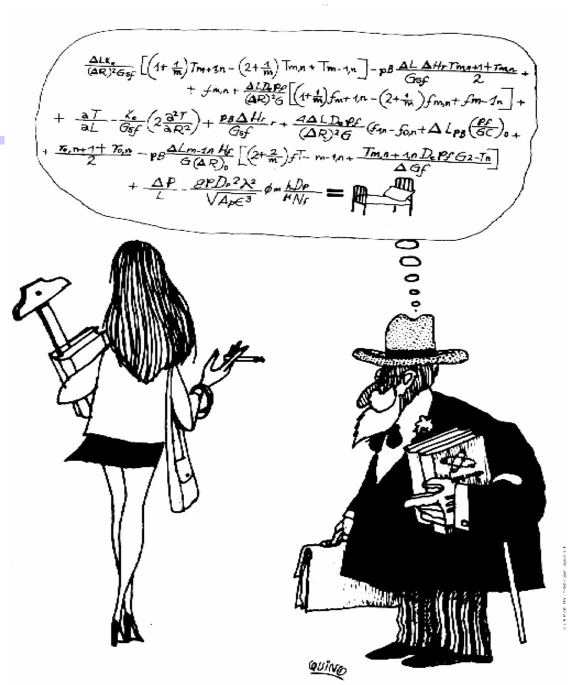
Slow transfer

Blood

Wound model (II)

- Q_1 = metabolically inert, it remains where it was deposited
- Q_2 = enters the bloodstream quickly via the vascular breaches
- Q_3 = diffuse slowly in the soft tissue (conjunctive tissue, muscles ..) from where it is finally transferred to the blood, either directly or indirectly via the lymph nodes.





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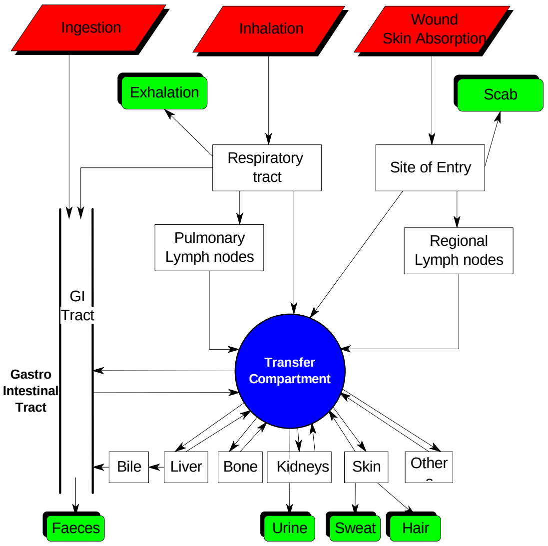
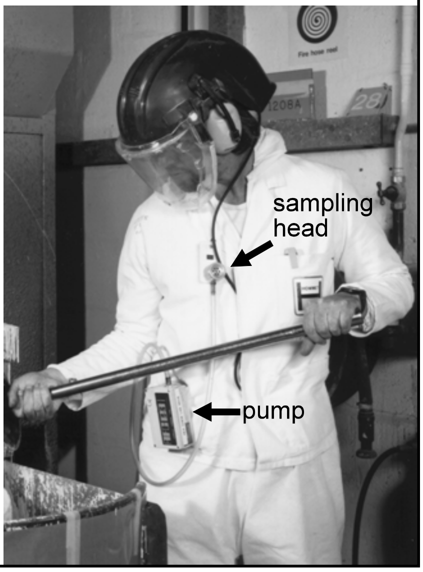
Monitoring Internal contamination

Routes of entry



Monitoring type (I)

- Air sampling
  - ➢ Static air sampler
    - ♣localise
  - ➢ Portable air sampler
  - ➢ Personal air sampler PAS
    - ♣Low sampling rate
    - ♣Trigger biological monitoring



