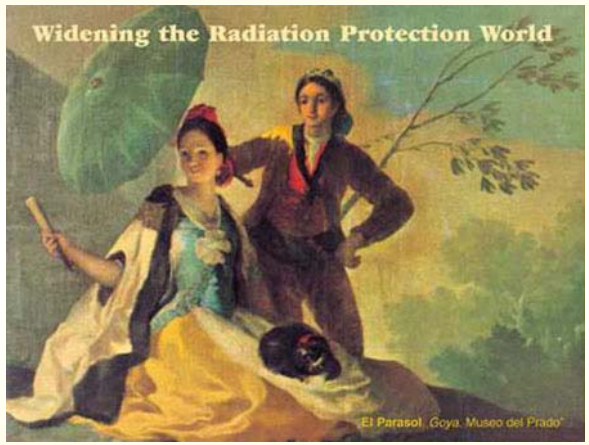
International Radiation Protection Association
11th International Congress
Madrid, Spain - May 23-28, 2004

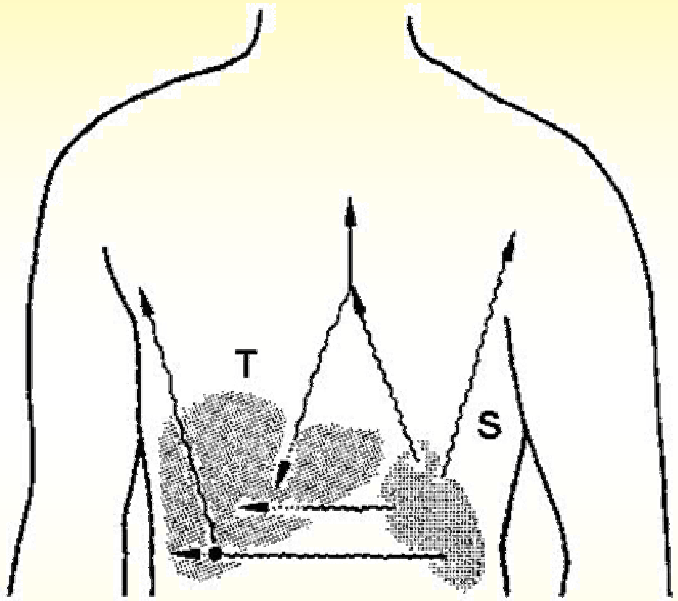


Refresher Course

"Programmes for Internal Dose Monitoring"

Part 1:	**Basic Aspects and Essential Elements**	**K Henrichs**
Part 2:	**Uncertainties in Assessments of Internal Doses and Advice on Monitoring**	**A. Hodgson**

Dosimetry of incorporated radionuclides



S = region containing radioactivity

T = region of interest

DOSE in T

energy per mass unit transported to T per disintegration in S

X

# of disintegrations in S

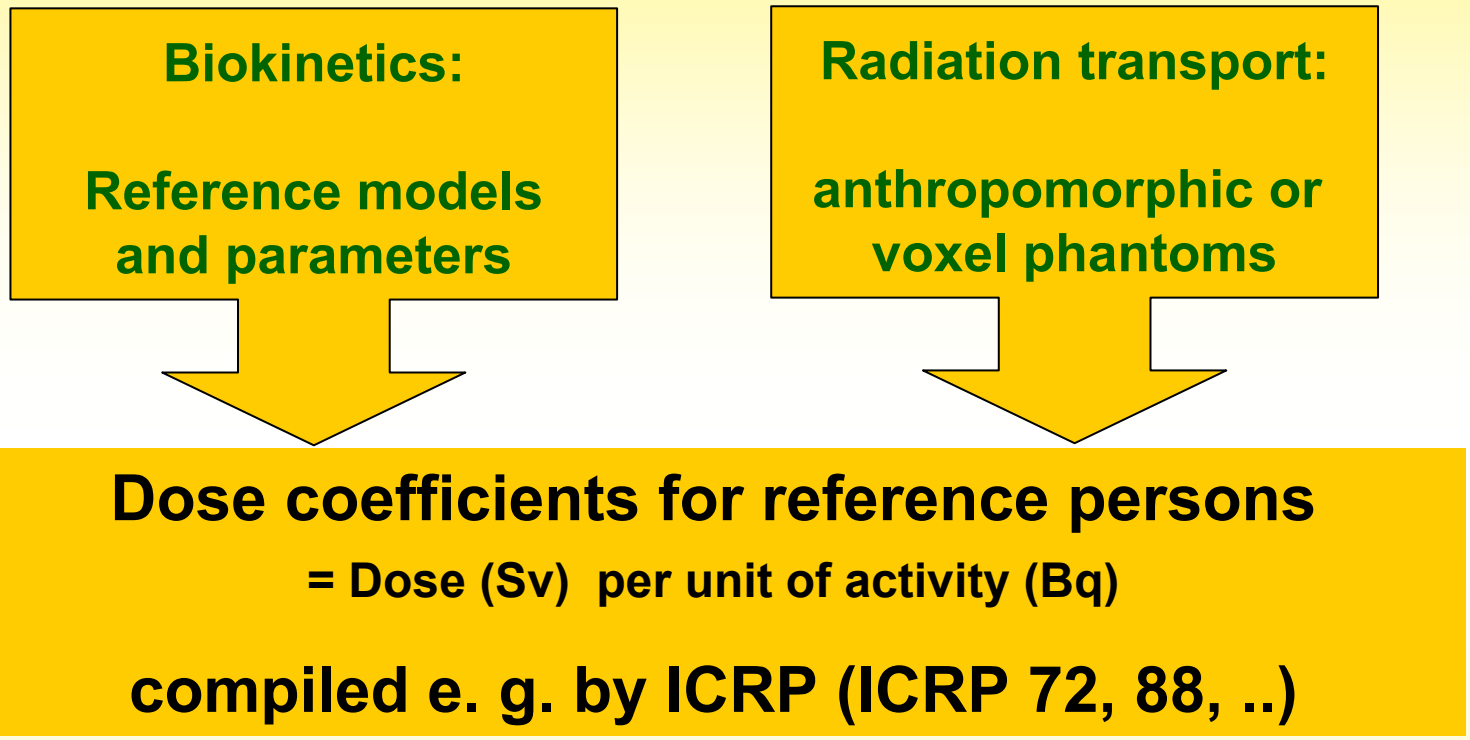
= time integral of activity

depending on

- radiation type
- energy emitted
- masses
- geometry
  i. e. gender, age, health

- physical halflife,
- distribution & retention
  - element, compound
  - path of intake
  - AMAD, f1, …
  - age, gender

Dose coefficients ….



… help to quantify exposures for reference persons if intakes are known

Monitoring is …

ISO 20553:

to a Risk of Internal Contamination with Radioactive Material

- performed to

- verify that each worker is protected adequately against risks from radionuclide intakes
- document the protection complies with legal requirements

- retrospective:

Measure:
- room activity
- body burden
- excreta

Calculate:
intake*
using reference retention data

Calculate:
exposure
using reference dose coefficients

*additional uncertainty:
unknown time of incorporation event

Distinguish …

Routine monitoring	to quantify normal exposures, i.e. where there is no evidence to indicate that acute intakes have occurred or where chronic exposures cannot be ruled out.
Special monitoring	to quantify significant exposures following actual or suspected abnormal events.
Confirmatory monitoring	required to check the assumptions underlying the procedures previously selected.
Task-related monitoring	applies to a specific operation.

Individual monitoring	needed to assess the exposure of a single worker by measuring individual body activities, excretion rates or activity inhaled (using personal air samplers).
Workplace monitoring	provides exposure assessments for a group of workers assuming identical working conditions

Necessity of monitoring: classification of processes, workers …

Inputs:
- earlier monitoring results
- compounds, AMAD, dose coefficients,
- estimate of incorporation probabilities
- …

Risk assessment for each work process

Classification of each worker: no / low / high risk

Criteria:

no risk:	expected annual exposure likely to be < 1 mSv/a
low risk:	expected annual exposure may exceed 1 mSv/a but likely < 6 mSv/a
high risk:	annual exposure may exceed 6 mSv/a

Inputs:
- radionuclide: emissions
- compounds: biokinetics, …
- AMAD, f1, ..
- avail. tech., detection limits

Design of the monitoring programs

no risk:	no monitoring
low risk:	collective or workplace monitoring
high risk:	individual monitoring

Exposure risk
constant in time: routine monitoring
varying: task related or special monitoring

Output:
Assignment of each worker to a spec. monit. procedure

Radiation type and biokinetics determine measurement methods:

in-vivo measurements:		for photon emitters (γ, X-ray)
	whole body counter:	e. g. Cs-137, Co-60
	partial body counter:	e. g. I, Te (thyroid), Am + Pu (lungs)
	typ. detection limit:	10 - 500 Bq

in-vitro, excretion analysis:		for α- and β-emitters
	urine, feces, nose blow	e. g. Sr-90, H-3
	typ. detection limit:	1 mBq (α-emitters)

air-monitoring:		
	room:	if sensitivity of individual methods is not sufficient
	personal:	if high intakes are expected

Select method and interval to ensure …

- the detection of an annual dose > 1mSv:

for in vivo measurements $e(50) * DL / R(\Delta T) * 365 / DT \leq 1$ mSv/a

for in vitro measurements $e(50) * DL / E(\Delta T) * 365 / DT \leq 1$ mSv/a

with

$e(50)$	= dose coefficient,
DL	= detection limit,
$R(t)$	= retention at t since incorporation,
$E(t)$	= excretion rate at t since incorporation,
ΔT	= time interval for routine monitoring.

