The issue of dosimetry and uncertainties in the context of internal emitters

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INSTITUT DE RADIOPROTECTION ET DE SÛRETÉ NUCLÉAIRE

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EU scientific seminar « Issues with internal emitters »

Luxembourg, 23rd November 2010

INTERNAL DOSIMETRY

environmental measurement c

i = c x b x t

i = m / M intake

biokinetic model M

distribution in tissues

elimination

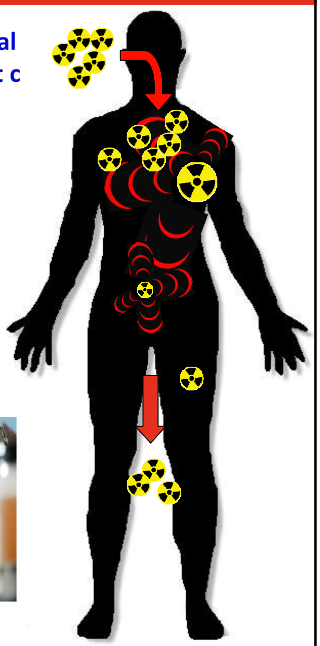
deposition of energy

dosimetric model e

dose

d = i x e

in vivo / in vitro measurement m



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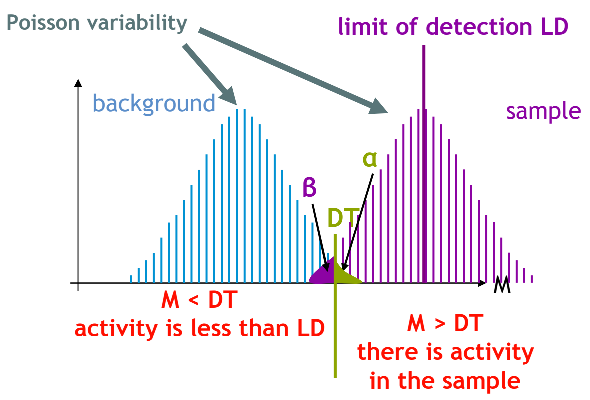
MEASUREMENT UNCERTAINTIES

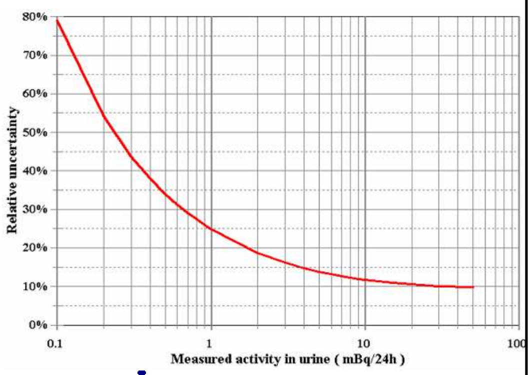


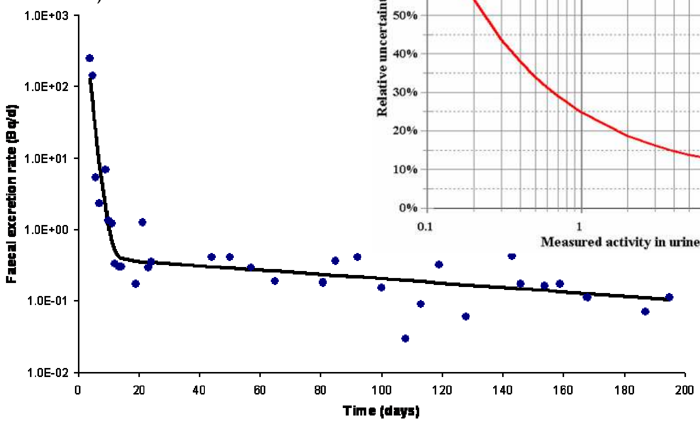
- α risk of false positive
- β risk of false negative

MEASUREMENT UNCERTAINTIES

in vitro measurement

relative uncertainty due to Poisson variability and chemical yield (Hurtgen and Cossonnet 2003)

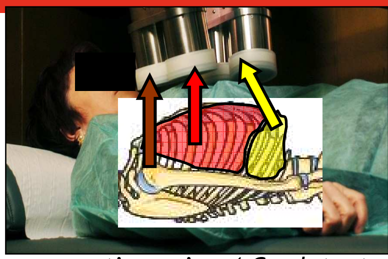




variability of Pu faecal excretion after inhalation of ^{239}Pu for 24 h samples (Marsh et al, 2007)

MEASUREMENT UNCERTAINTIES

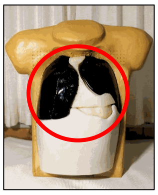
in vivo counting



Lung counting using 4 Ge detectors

Calibration using physical anthropometric phantoms

$$A_{lungs} = \frac{N_{counts}}{\varepsilon \times I_{ray} \times t_{counting}}$$



Livermore

- Rough representation
- Restricted nature and distribution of activity

Adequacy of calibration coefficients to real conditions?