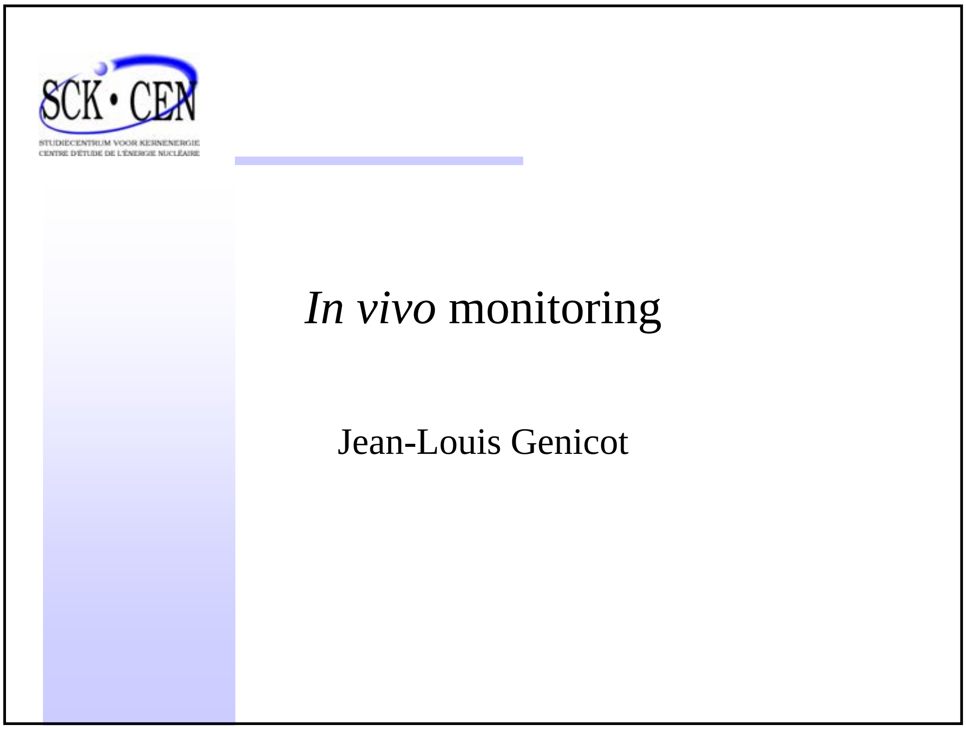
Monitoring type (II)

- Direct measurements - *in vivo* monitoring
    - ➢ Possible when the incorporated radionuclide emit penetrating radiation of sufficient energy and yield to be detectable outside the body (X ray or gamma photon)

- Indirect measurements – excreta measurements
    - ➢ organs & tissues concerned are not sampled
    - ➢ Knowledge of relationships between
    - ◆ bioassay samples
    - ◆ organ burdens of interest

Monitoring type

- Direct measurements
    - ➢ Whole body counting
    - ➢ Thyroid measurement
    - ➢ Lung counting
    - ➢ Wound counting
- Indirect measurements
    - ➢ Nose-blow
    - ➢ Urine
    - ➢ Faeces
    - ➢ Blood, hair, sweat, saliva …



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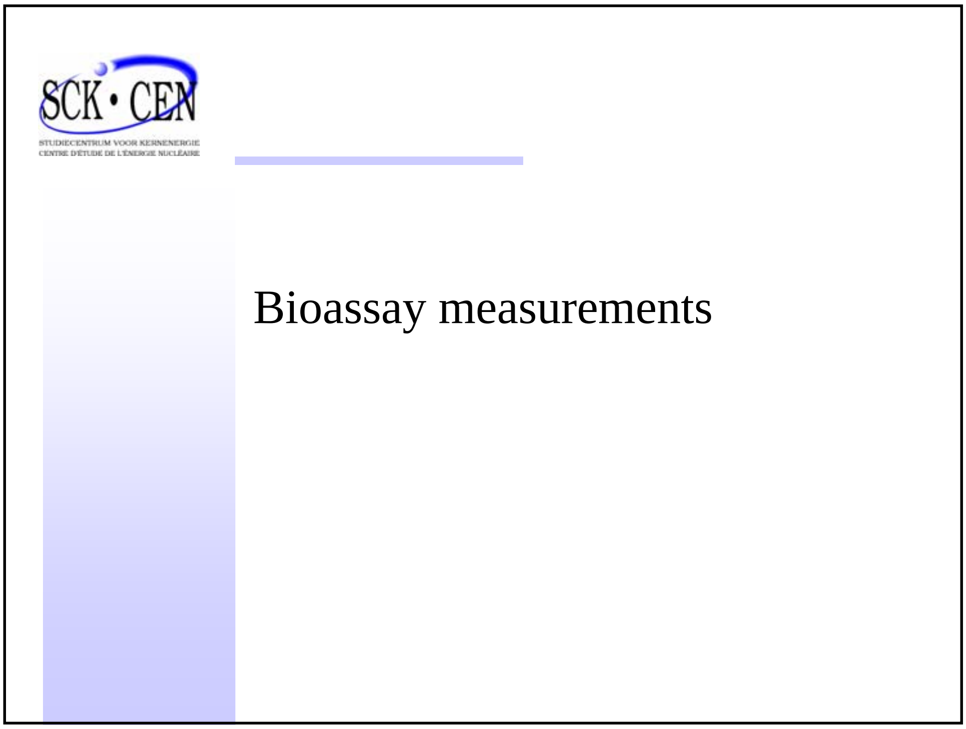
In vivo monitoring

