IRSN INSTITUT DE RADIOPROTECTION ET DE SÛRETÉ NUCLÉAIRE

Faire avancer la sûreté nucléaire

Basic principles and methods of internal dosimetry

Practical case of internal dose calculation

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Internal contamination implies internal dose

Internal contamination monitoring techniques

Dose calculation

Documentation and software

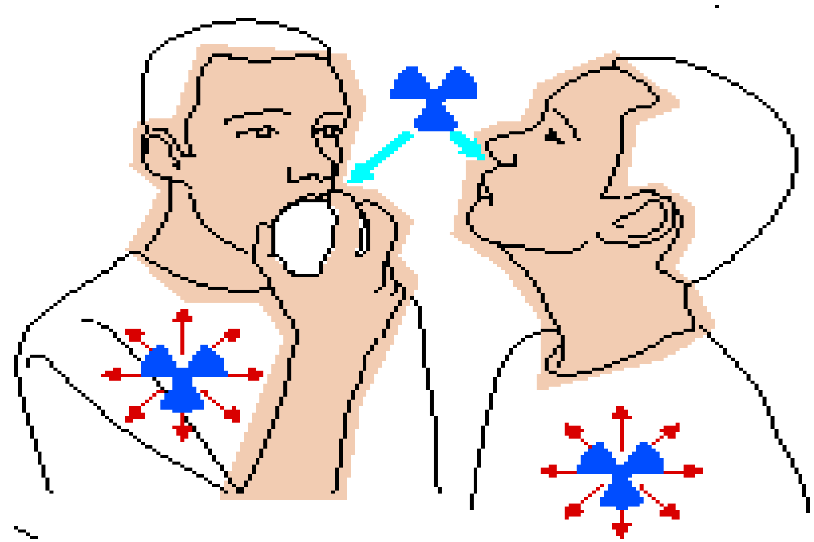
Practical case

Internal contamination implies internal dose

Chronic professional intake of radionuclides

Incidental, accidental acute intake of radionuclides

Inhalation, Ingestion, Injection, Wound



Nuclear industry

- power plants, fuel processing units, mines
- workers, public

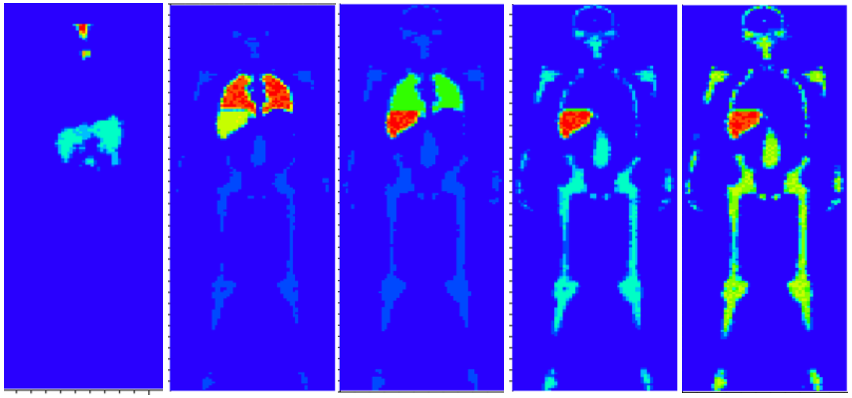
Hospital

- therapeutic and diagnostic nuclear medicine
- patient, workers, public

Internal contamination implies internal dose

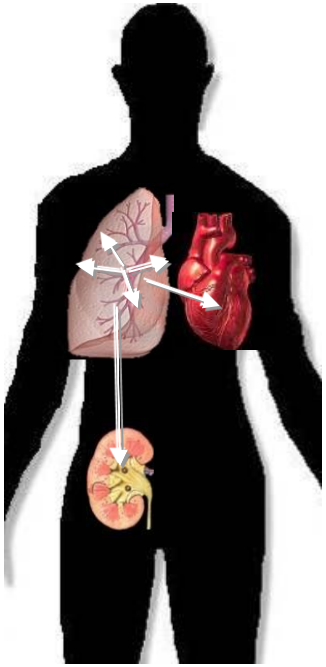
The radionuclides in the body :