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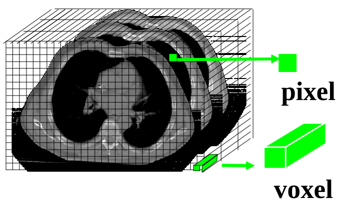
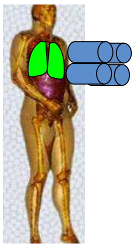
MEASUREMENT UNCERTAINTIES

in vivo counting

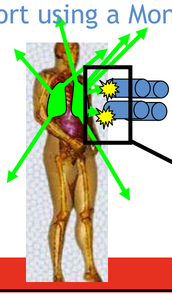
- Modelisation of the *in vivo* counting using numerical voxel phantoms





- Measured worker
- Internal contamination
- Detectors

- Simulation of particle transport using a Monte Carlo code



Simulated spectrum

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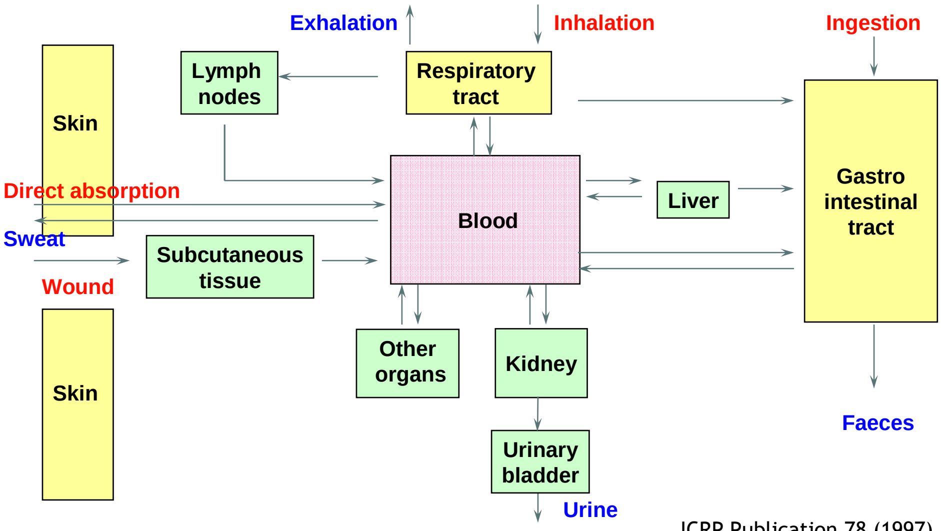
BIOKINETIC MODELS

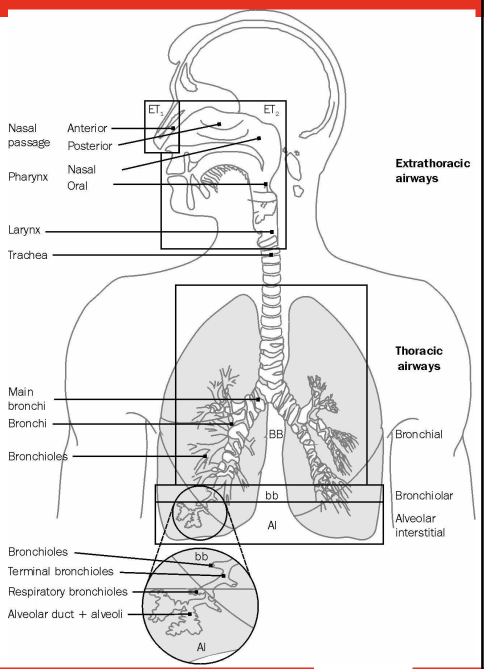


ICRP Publication 78 (1997)