- maximum potential underestimation < 3

i. e. assuming that a single intake occurred in the middle of the monitoring interval this requirement means:

$$R(\Delta T/2) / R(\Delta T) < 3$$

$$E(\Delta T/2) / E(\Delta T) < 3$$

Reference levels …

Level	Meaning
Recording level	The recording level is the level at or above which monitoring results have to be recorded. It shall be set at a value corresponding to an annual dose no higher than **1 mSv**. Results falling below this level may be shown as "below recording level".
Investigation level	The investigation level is the level at or above which investigation has to be made into the uncertainty associated with the measurements in order to refine the monitoring result. It shall be set at a value corresponding to an annual dose no higher than **6 mSv.**

… help that unnecessary, non-productive work can be avoided and resources can be used where they are most needed

Important elements to ensure quality…

- the definition of maximum tolerated deviations from the predefined frequencies of measurements,
- clear rules for collecting samples of urine or feces
  24 hours sampling periods for urine, 3 days for feces
- regulations to avoid contaminations
  (as well for in vitro as for in vivo measurements)
- the definition of action levels for further investigations
- definition of assumptions as the basis for the interpretation of measurements
- confirmatory monitoring
  regularly and after any major modification
- intercomparisons for measurement (sampling, laboratory)
- intercomparisons for dose assessment

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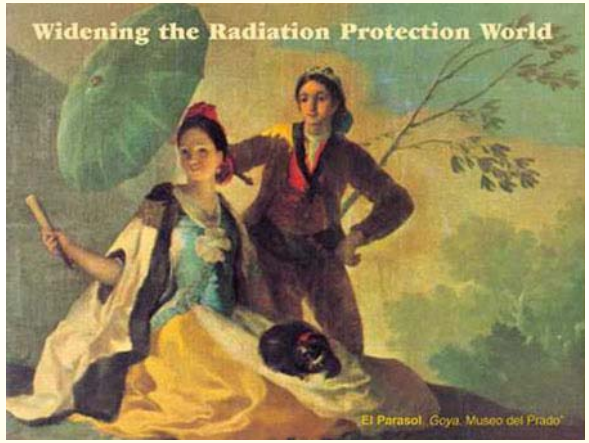


Refresher Course

Programmes for internal dose monitoring

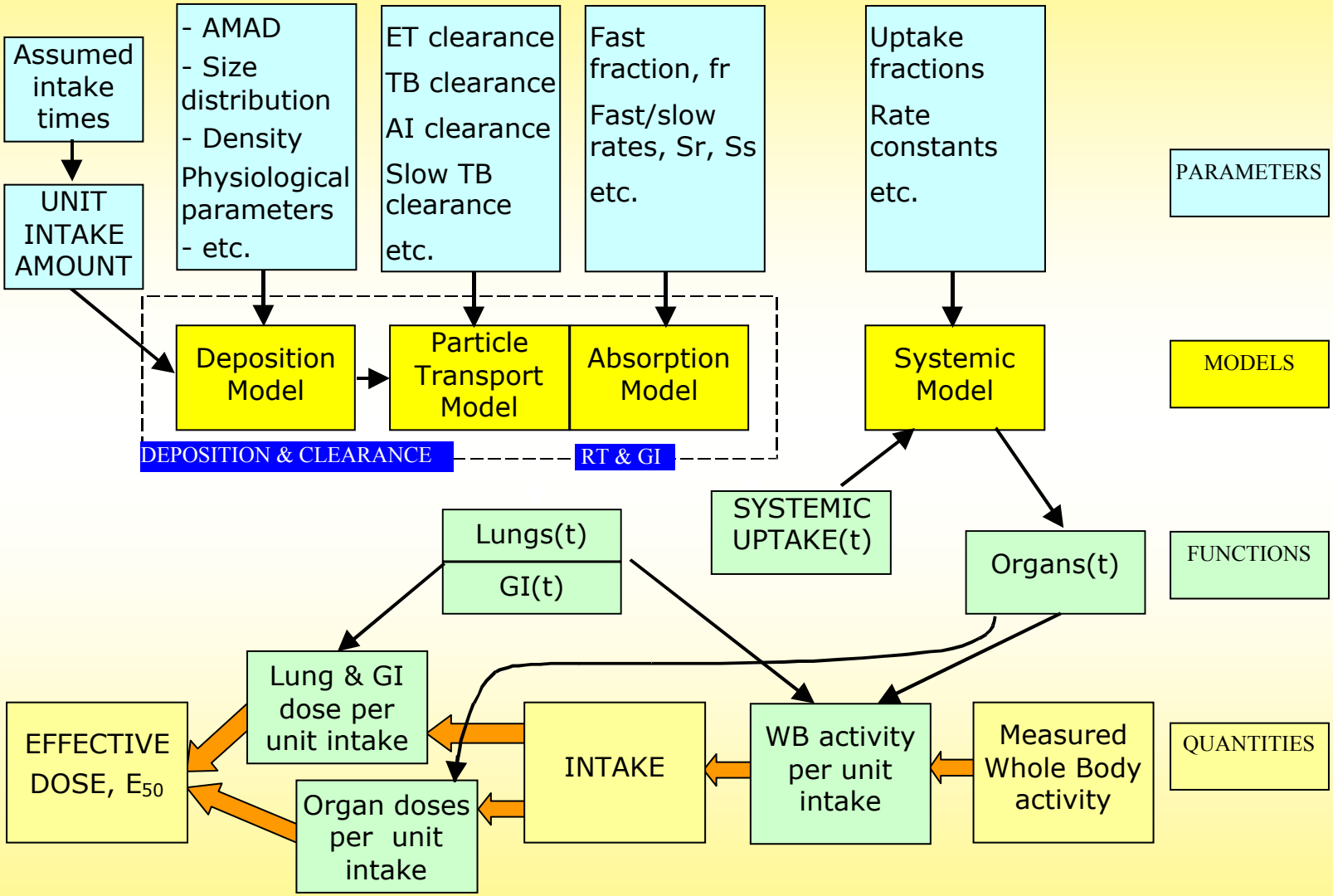
Alan Hodgson (NRPB, UK)

Optimisation of Monitoring for Internal Exposure

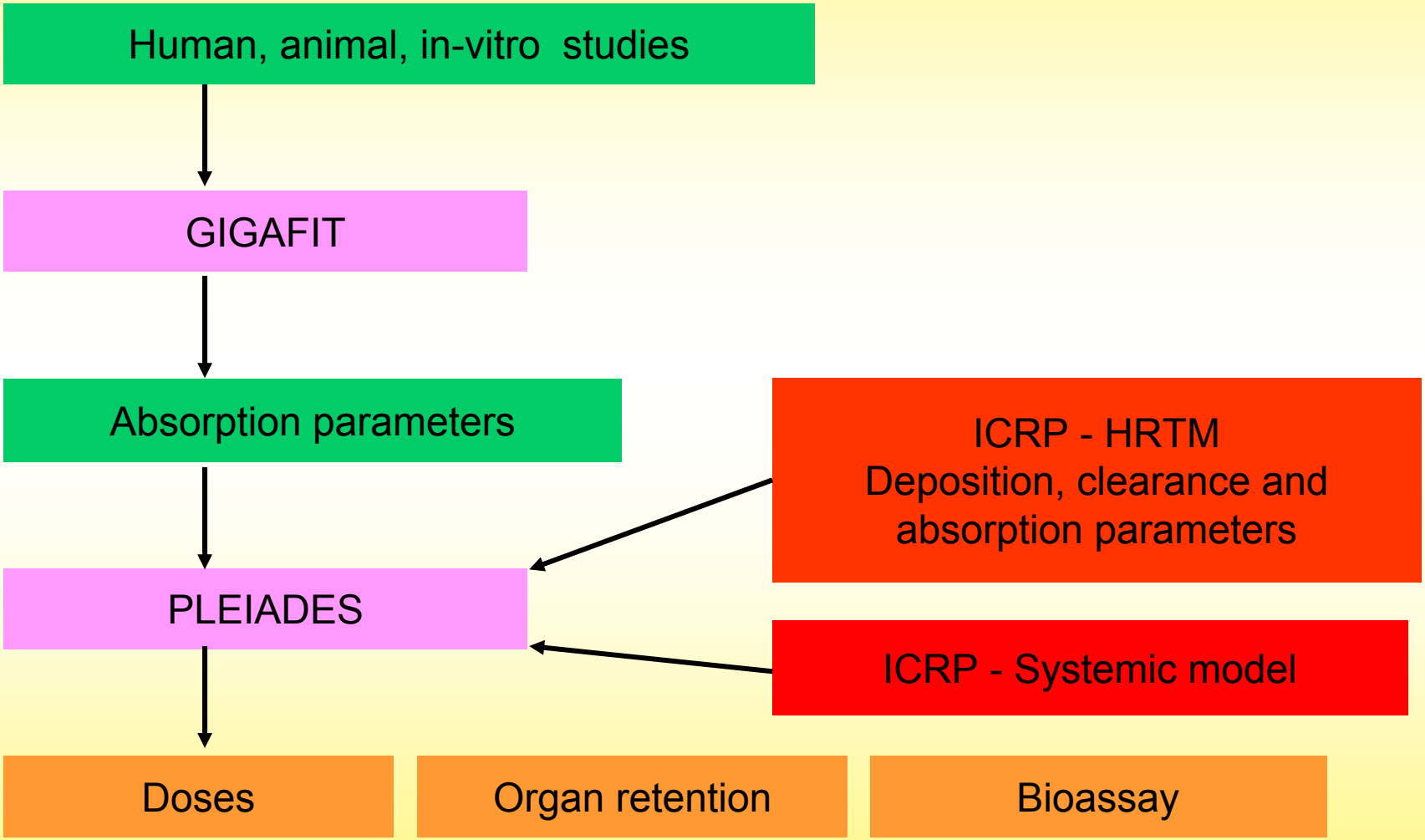
Etherington G, Cossonnet C, Franck D, Genicot J L, Hurtgen C, Jourdain J-R, Le Guen B, Rahola T, Sovijärvi J, Stradling G N, Ansoborlo E and Bérard P

Final report to be published as NRPB-W report. Obtainable as PDF from NRPB website - nrpb.org