- are distributed among organs
- are naturally eliminated



Time dependant & radionuclide specific
biokinetic model

- irradiate the organs in which they are
- irradiate the other organs



Internal contamination implies internal dose

Biokinetics and energy deposition enables to define the committed effective dose (Sv).

$$E = e(50) * Intake$$

Committed effective dose [Sv]

Bq

The dose coefficient per unit intake [Sv/Bq]
Depends on :

- the radionuclide,
- the chemical form of the radionuclide
- the intake pathway
- the age at intake

And is hopefully tabulated !!

Internal contamination monitoring techniques

$$E=e(50)*Intake$$

- Except in very exceptional cases the intake is not known.

- The intake can be assessed from :

- Knowledge of the work place, air monitoring records, …
- Specific measurements of
  - The retained activity (whole body activity, thyroid activity, lung activity)
    - ➢ in vivo measurements
  - The excreted activity (urine or feces)
    - ➢ radio-toxicological analysis

In vivo measurements

- Consists in measuring the radiation emitted from the body
- Requires a shielded room and calibration phantoms
- Gives the retained activity at the measurement time

In vivo measurements

- Recommended for

  Radionuclides emitting high energy and high intensity gamma rays

  e.g. ^{60}Co, ^{131}I, ^{137}Cs, ^{235}U, ^{241}Am, ^{18}F, ^{99m}Tc

- Not useful if

  - Pure beta emitter — ^{241}Pu, $^{3}_{1}$He (tritium)
  - Low energy gamma emitter
    Low intensity gamma emitters
    Alpha emitter — ^{234}U, ^{238}Pu, ^{239}Pu, ^{210}Po

But, for example, ^{234}U can be deduced from ^{235}U

radio-toxicological analysis (in vitro measurements)

- Consists in measuring the radiation emitted by urine or feces samples.
- Detect contamination (small volume) or 24 h-urines to assess dose.
- Theoretically all radionuclides can be measured : alpha, beta, gamma emitters.
- Practically :
  - Requires long chemical preparation and counting for alpha emitters,
  - Laboratories are accredited for a list of radionuclides.
- Take care in case of short life radionuclides : on site storage of samples, delivery delay, on lab storage of samples…

Recommended for :

^{3}H, ^{14}C, $^{32-33}$P, ^{35}S, ^{45}Ca, ^{90}Sr (β)

$^{238-239}$Pu, ^{244}Cm, $^{234-235-238}$U, $^{228-230-232}$Th (α)

^{55}Fe, ^{109}Cd (γ)

Dose calculation

How to deduce the intake from the measured retention/excretion ?

* Retention/Excretion functions are tabulated

* They give the expected Retention/Excretion for an intake of 1 Bq.