BIOKINETIC MODELS

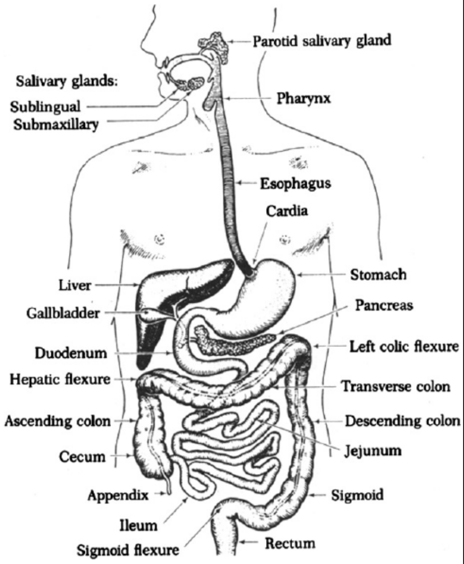
human respiratory tract model
ICRP publication 66 (1994)

deposition, transport and absorption of particles into blood after inhalation



BIOKINETIC MODELS

Human alimentary tract model
ICRP publication 100 (2006)



Predicts fecal excretion, absorption into blood and retention in the alimentary tract.

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NCRP REPORT No. 156

BIOKINETIC MODELS

DEVELOPMENT OF A BIOKINETIC MODEL FOR RADIONUCLIDE-CONTAMINATED WOUNDS AND PROCEDURES FOR THEIR ASSESSMENT, DOSIMETRY AND TREATMENT

NCRP
National Council on Radiation Protection & Measurements

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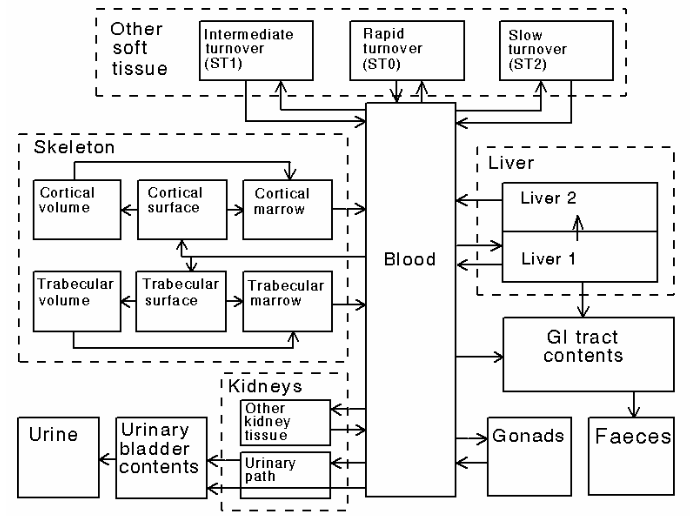
BIOKINETIC MODELS

systemic model for plutonium



ICRP publication 67 (1994)

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BIOKINETIC MODELS

systemic model for plutonium

λ(blood -> tissue) = outflow rate from circulation x fraction entering the tissue

λ(tissue 1 -> tissue(s) 2) = ln(2) / removal half-time

Transfer	rate (d^{-1})
Blood to Liver 1	1.941×10^{-1}
Blood to Cortical surface	1.294×10^{-1}
Blood to Trabecular surface	1.941×10^{-1}
Blood to Urinary bladder content	1.29×10^{-2}
Blood to Kidney (urinary path)	6.47×10^{-3}
Blood to Other kidney tissue	3.23×10^{-3}
Blood to ULI contents	1.29×10^{-2}
Blood to testes	2.3×10^{-4}
Blood to ovaries	7.1×10^{-5}
Blood to ST0	2.773×10^{-1}
Blood to ST1	8.06×10^{-2}
Blood to ST2	1.29×10^{-2}
ST0 to Blood	6.93×10^{-1}
Kidneys (urinary path) to Bladder	1.386×10^{-2}
Other kidney tissue to Blood	1.39×10^{-3}

Transfer	rate (d^{-1})
ST1 to Blood	4.75×10^{-4}
ST1 to Urinary bladder contents	4.75×10^{-4}
ST2 to Blood	1.9×10^{-5}
Trabecular surface to Volume	2.47×10^{-4}
Trabecular surface to Marrow	4.93×10^{-4}
Cortical surface to Volume	4.11×10^{-5}
Cortical surface to Marrow	8.21×10^{-5}
Trabecular volume to Marrow	4.93×10^{-4}
Cortical volume to Marrow	8.21×10^{-5}
Cort/Trab marrow to Blood	7.6×10^{-3}
Liver 1 to Liver 2	1.77×10^{-3}
Liver 1 to Small intestine	1.33×10^{-4}
Liver 2 to Blood	2.11×10^{-4}
Gonads to Blood	1.9×10^{-4}