Assessment of doses from monitoring measurements



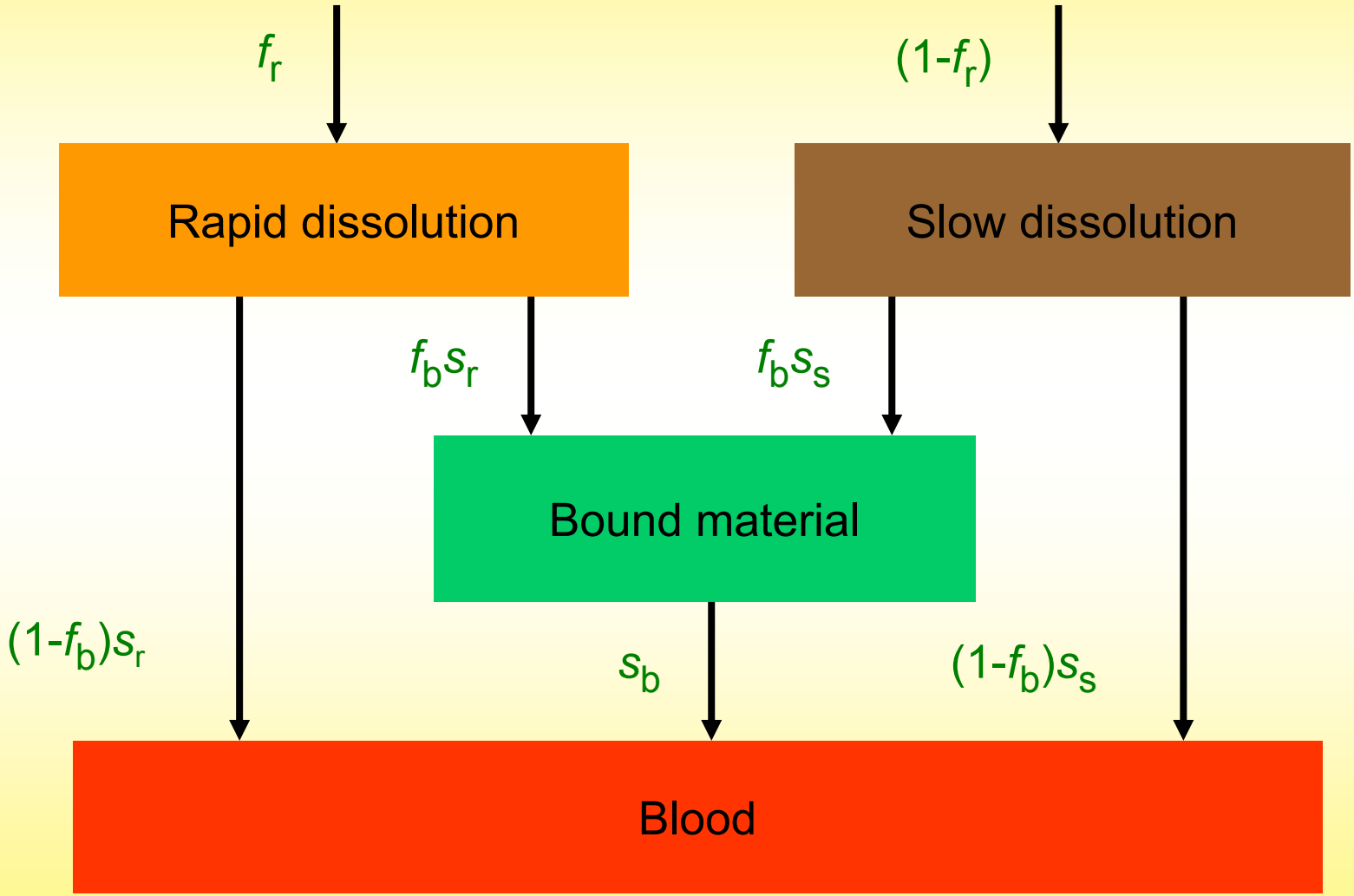
Assessing Intakes and Doses



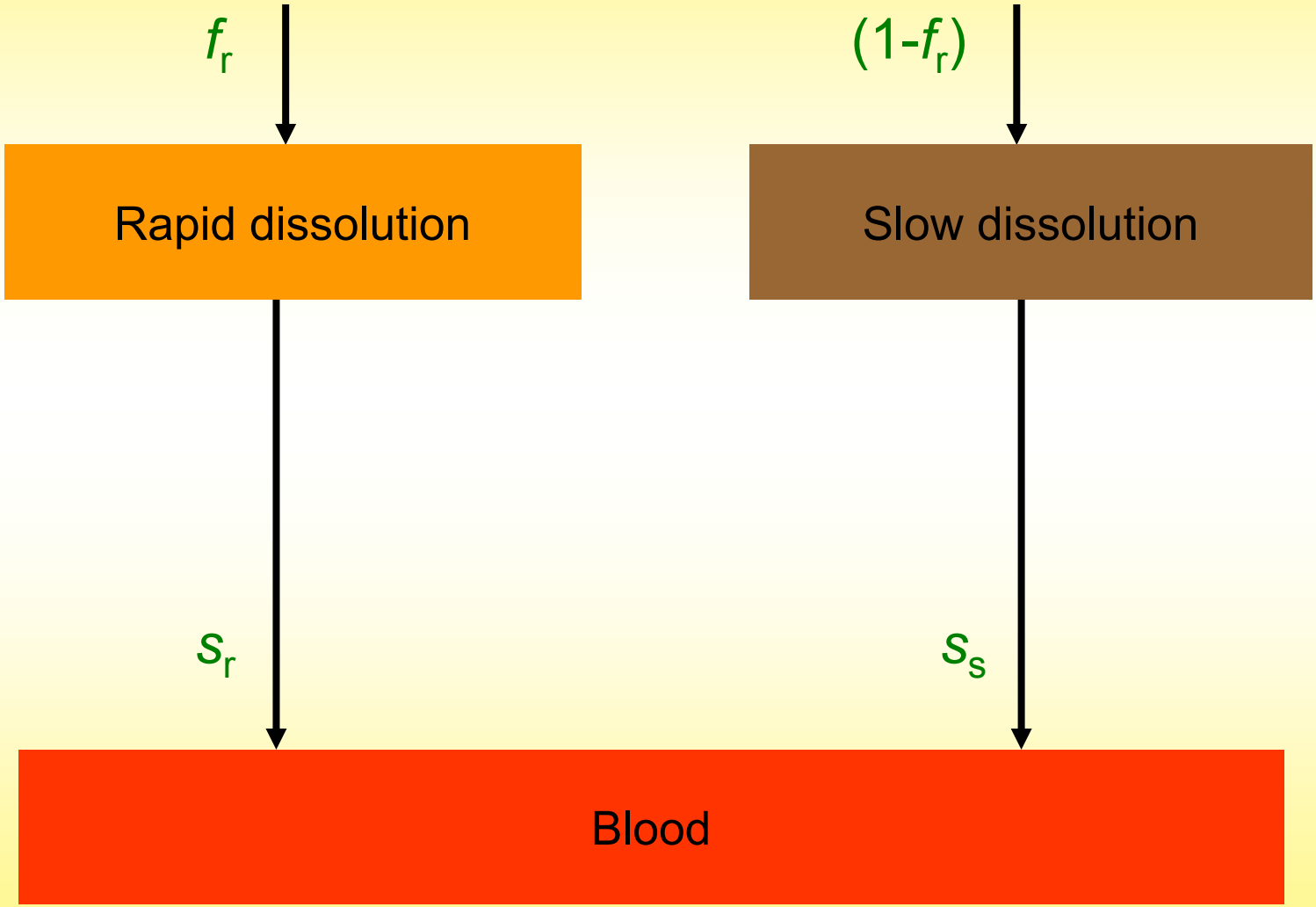
Uncertainties in biokinetic modelling

Absorption Parameter Values

Alternative Representation of Absorption



…much simpler if exclude the ‘bound state’