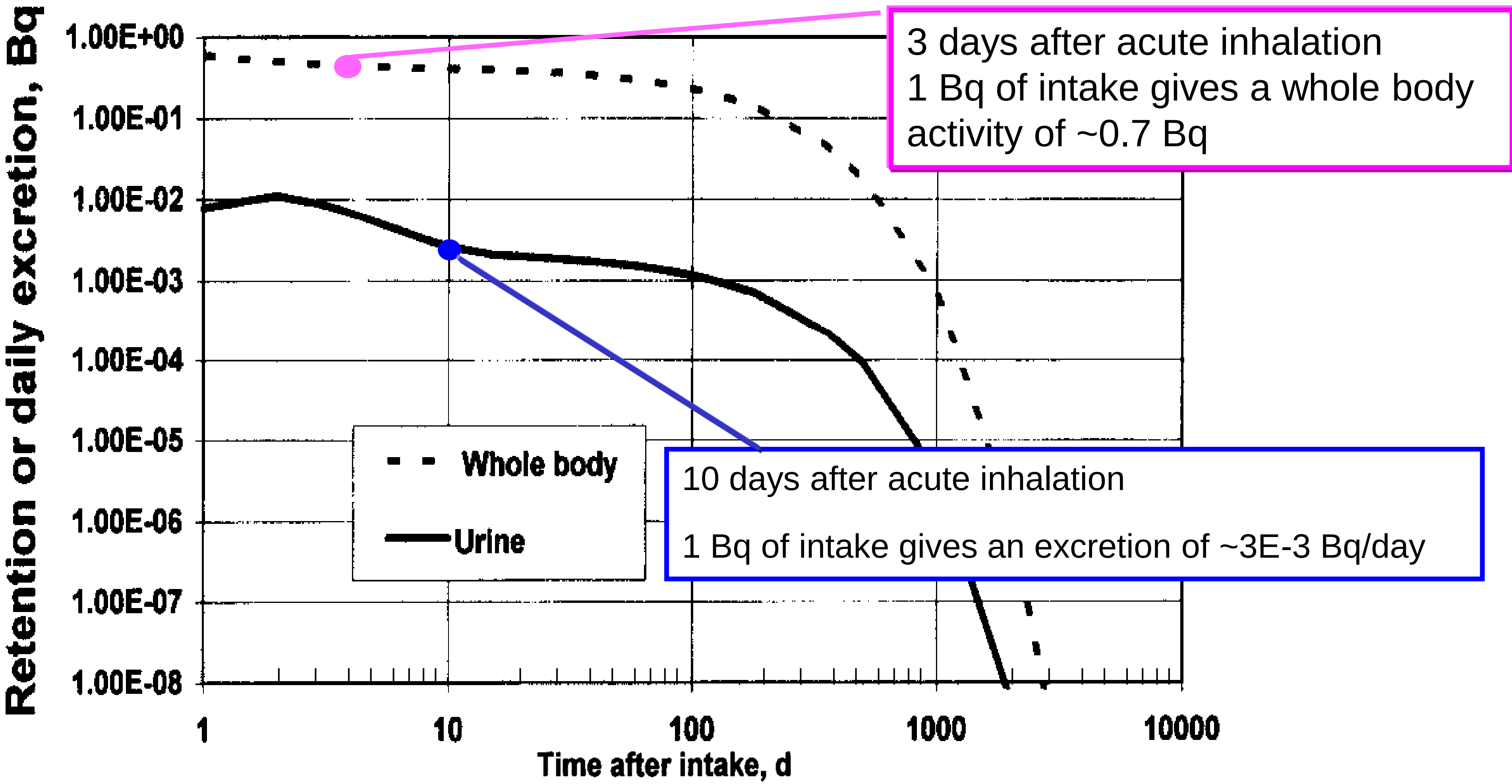
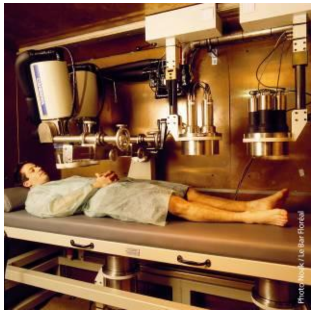


Fig. A.7.4. ^{137}Cs Inhalation Type F: predicted values (Bq per Bq intake) following acute intake.

Dose calculation

(i) Identify & measure the retained/excreted activity

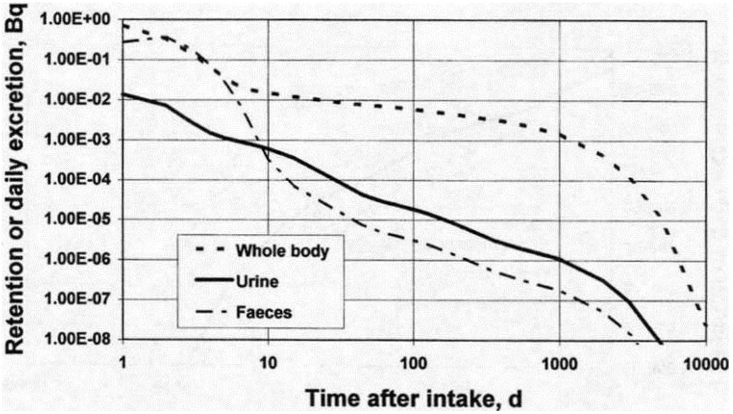


(ii) **Calculate the intake**

$$Intake\ [Bq] = \frac{Measure\ [Bq]}{m(t)\ [Bq/Bq\ of\ Intake]}$$

m(t): model prediction

Excretion/retention function



(iii) **Calculate the dose**

E=e(50)*Intake

Documentation and software

How to select retention functions *"m(t)"* and dose coefficients *"e(50)"* ?