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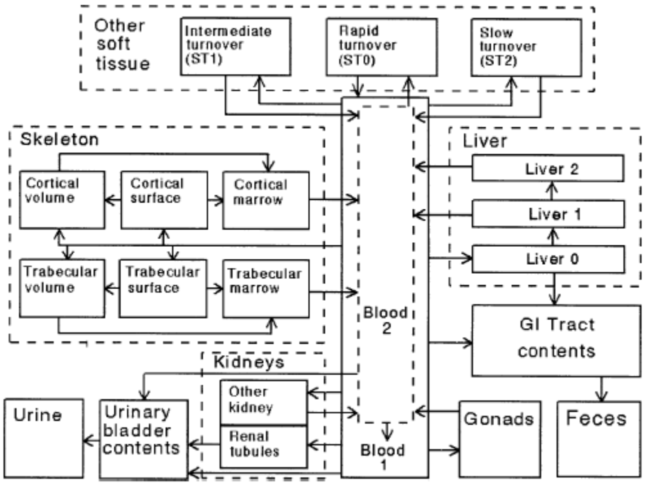
BIOKINETIC MODELS

systemic model for plutonium



Leggett et al. 2005

BIOKINETIC MODELS

systemic model for plutonium

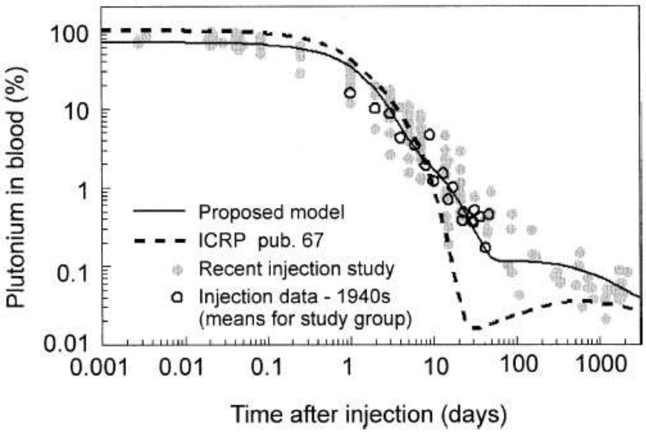


FIG. 5. Percentage of injected plutonium in blood as a function of time after administration, as predicted by the model of ICRP Publication 67 (*6*) and the proposed model, and determined in human injection studies conducted in the 1940s (*15*) and in recent years (*28*; D. Newton, personal communication).

Leggett et al. 2005

BIOKINETIC MODELS

systemic model for plutonium

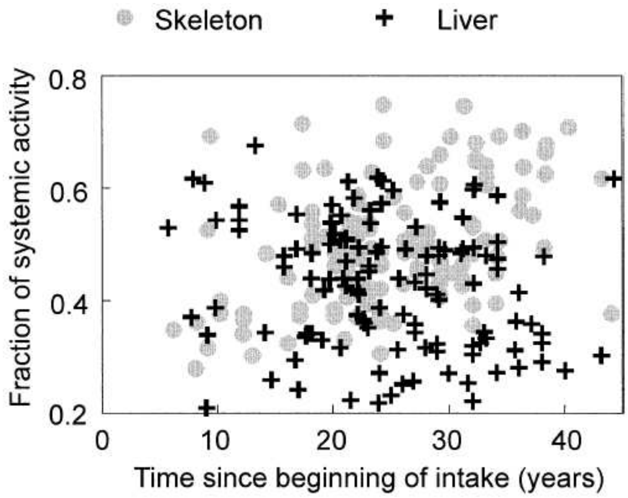


FIG. 2. Division of plutonium between liver and skeleton in occupationally exposed subjects (*23, 33, 37, 39, 41*).

Leggett et al. 2005

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UNCERTAINTY IN BIOKINETIC MODELS

- Discussed in a series of authoritative articles
  - Leggett RW, Bouville A, Eckerman KF (1998) Reliability of the ICRP's systemic biokinetic models. Radiat Prot Dosim 79(1-4):335-342
  - Leggett RW (2001) Reliability of the ICRP's dose coefficients for members of the public. I. Sources of uncertainty in the biokinetic models. Radiat Prot Dosim 95(3): 199-213
  - Harrison JD, Leggett RW, Nosske D, Paquet F, Phipps AW, Taylor DM, Métivier H (2001) Reliability of the ICRP's dose coefficients for the members of the public. II. Uncertainties in the absorption of ingested radionuclides and the effect on dose estimates. Radiat Prot Dosim 95: 295-308
  - Leggett RW (2003) Reliability of the ICRP's dose coefficients for members of the public. III. Plutonium as a case study of uncertainties in the systemic biokinetics of radionuclides Radiat Prot Dosim 106: 103-120