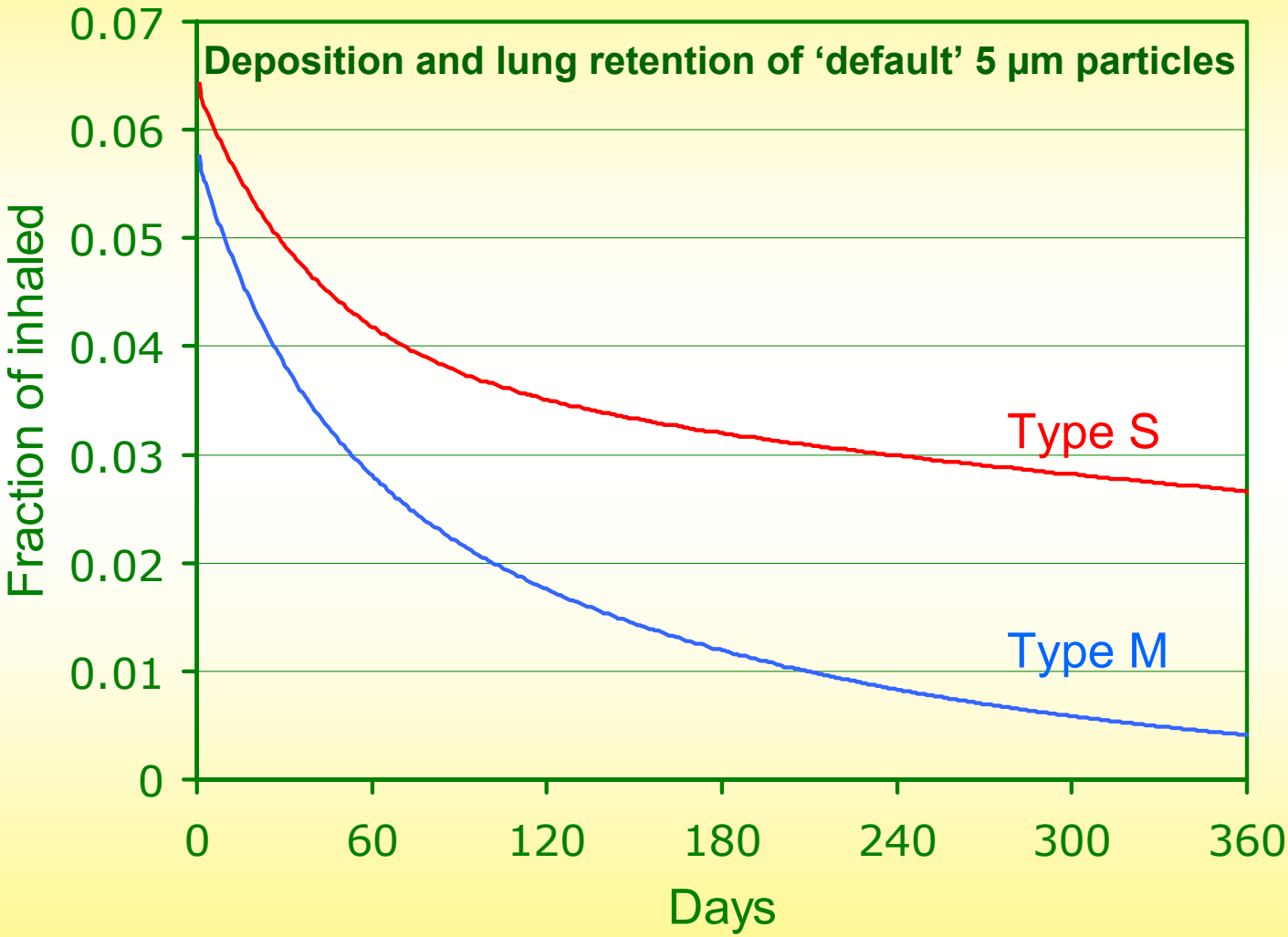


Intake Uncertainties - Absorption Parameter Values

Absorption Type*	Rapid Fraction (f_r)	Rapid Rate (s_r) d^{-1}	Slow Rate (s_s) d^{-1}
Slow	0.001	100 *(t/2 ~ 10 min)*	1×10^{-4} *(t/2 ~ 7000 d)*
Moderate	0.1	100 *(t/2 ~ 10 min)*	5×10^{-3} *(t/2 ~ 140 d)*
Fast	1	100 *(t/2 ~ 10 min)*	-

*ICRP Publication 66 '*Human Respiratory Tract Model for radiological protection'* (1994)

ICRP Default Absorption Parameter Values



Practical example

Acute Inhalation Exposure of Plutonium Nitrate

Plutonium Compounds: Exposure Limits and Assessment of Intake and Dose after Inhalation

N Stradling, A Hodgson, T Fell, E Ansoborlo, P Bérard, G Etherington and B Le Guen

NRPB Chilton, CEA Marcoule, CEA Saclay, EDF-GDF St Denis

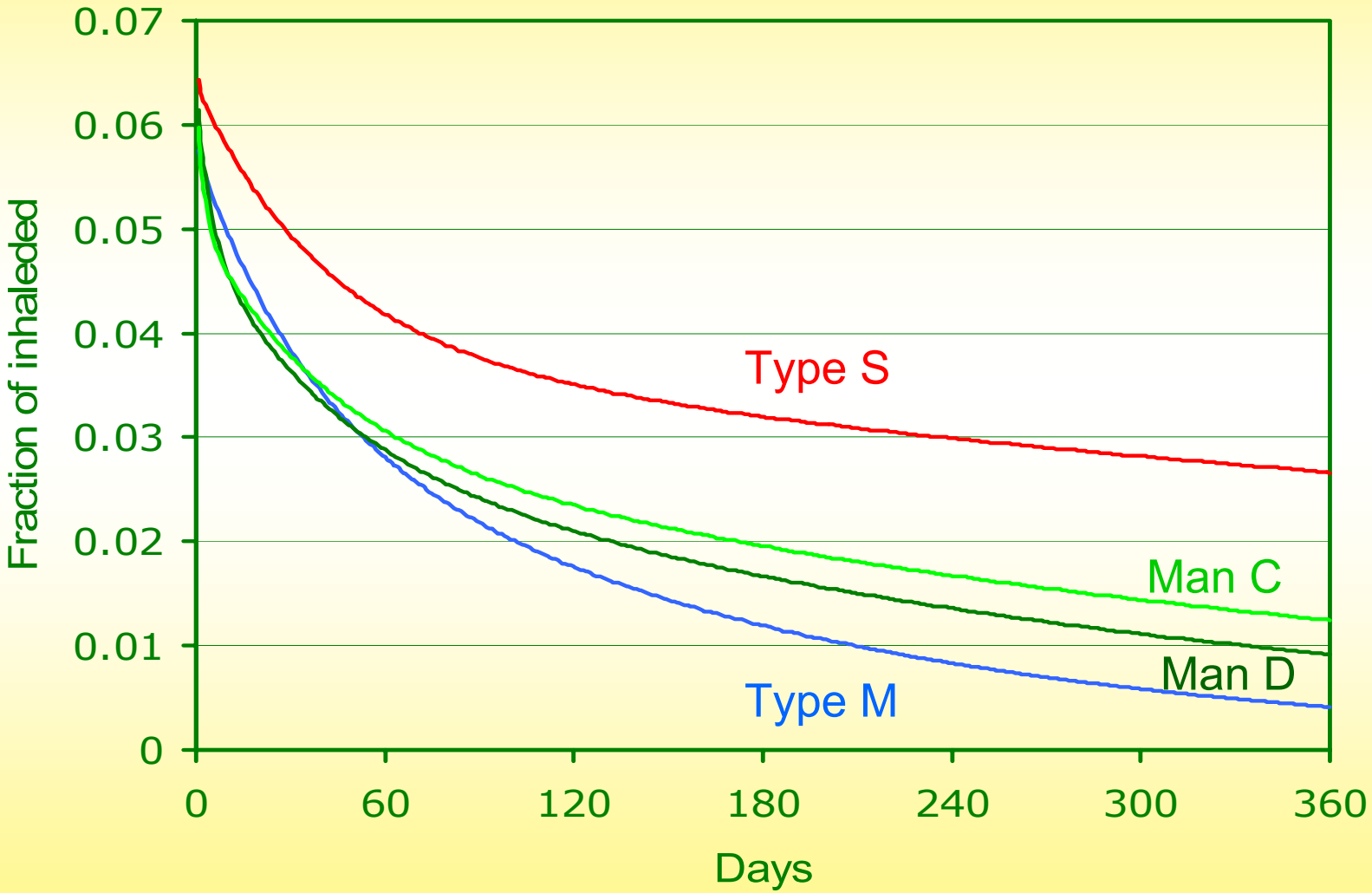
NRPB-W52
Obtainable as PDF from NRPB website - nrpb.org

Intake Uncertainties - Absorption Parameter Values

Absorption Type*	Rapid Fraction (f_r)	Rapid Rate *half-time*	Slow Rate (s_s) *half-time*
Slow	0.001	~ 10 min	~ 7000 d
Man C*	0.21	~ 3 d	~ 300 d
Man D*	0.20	~ 1.5 d	~ 430 d
Moderate	0.1	~ 10 min	~ 140 d

*Values from volunteer studies using $^{237+244}$Pu (Etherington et al 2002; Hodgson et al 2002)

Lung Retention of inhaled Pu nitrate



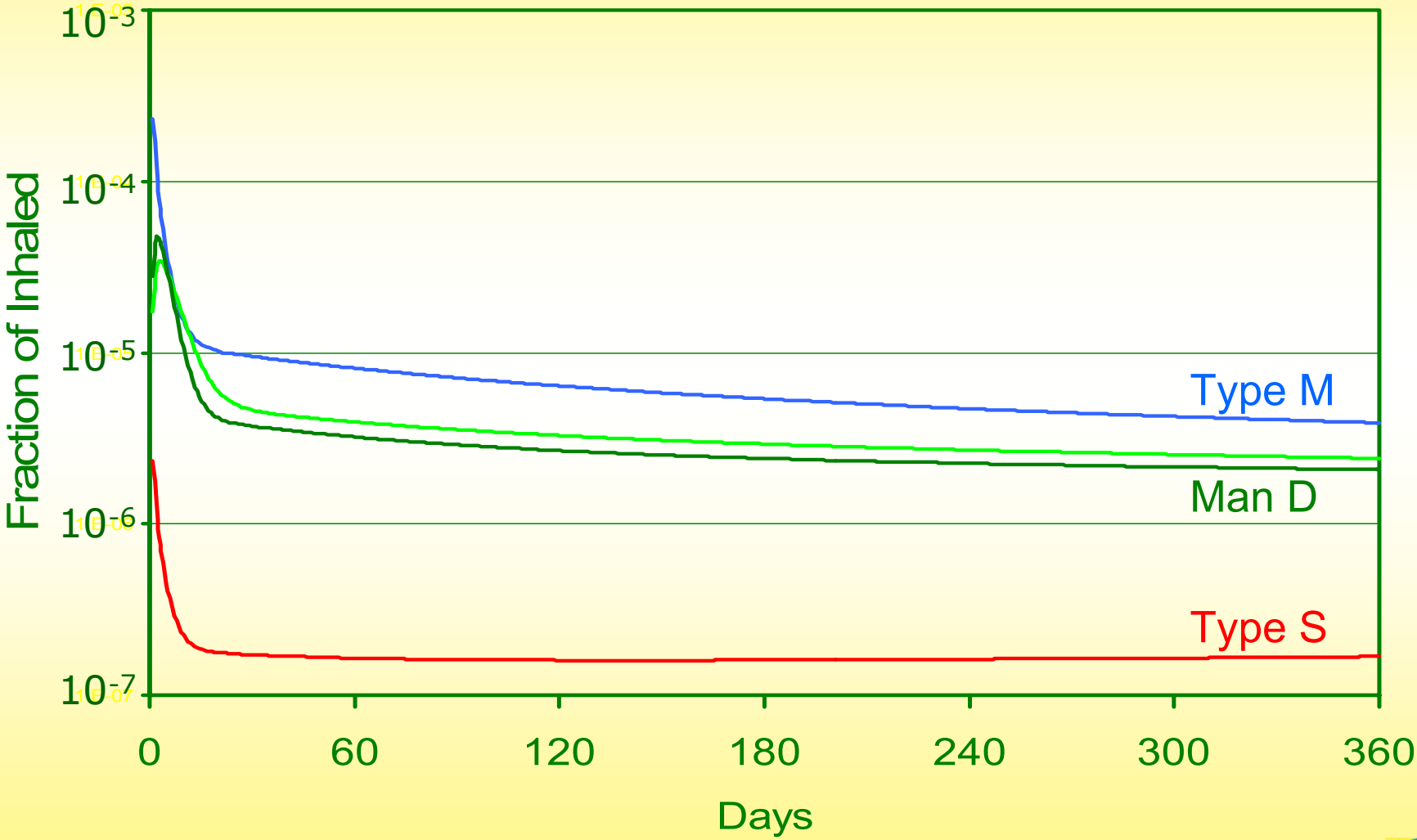
Pu Nitrate: Lung Monitoring after acute intake