Jean-Louis Genicot



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Bioassay measurements

Types of Bioassay samples (I)

- Chemical element involved
- Physical & chemical form
- Magnitude of the internal deposition
- Biological & Physical half-lives of radionuclides involved
- Elapsed time since the deposition
- Sensitivity of analytical method

Types of Bioassay samples (II)

- Urine
  - most used
  - 24 hours sampling
  - at SCK-CEN 3 consecutive days (36h)
  - ^3H_2O: a voiding
  - repetitive sampling

Types of Bioassay samples (III)

- Faeces
  - not often used for routine
  - accidental inhalation
- Nose-blow, Nose-swap
  - α emitters
  - triggers complementary analysis

Types of Bioassay samples (IV)

- blood
- sweat
- saliva
- hair
- teeth
- breath
  - $^{14}CO_2$, $^{3}H_2O$, ^{222}Rn, ^{220}Rn
- tissue
  - remove for medical purpose, post mortem

Radiochemical Procedure (I)

- Sample preparation & Pre-concentration
- Urine
  - wet ashing
  - co-precipitation
- Faeces
  - ashing
  - dissolution
  - HF treatment

Radiochemical Procedure (II)

- Chemical separation
  - ion-exchange resin
  - solvent extraction
  - combination
  - …

Radiochemical Procedure (III)

- Source preparation
- α emitters
  - direct evaporation
  - co-precipitation with LnF
  - Electro-deposition
- ß emitters
  - precipitation & filtration of insoluble salt
  - $MgNH_4PO_4$, $SrCO_3$, $Y_2(C_2O_4)_3$, PdI_2

Measuring Techniques

- α spectrometry
- ß counting
- Liquid Scintillation Counting - LSC
- γ spectrometry
- Fluorimetry
- Neutron Activation Analysis - NAA
- Delay Neutron Assay - DNA
- Mass spectrometry - ICPMS, SIMS
- Fission Track Analysis

α spectrometry

- Th, U, Pu, Am, Cm...
- radiochemical procedure
- source preparation
  - co-precipitation LnF
  - electro-deposition
- Yield determinant
  - ^{229}Th, ^{232}U, ^{242}Pu, ^{243}Am
- MDA = 0.1 mBq/l

ß Counting

- strong ß emitters
  - ^{32}P, ^{89}Sr, ^{90}Sr, ^{90}Y, ^{131}I
- radiochemical procedure
- source: insoluble salt
- gas proportional counter - low background
- MDA = 0.08 Bq/l

  for ^{90}Sr, urine sample of 250cc

Liquid Scintillation Counting LSC

- weak energy ß emitters - ^{3}H, ^{14}C, ^{63}Ni, ^{241}Pu
  - direct measurement
  - use of internal standard
  - MDA = 5 Bq/l for ^{3}H in urine (Vol. = 9 cc)
- pure ß emitters - ^{32}P, ^{89}Sr, ^{90}Sr
  - radiochemical procedure
  - MDA = 0.12 Bq/l (Vol. = 600 cc)