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UNCERTAINTY IN BIOKINETIC MODELS

- **Mostly dependant on the availability of relevant data**
  - behaviour of the element in human subjects (H1)
  - behaviour of the element in other mammalian species (A1)
  - chemical analogue in human subjects (H2)
  - chemical analogue in other mammalian species (A2)
  - basic physiological data (P)
- **Quantification of reliability of the model**
  - quantity of interest in [A,B] with roughly 90% probability
  - uncertainty factor UF = $(B/A)^{1/2}$
  - reliability :
    - high if UF < 2.2 (category I)
    - moderate to high if 2.2 < UF < 3.3 (category II)
    - low to moderate if 3.3 < UF < 8 (category III)
    - low if UF > 8 (category IV)

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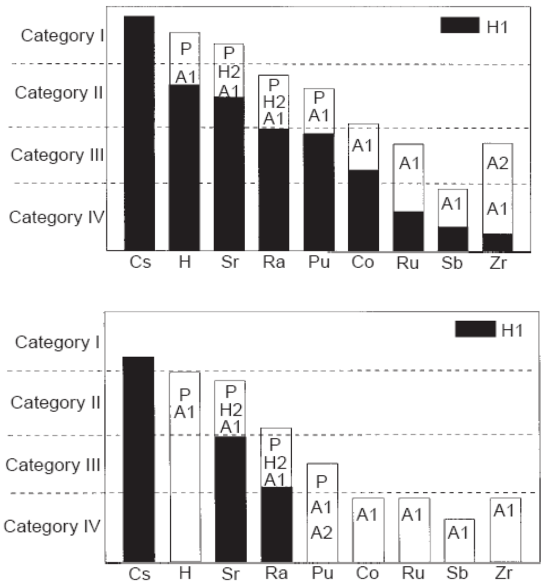
UNCERTAINTY IN BIOKINETIC MODELS



adults

Leggett et al. 1998

children

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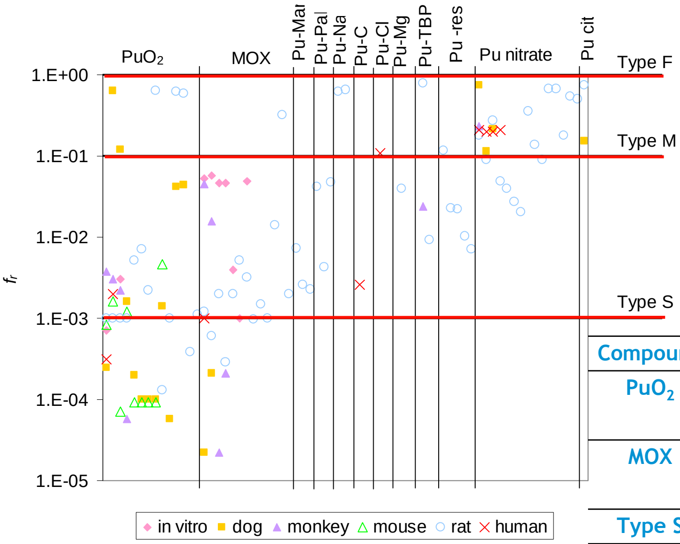
UNCERTAINTY IN BIOKINETIC MODELS

absorption of Pu : rapidly dissolved fraction f_r



Davesne et al. 2010

Compound		f_r
PuO_2	Median	1.1 x 10^{-3}
	GSD	14.3
MOX	Median	2.0 x 10^{-3}
	GSD	11.2
Type S		1.0 x 10^{-3}

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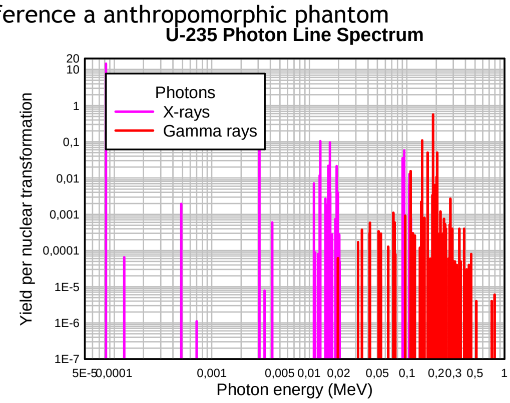
DOSIMETRIC MODELS

ICRP publication 110 (2010) : reference computational phantoms of the adult male and female

application of a Monte Carlo particle transport code to reference a anthropomorphic phantom