Minimum detectable dose (Sv) after acute intake

Days	Man C	Man D	Type M
1	1.0	1.0	1.7
7	1.3	1.3	1.9
30	1.7	1.6	2.5

MDA: 3 kBq

Urinary Excretion of inhaled Pu Nitrate



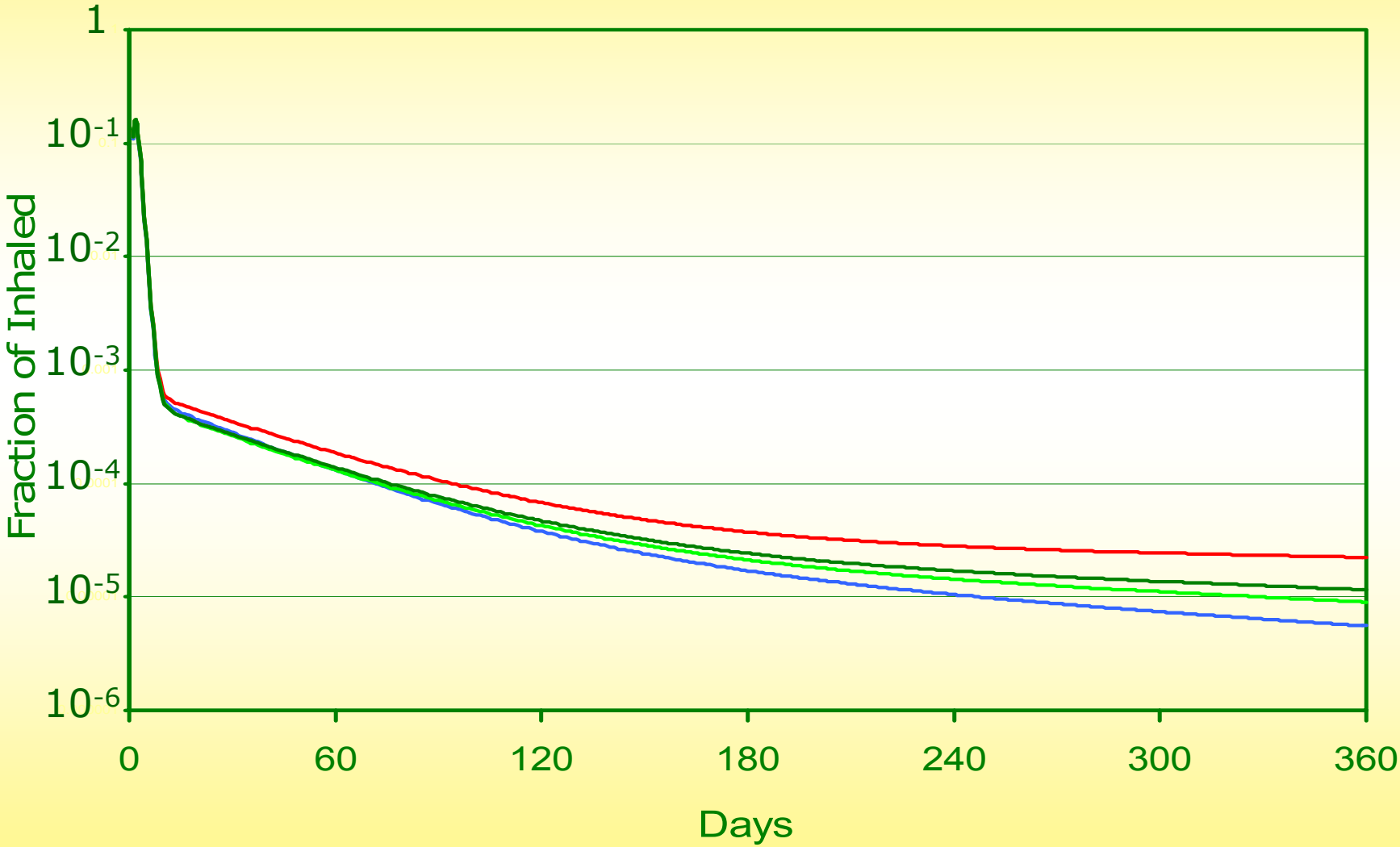
Pu Nitrate: Urine Assay

Minimum detectable dose (mSv) after acute intake

Days	Man C	Man D	Type M
1	0.12	0.07	0.014
7	0.09	0.10	0.11
30	0.45	0.54	0.34

MDA: 1 mBq d^{-1}

Faecal Excretion of inhaled Pu Nitrate



Pu Nitrate: Feacal Assay

Minimum detectable dose (μSv) after acute intake

Days	Man C	Man D	Type M
1	0.2	0.2	0.3
7	8.6	8.4	14
30	80	74	115

MDA: 1 mBq d^{-1}

Summary: Pu Nitrate

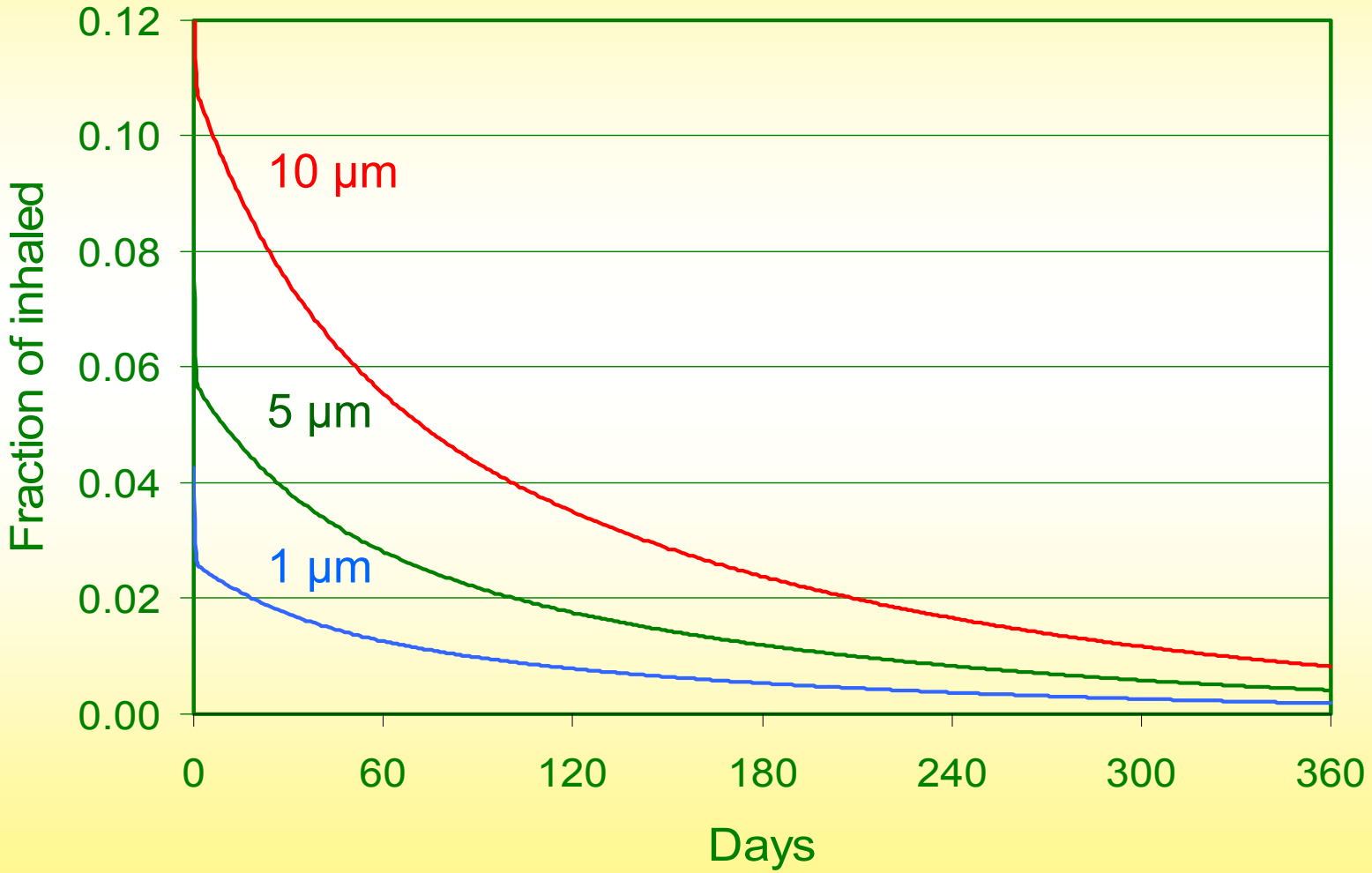
Acute exposure

- Lung monitoring - *is of little practical value*
- Urine assay – *doses 0.1 mSv up to 7 d after intake*
- Faecal assay – *doses < 0.1 mSv up to 30 d after intake*