γ Spectrometry

- direct measurement
- 250 cc sample
- MDA = 0.2 Bq/l
- *in-vivo* measurement
  - Whole-body
  - Thyroid

SCK•CEN
STUDIECENTRUM VOOR KERNENERGIE
CENTRE D'ÉTUDE DE L'ÉNERGIE NUCLÉAIRE

From measurements to Intake

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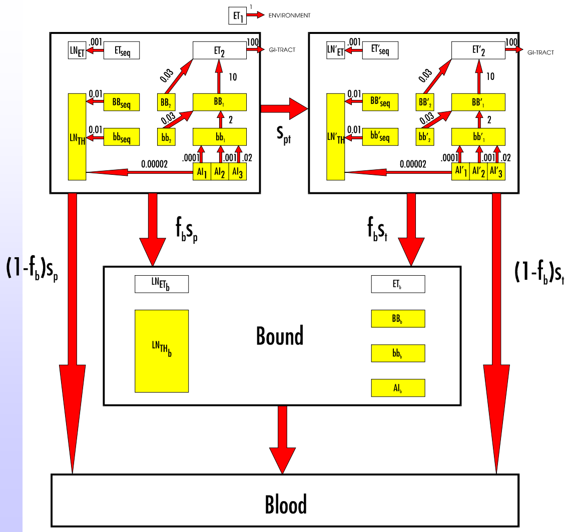
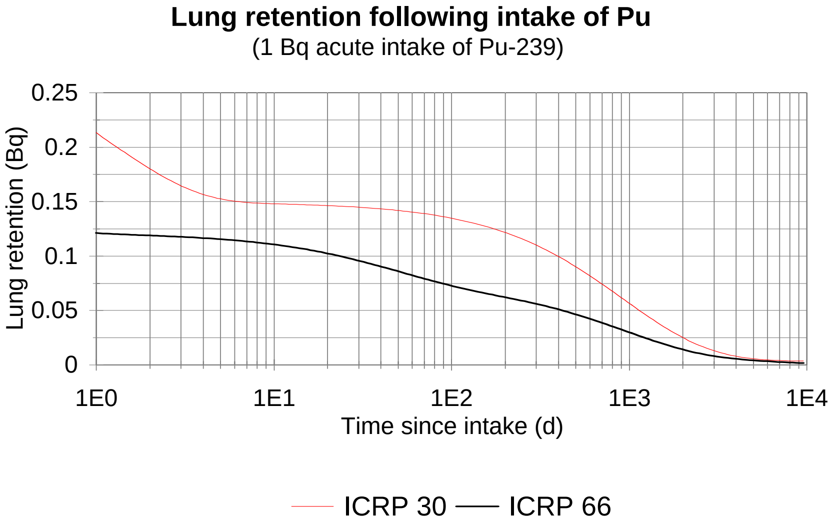
Lung Model



Lung Retention

- Calculate the retention of a radionuclide at times after inhalation
- Needed
  - ➢ AMAD
  - ➢ Solubility class
  - ➢ Lung Model (new) from ICRP 66
- Σ all the compartments
- Then…

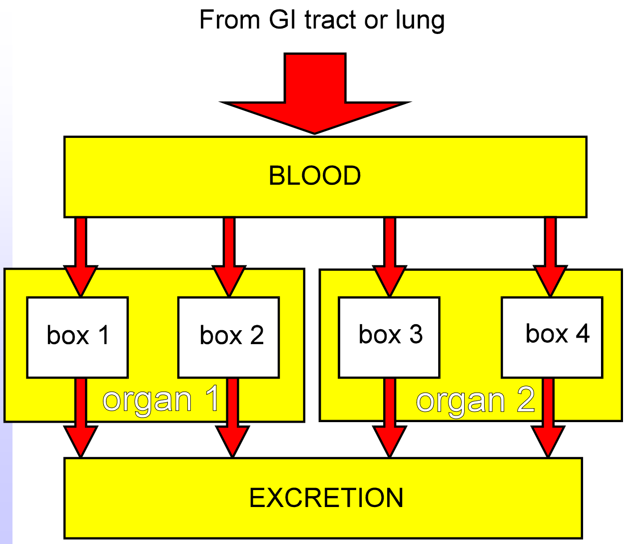
Lung Retention ^{239}Pu Class Y acute inhalation 1 µm AMAD