ICRP publication 107 (2009) decay data: energies and intensities of emissions

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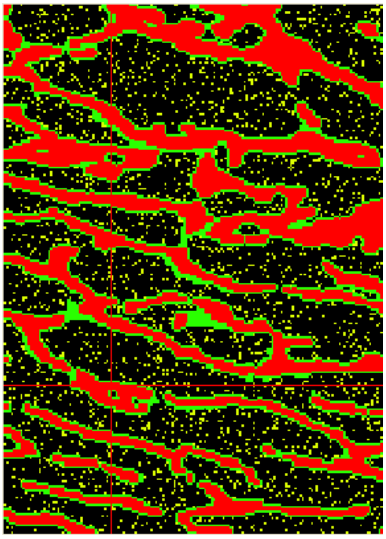
LOCAL GEOMETRY



Source and target regions in the skeleton

spongious region of right scapulae with 90% cellularity (50 µm thick voxels)

red, trabecular bone

black, active haematopoietic marrow : target for leukaemia induction

yellow, inactive marrow

green, endosteum : target for bone cancer induction

(50 µm layer instead of former 10 µm)

Target cells are also identified in the respiratory and alimentary tracts

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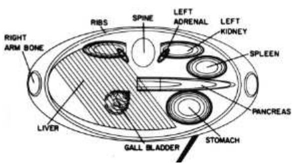
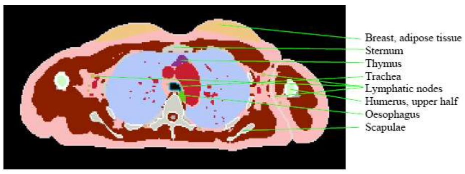
UNCERTAINTY IN DOSIMETRIC MODELS

- main sources (NCRP commentary No. 15,1998)
  - incomplete information on masses, compositions, shapes and locations of the organs and tissue of the human body
  - oversimplifications of the representations of certain complex anatomical structures in the body when calculating the energy deposition
  - limitations in the physical data (e.g. energy and intensity of radiations emitted by the radionuclides, photon interaction coefficients; etc.)
  - limitations in computational procedures for evaluating the energy deposition of penetrating radiations





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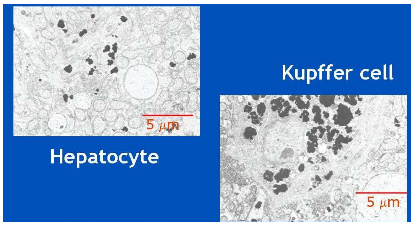
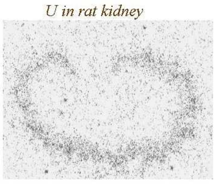
UNCERTAINTY IN DOSIMETRIC MODELS

location of short-range (α, β, Auger) emitters in tissues



thorium in hamster liver (Brooks et al. 1985)

U in rat kidney



Heterogeneous distribution of U in tissues

U in rat alveolar macrophage

uranium in rat tissues

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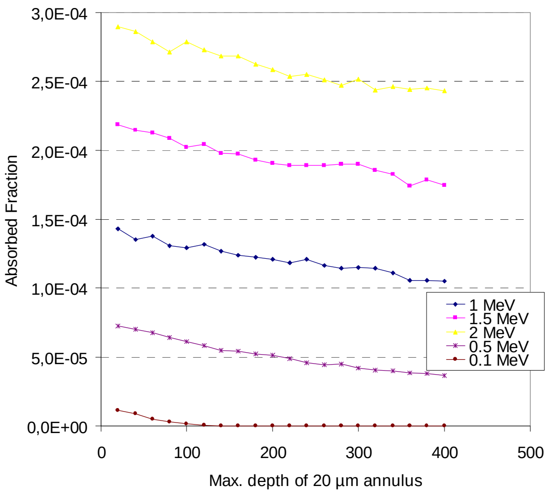
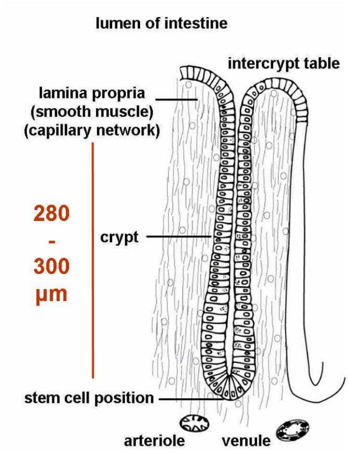
UNCERTAINTY IN DOSIMETRIC MODELS