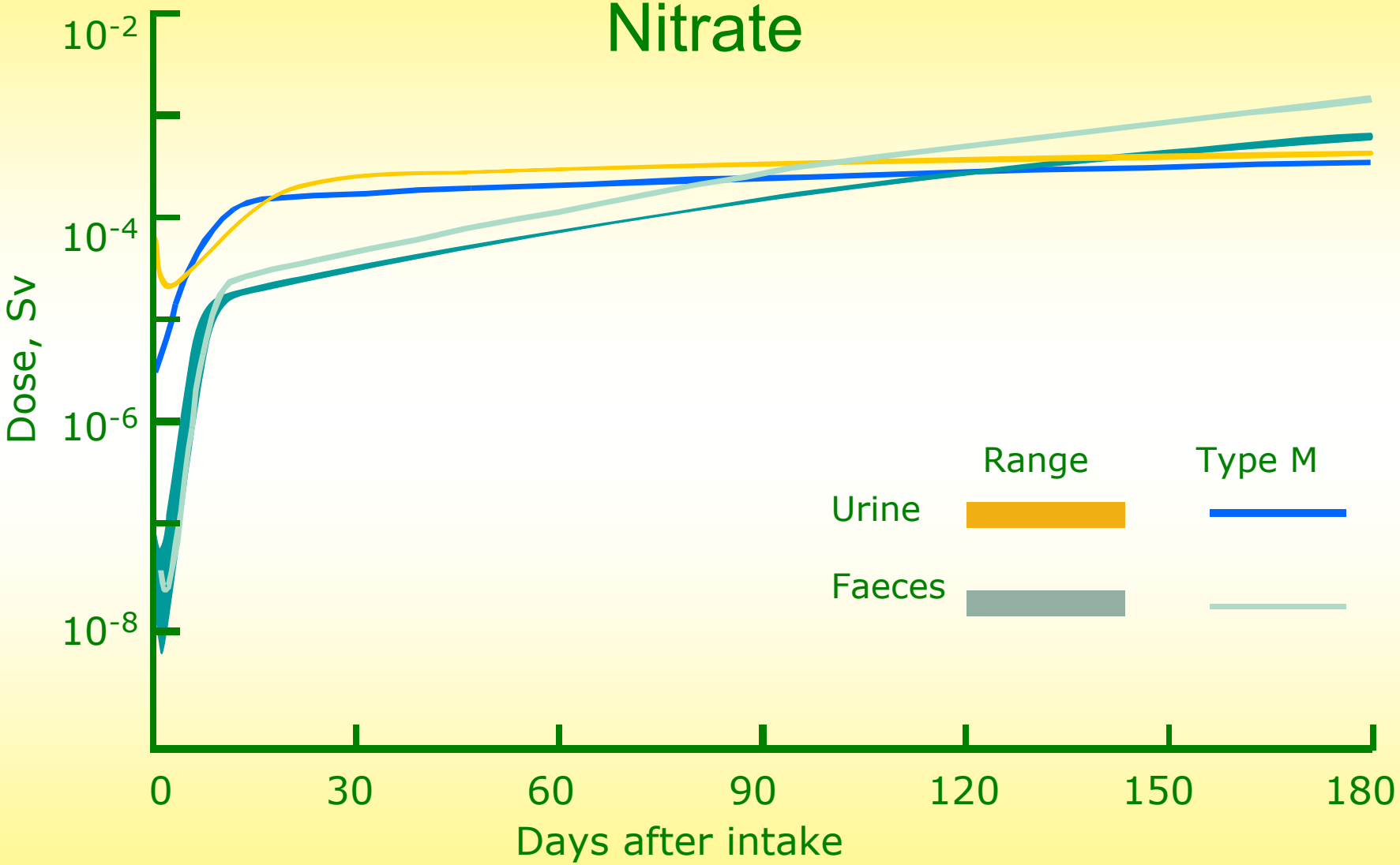
Uncertainties in biokinetic modelling

Particle size

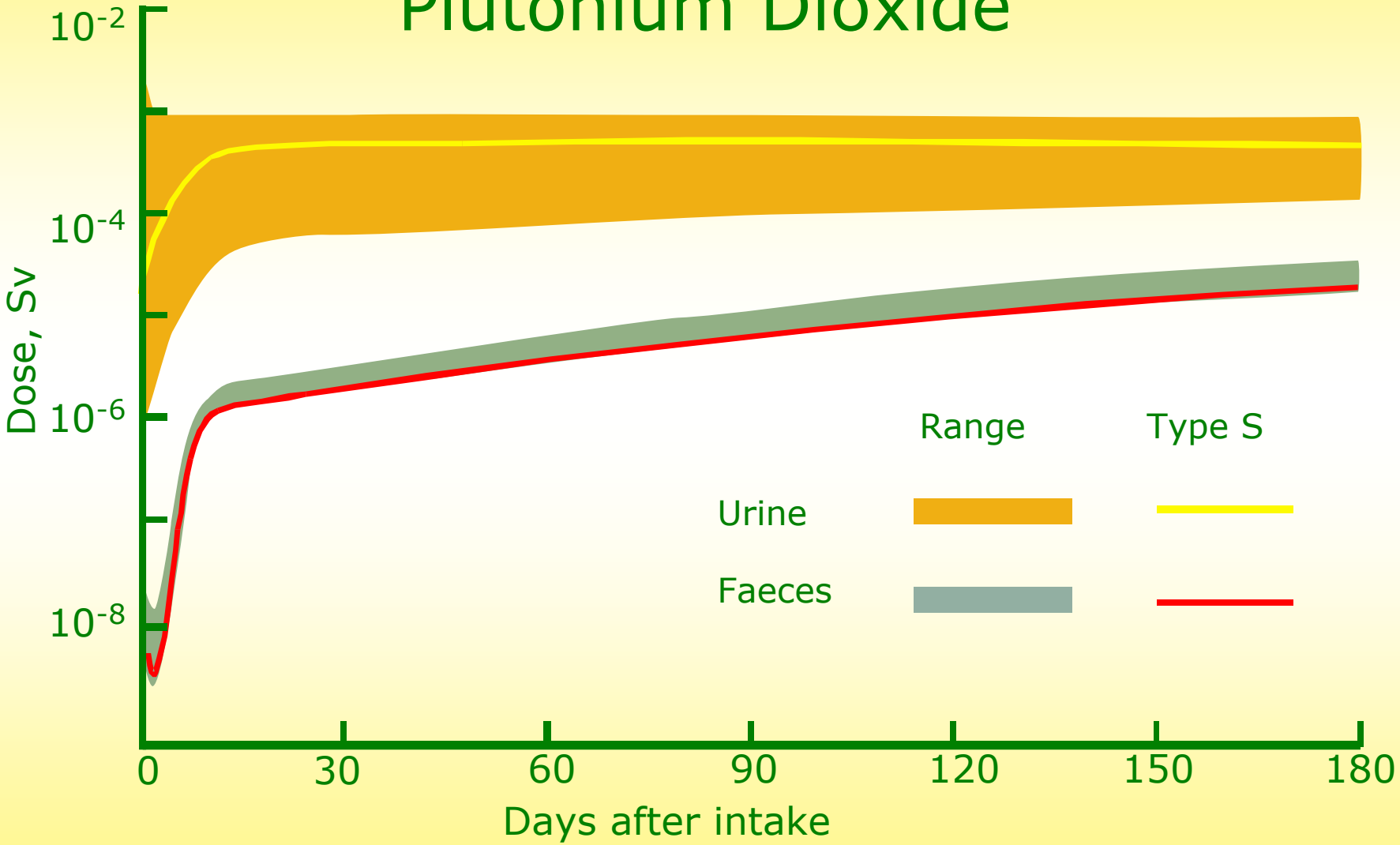
Lung retention; ICRP Type M compound



Minimum Detectable Doses for Plutonium Nitrate



Minimum Detectable Doses for Plutonium Dioxide



Uncertainties in biokinetic modelling

Systemic retention half-time

Practical example

Acute and Repeated Inhalation Exposure to Cs-137

Assessment of Intake and Dose after Inhalation of Caesium-137 by Workers and Adult Members of the Public