Whole body retention

- Total amount of activity in the body
- Includes activity retained
  - Respiratory tract
  - Alimentary tract (f_1)
  - Blood
  - Body organs
- Activity in body organs (excluding HAT & HRT) = **systemic activity**

Simple biokinetic models



From GI tract or lung

BLOOD

box 1

box 2

box 3

box 4

organ 1

organ 2

EXCRETION

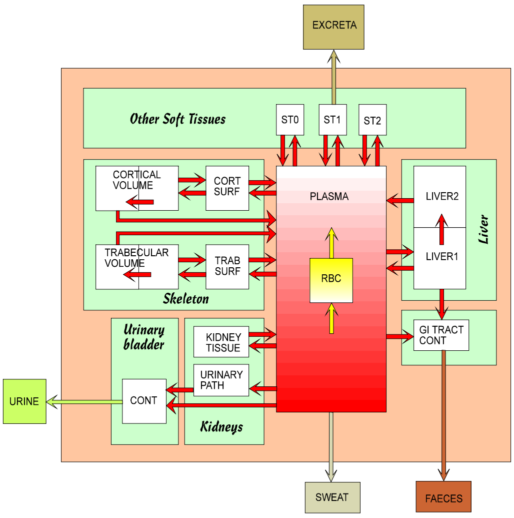
Systemic retention function

- Organ or tissue represented by a sum of exponential terms
- Whole body = sum of each organ = sum of exponential terms

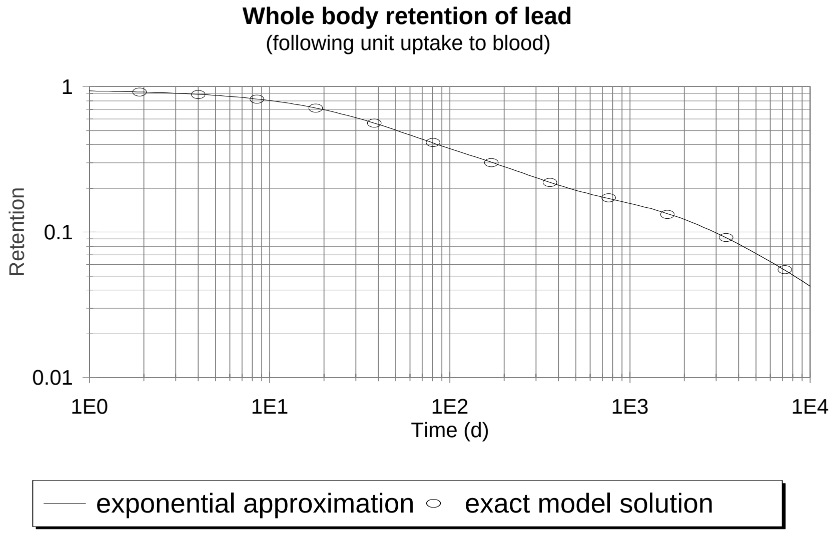
$$R(t) = \sum_{i=1}^{5} a_i \, e^{-\lambda_i t}$$

- Systemic retention function.
  In ICRP Publication 54 given for 22 elements

Lead biokinetic model
ICRP Publication 67



Comparison of ICRP 67 model with exponential approximation

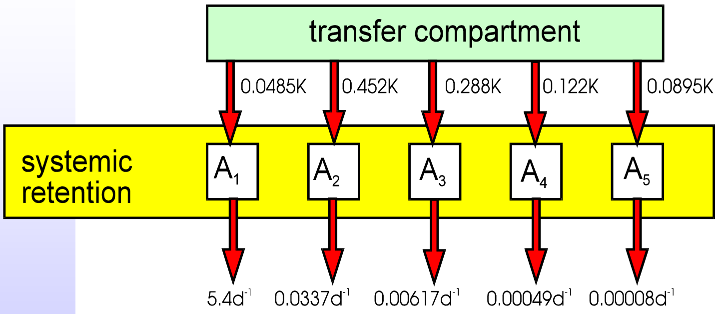

Whole body retention of lead

(following unit uptake to blood)