location of target cells for cancer induction





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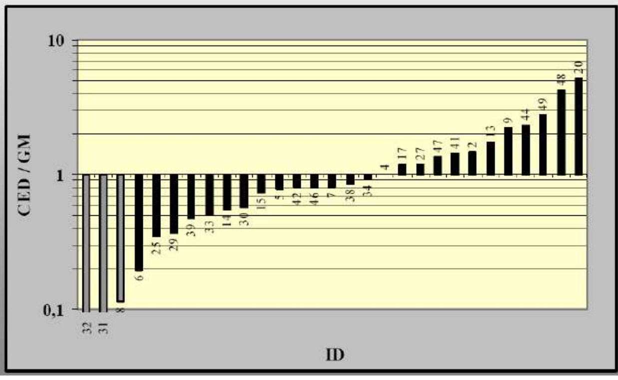
APPLICATION OF THE MODELS

"the problem"

Third European Intercomparison Exercise

Case 7: Pu-239 (II) | **29 answers** | **2,16....131000 mSv**



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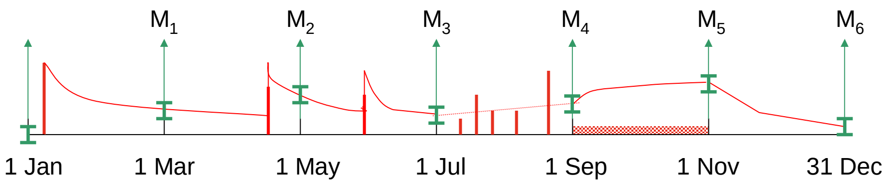
APPLICATION OF THE MODELS

individual variability : deviation from the reference biokinetic and dosimetric model

time of contamination ?



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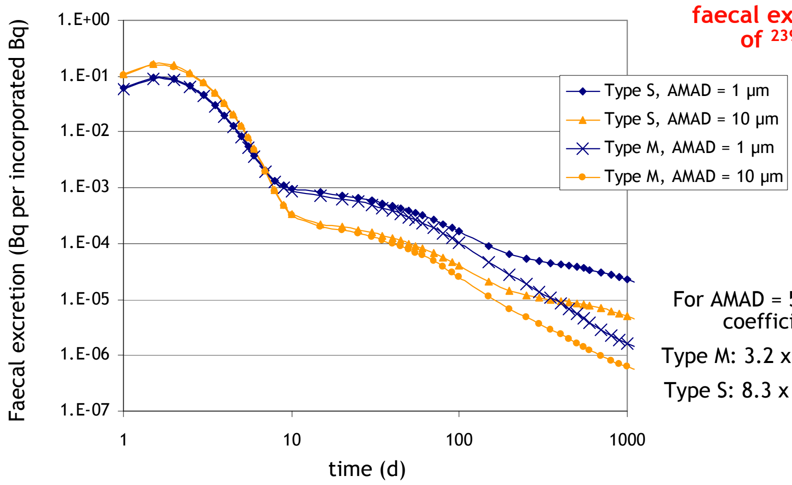
APPLICATION OF THE MODELS

physico-chemical form (AMAD, absorption type) ?



faecal excretion of ^{239}Pu

For AMAD = 5 µm, dose coefficients:

Type M: 3.2×10^{-5} $Sv.Bq^{-1}$

Type S: 8.3×10^{-6} $Sv.Bq^{-1}$

APPLICATION OF THE MODELS

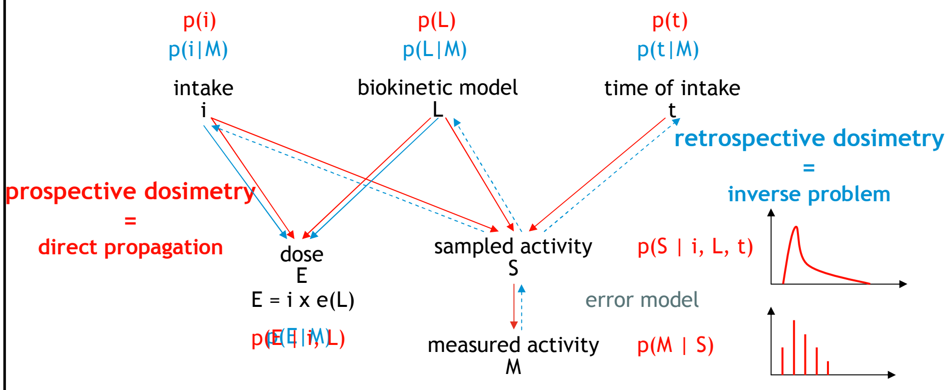
General philosophy of the IDEAS guidelines (Doerfel et al. 2006)

Harmonisation:
by following the procedures any two assessors should obtain the same estimate of dose from a given data set

Optimisation:
the "best" estimate of dose should be obtained from the available data

Proportionality:
the effort applied to the evaluation should be proportionate to the dose – the lower the dose, the simpler the process should be.