N Stradling, A Hodgson, T Fell, T Smith, G Etherington, and T Rahola

NRPB Chilton, STUK Helsinki

NRPB-W51
Obtainable as PDF from NRPB website - nrpb.org

Absorption from Lungs and Body Retention of Caesium

Assumptions

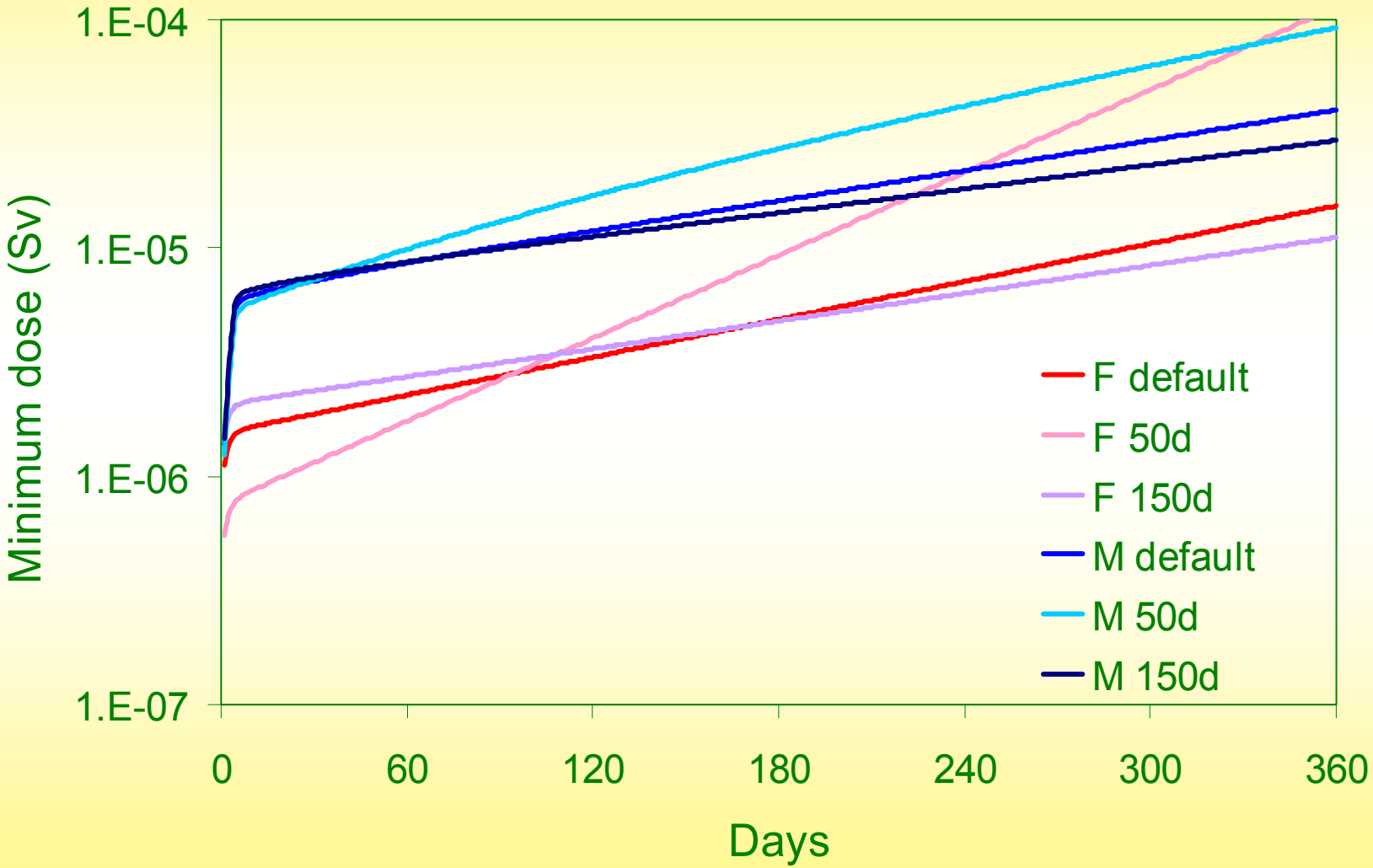
- Absorption

Default Type F- *but can vary between default Types F and M (ICRP 78, 1997)*

- Body Retention

Half-times of 2 d (10%) and 110 d (90%)- *but longer term half-time can vary from about 50 d to 150 d (ICRP 56, 1989)*

Acute Intake: MDA 100 Bq Whole Body



Whole Body Monitoring: Acute Exposure to Type F compound

Days	Dose (μSv) for systemic half-time of;		
	50 days	110 days	150 days
7	0.83	1.6	2.1
30	1.2	1.9	2.4

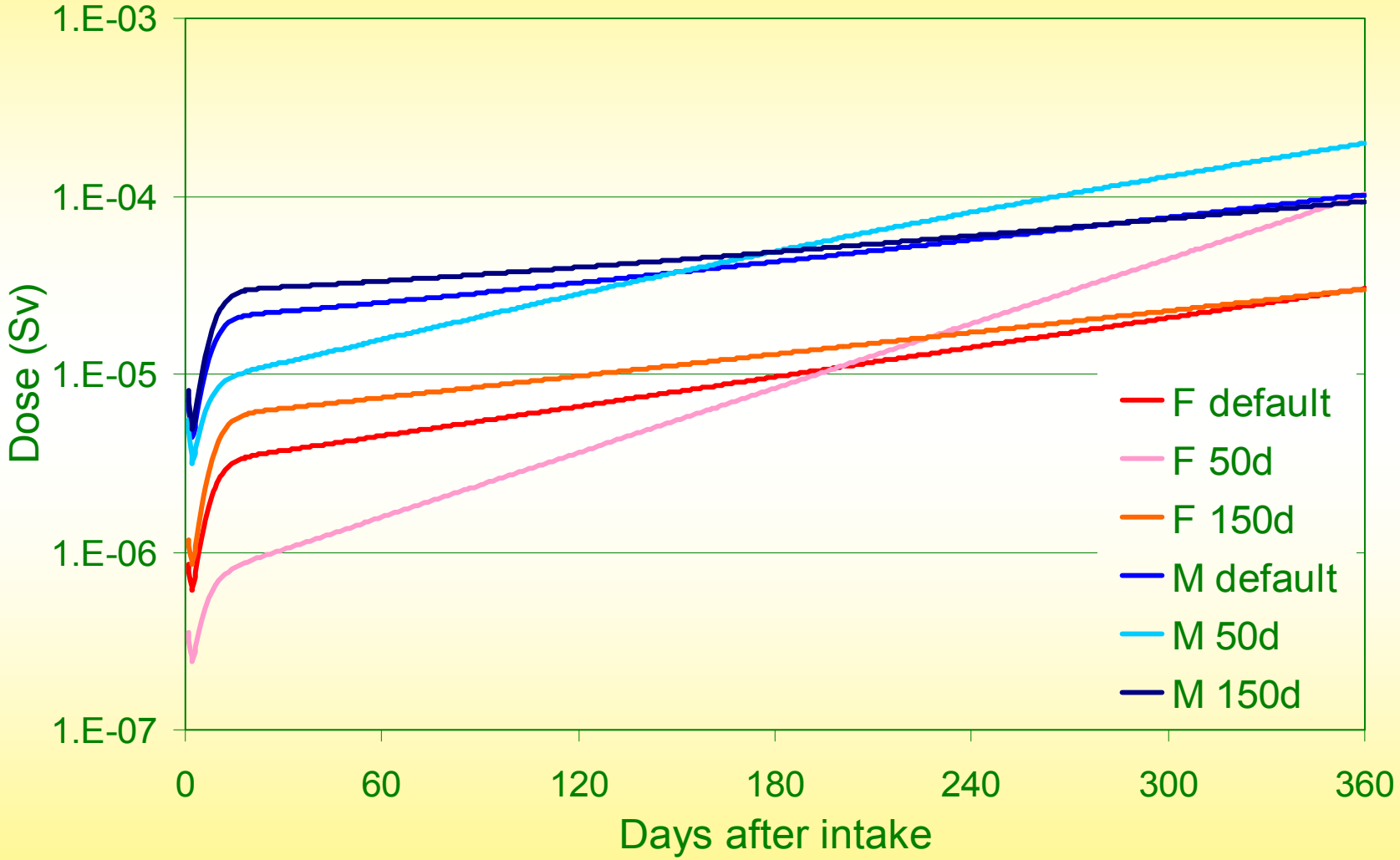
MDA of 100 Bq

Whole Body Monitoring: Acute Exposure to Type M compound

Days	Dose (μSv) for systemic half-time of;		
	50 days	110 days	150 days
7	5.5	5.9	6.4
30	7.1	7.2	7.5
90	13	10	10

MDA of 100 Bq

Acute Intake : MDA 1 Bq d^{-1} in Urine



Urine assay: Acute Exposure to Type F compound

Days	Dose (μSv) for systemic half-time of;		
	50 days	110 days	150 days
7	0.54	1.8	2.8
30	1.9	3.7	2.4

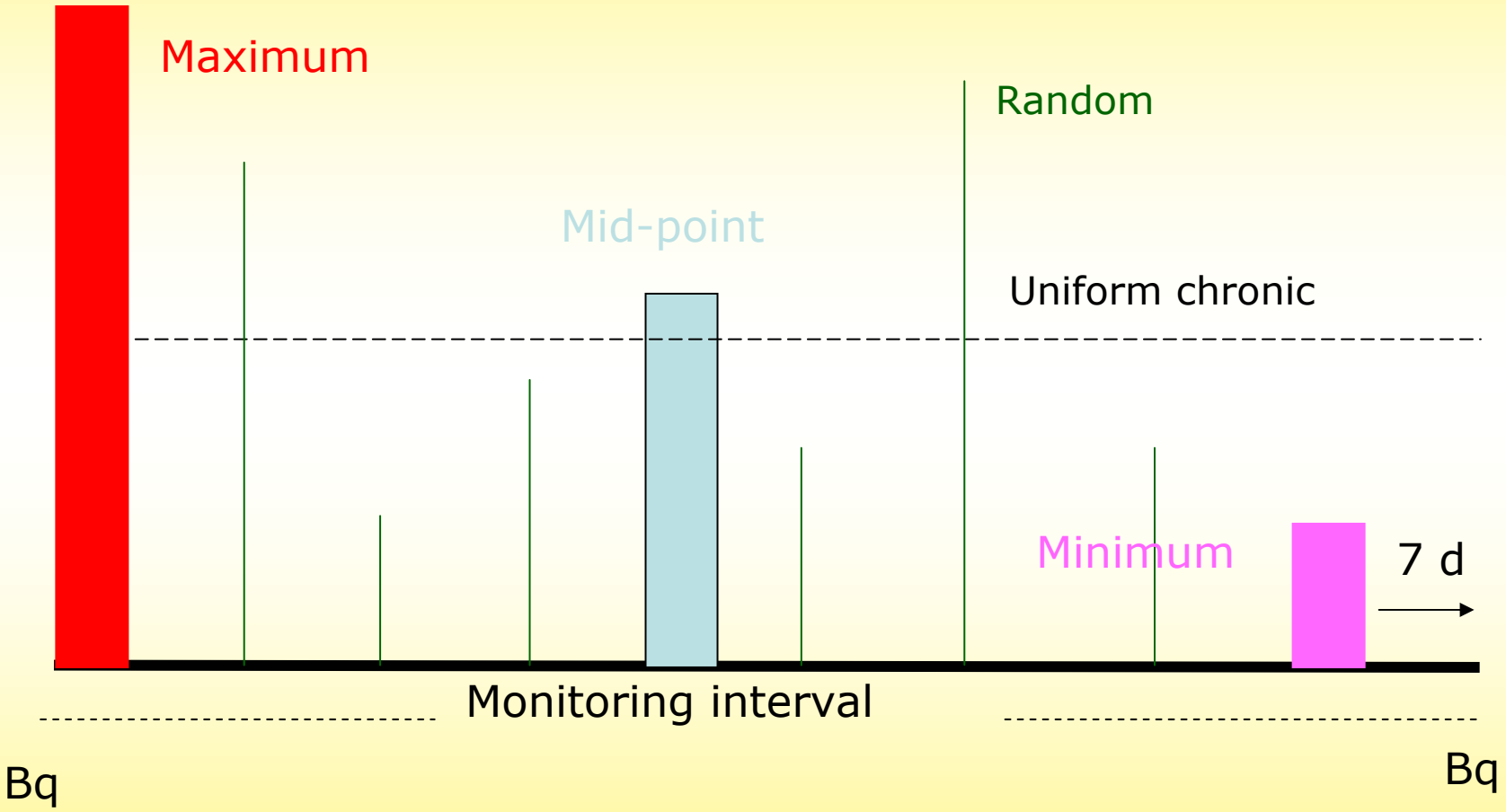
MDA of 1 Bq d^{-1}

Urine assay: Acute Exposure to Type M compound

Days	Dose (μSv) for systemic half-time of;		
	50 days	110 days	150 days
7	6.9	12	15
30	12	22	31
90	21	29	36