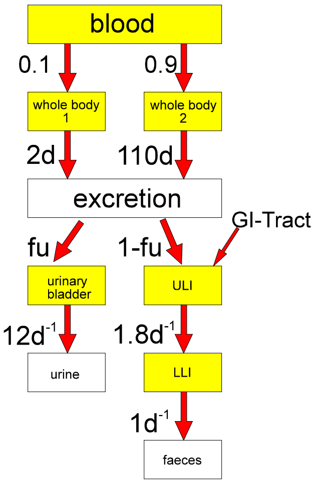
Lead systemic retention function

$$R(t) = 0.0485e^{-5.4t} + 0.452e^{-0.0337t} + 0.122e^{-0.000491t} + 0.0895e^{-0.0000767t} + 0.288e^{-0.00617t}$$

Lead compartment system



Systemic retention of Caesium



Urinary excretion (ICRP 30)

- Retention function R(t) = sum of exponential
- Instantaneous excretion rate obtained by differentiation of systemic retention function
- f_u = fraction of excreted activity to urine

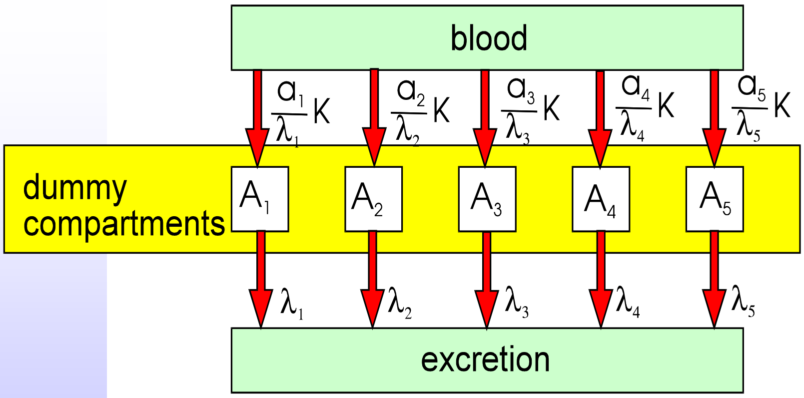
$$\frac{dU}{dt} = -\, f_u \, \frac{dR(t)}{dt} = f_u \ \lambda_i \sum_{i=1}^{5} a_i \, e^{-\lambda_i t}$$

Caesium excretion

- Caesium retention $R(t) = 0.1 e^{-\frac{\ln(2)t}{2}} + 0.9 e^{-\frac{\ln(2)t}{110}}$
- f_u = 80 %
- Urinary excretion

$$\frac{dU}{dt} = 0.08 \, \frac{\ln(2)}{2} \, e^{-\frac{\ln(2)t}{2}} + 0.72 \frac{\ln(2)}{110} e^{-\frac{\ln(2)t}{110}}$$

Excretion compartmental representation



blood

$\frac{a_1}{\lambda_1}K$ $\frac{a_2}{\lambda_2}K$ $\frac{a_3}{\lambda_3}K$ $\frac{a_4}{\lambda_4}K$ $\frac{a_5}{\lambda_5}K$

dummy compartments

A_1 A_2 A_3 A_4 A_5

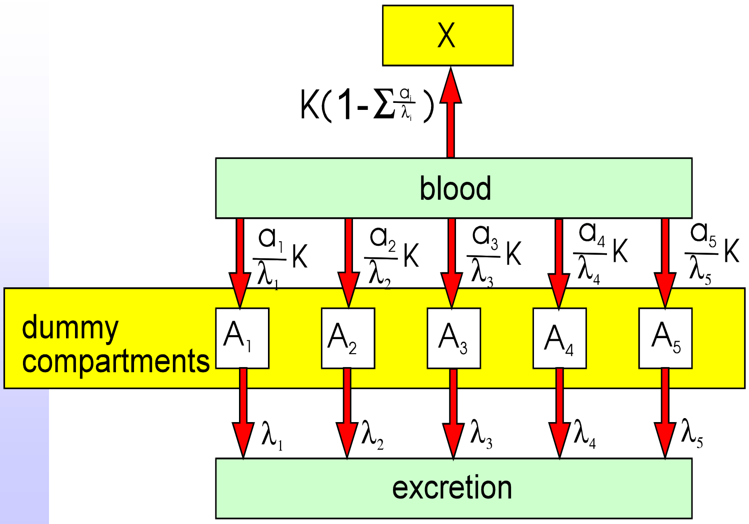
λ_1 λ_2 λ_3 λ_4 λ_5

excretion

Excretion compartmental representation (II)