PROPAGATION OF UNCERTAINTY

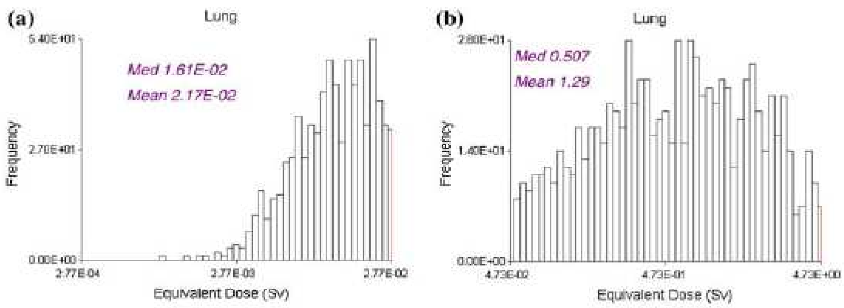


- Techniques for solving inverse problems
  - Classical method (Molokanov et al, 2010)
  - WeLMoS method (Puncher and Birchall, 2008)
  - Bayesian network (Davesne et al, 2010)
  - Markov chain Monte Carlo (Miller et al, 2002)

PROPAGATION OF UNCERTAINTY

Birchall et al. 2010

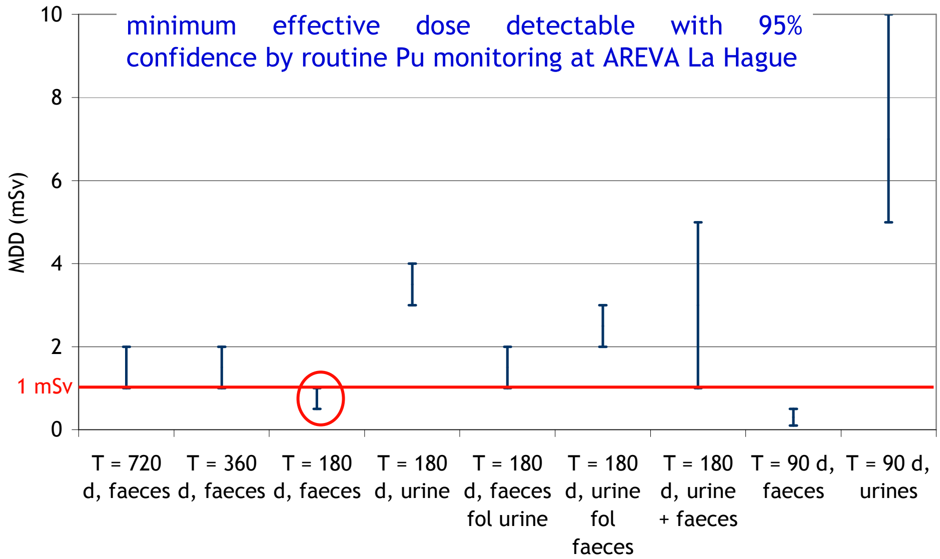
Uncertainty on lung dose from Pu inhalation for epidemiological study of nuclear workers



from urine bioassay measurement, taking account of biokinetic uncertainty in the human respiratory tract model, applying the WeLMoS method

PROPAGATION OF UNCERTAINTY

Davesne et al. 2010



DRAFT CONCLUSIONS

- Internal dosimetry is complex but relies on sophisticated measurement techniques and dosimetric models which are upgraded with scientific progresses.
- Model complexity warrants guidance in their application and reminder of their limitations and unavoidable associated uncertainties.
- Quantification of uncertainty is important for epidemiological studies, retrospective assessment of individual risk, nuclear medicine and quality assurance of monitoring programs.
- Robust mathematical methods have recently been applied to this issue. NCRP report 164 on uncertainties in internal radiation dose assessment was released this month. The harmonization of approach to uncertainty at the European level is a challenge for the years to come.
- Further research is desirable to investigate the respective location of internal emitters and target regions for health effects in the human body ; and to link the outcome of dosimetry and microdosimetry with the observation of biological responses in the various situations of exposure.