MDA of 1 Bq d^{-1}

Intake Model for Repeated Exposure



Whole Body Monitoring: Repeated Exposure to Type F compound

Days	Mid-point intake 110 days	Maximum dose (μSv) for systemic half-time of; 50 days	110 days	150 days
90	2.1	2.7	2.8	3.2
180	2.8	9.3	4.9	4.8
360	4.9	115	15	11

MDA of 100 Bq

Urine assay: Repeated Exposure to Type F compound

Days	Mid-point intake 110 days	Maximum dose (μSv) for systemic half-time of; 50 days	110 days	150 days
90	4.1	2.4	5.5	8.5
180	5.5	8.4	9.6	13
360	9.6	102	30	30

MDA of 1 Bq d^{-1}

Whole Body Monitoring: Repeated Exposure to Type M compound

Days	Mid-point intake 110 days	Maximum dose (μSv) for systemic half-time of; 50 days	110 days	150 days
90	7.9	13	10	10
180	10	27	16	14
360	16	36	40	30

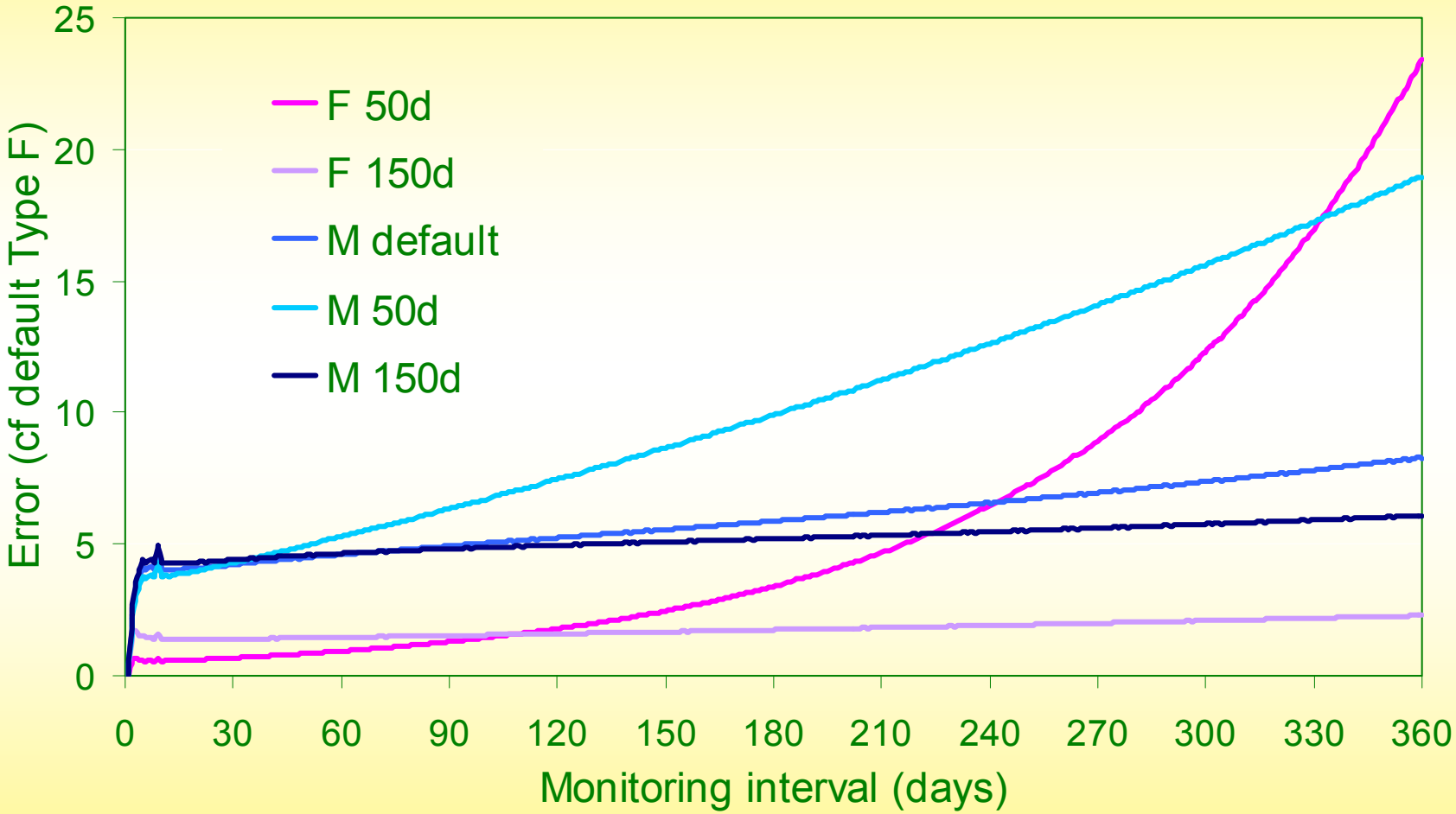
MDA of 100 Bq

Urine assay: Repeated Exposure to Type M compound

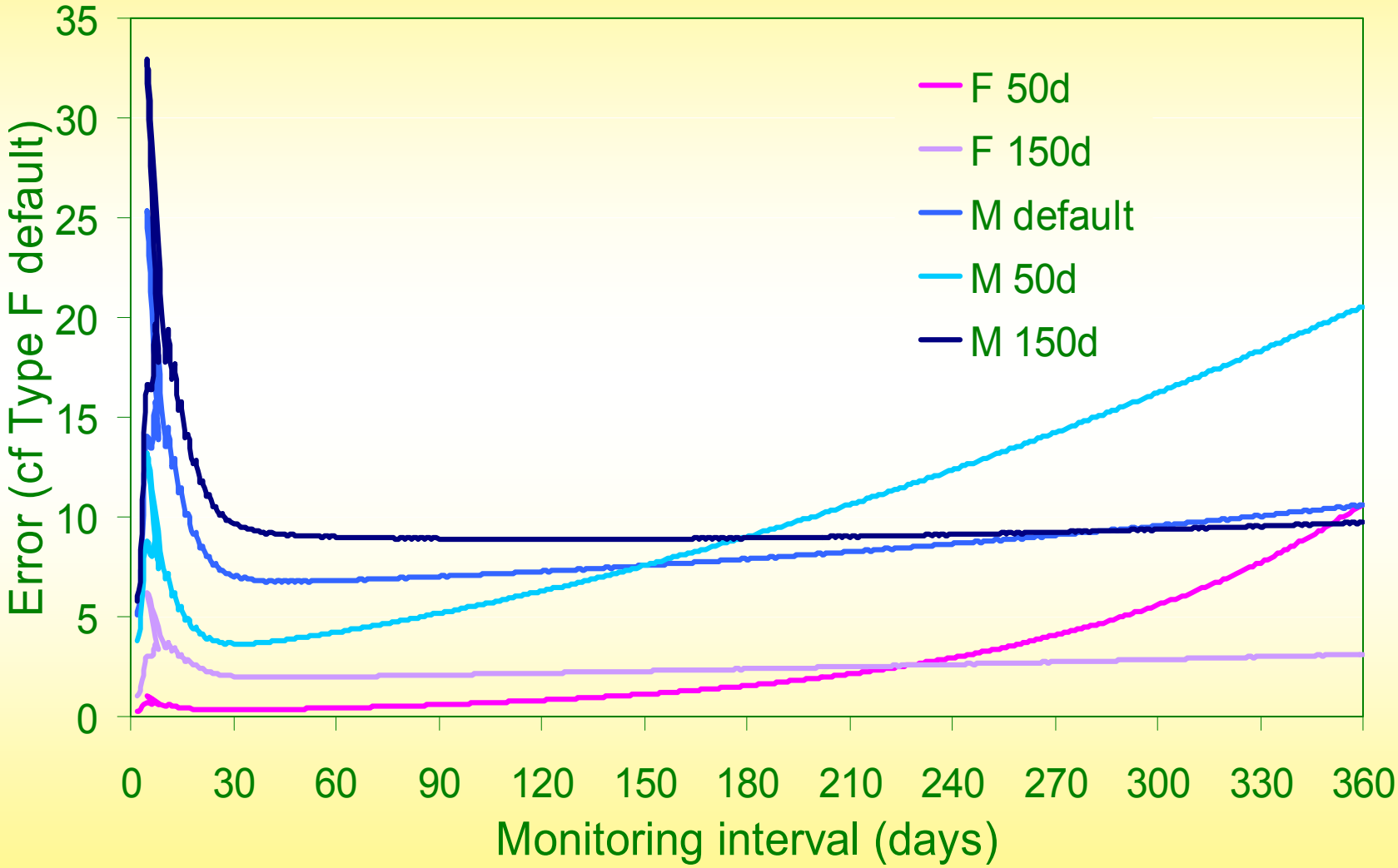
Days	Mid-point intake 110 days	Maximum dose (μSv) for systemic half-time of; 50 days	110 days	150 days
90	24	21	29	36
180	29	49	43	48
360	43	198	102	94

MDA of 1 Bq d^{-1}

Cs-137: Repeated Intake: Whole Body



Cs-137: Urine Assay : Repeated Intake



Summary - Inhalation of Cs

Acute exposure

- *WBM and urine assay can be used for assessing doses less than 1 mSv irrespective of absorption parameter values*

Repeated exposure

- *WBM can be used to assess doses of less than 1 mSv y^{-1} with monitoring interval of 180 d, irrespective of absorption parameter values*
- *Urine assay can be used to assess doses of less than 1 mSv y^{-1} with monitoring interval of 180 d provided background levels are low (say less than 10 Bq d^{-1}) and default Type M biokinetics can be excluded*