- K is very fast
- Dummy compartments start with a_i/λ_i amounts
- Instantaneous excretion rate = sum of exponential terms $a_i \exp(-\lambda_i t)$
- Integration, total amount excreted at $t=\infty$, $\Sigma(a_i/\lambda_i)$
- If all material in blood is excreted, $\Sigma(a_i/\lambda_i)=1$
- If material goes to tissue or organ indefinitely retained
  excreted via a different route
- => an other compartment where $[1- \Sigma(a_i/\lambda_i)]$ not available for excretion

Excretion compartmental representation (III)



X

$K(1-\Sigma\frac{a_i}{\lambda_i})$

blood

$\frac{a_1}{\lambda_1}K$ $\frac{a_2}{\lambda_2}K$ $\frac{a_3}{\lambda_3}K$ $\frac{a_4}{\lambda_4}K$ $\frac{a_5}{\lambda_5}K$

dummy compartments

A_1 A_2 A_3 A_4 A_5

λ_1 λ_2 λ_3 λ_4 λ_5

excretion

Faecal excretion

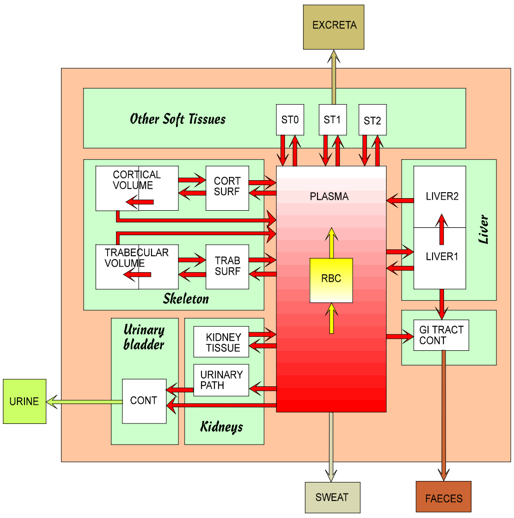
- Faecal excretion comprises 2 components
  - ➢ Activity cleared from the lungs by mechanical transport through the HAT
  - ➢ Activity in blood extracted by the liver = systemic faecal excretion
- Caesium example: systemic faecal excretion

$$\frac{dF}{dt} = 0.02\,\frac{\ln(2)}{2}\,e^{-\frac{\ln(2)t}{2}} + 0.18\,\frac{\ln(2)}{110}\,e^{-\frac{\ln(2)t}{110}}$$

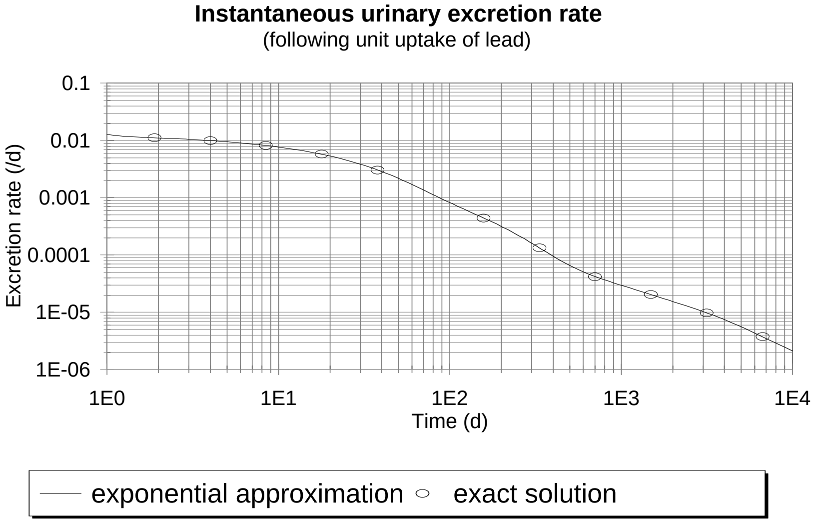
Urinary excretion rates

- By differentiation of the retention function
- Not simple with the new models
- Urinary excretion is explicitly in the model
- Calculation of instantaneous urinary excretion rate by:
  - Solving the amount in the urine compartment at times t and t-δt and dividing by (t-δt) = instantaneous rate as δt tends to 0
  - Solving for the amount in the urinary bladder contents (CONT) at time t and multiplying by the rate constant from CONT to URINE

Lead biokinetic model
ICRP Publication 67



Comparison of instantaneous urinary excretion of lead

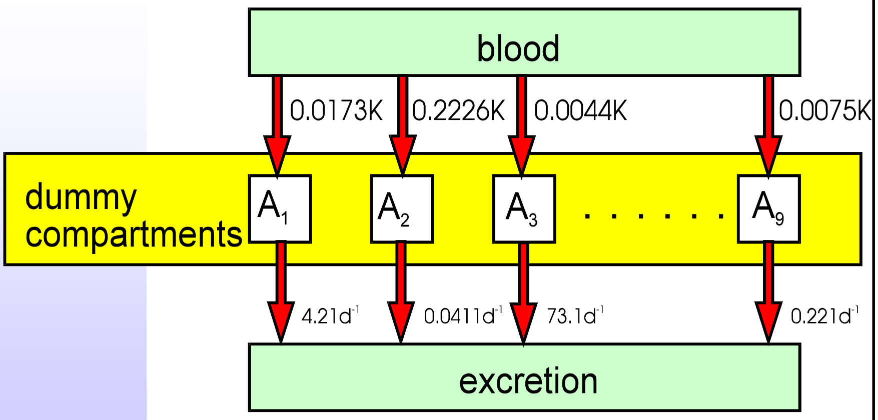

Instantaneous urinary excretion rate
(following unit uptake of lead)

Lead urinary excretion

- Calculate this for 1 to 10^4 days
- Can fitted a function with sum of exponential
- At t=0, CONT = 0 => $\Sigma a_i = 0$

$$\frac{dU}{dt} = 0.07264e^{-4.21t} + 0.00915e^{-0.0411t} - 0.327e^{-73.7t} + 0.242e^{-11t} + 0.00145e^{-0.00901t} + 0.000026e^{-0.000431t} + 0.00000378e^{-0.0000761t} + 0.0000707e^{-0.00205t} + 0.00166e^{-0.221t}$$

Instantaneous urinary excretion rate of lead



blood

$0.0173K$ $0.2226K$ $0.0044K$ $0.0075K$

dummy compartments

A_1 A_2 A_3 . . . . A_9

$4.21d^{-1}$ $0.0411d^{-1}$ $73.1d^{-1}$ $0.221d^{-1}$

excretion

Daily urinary excretion rates

- Can be calculated by either:
  - Integrating the instantaneous excretion rate function from t-1 to t
  - Calculating the amount in the excretion compartment at times t-1 and t and subtracting one from he other
- To calculate daily excretion rates following inhalation (or ingestion) the respiratory tract and GI tract must be added to the compartment representation and the second calculation option used

Systemic instantaneous faecal excretion rate

$$\frac{dF}{dt} = 0.06073\,e^{-1.23t} - 0.613\,e^{-1.26t} + 0.0000262\,e^{-0.00154t} + 0.00457\,e^{-0.0277t} + 0.0000139\,e^{-0.000412t} + 0.00000216\,e^{-0.000075t} + 0.000595\,e^{-0.00732t} + 0.00046\,e^{-44.4t}$$

- Non-systemic component of faecal excretion from material in the GI tract must be added when convoluting with respiratory and GI tract

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Suggestion

- Thank you and …
- What about filling up
the Human Alimentary tract.

- ***“Bon appétit”***