- Reference documents
- How to use them, selection of relevant parameters

Software

- Computation of *m(t)* and *e(50)*
- Intake assessment from a series of measurements

How to select retention functions *“m(t)”* and dose coefficients *“e(50)”* ?

ICRP (http://www.icrp.org/publications.asp)

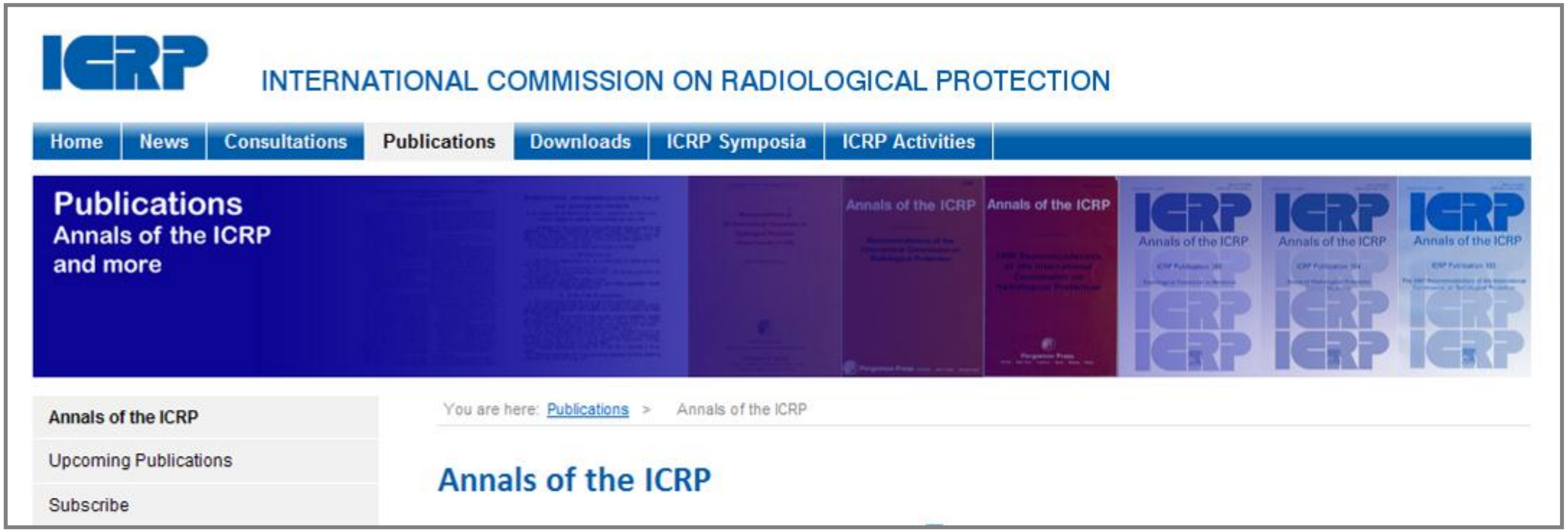
ICRP Publication 119 — *Compendium of Dose Coefficients based on ICRP Publication 60*

GIVES e(50), FREE

ICRP Publication 78 — *Individual Monitoring for Internal Exposure of Workers*

ICRP Publication 54 — *Individual Monitoring for Intakes of Radionuclides by Workers*

GIVE m(t), SUBSCRIPTION NEEDEED



How to select retention functions *"m(t)"* and dose coefficients *"e(50)"* ?

AIEA

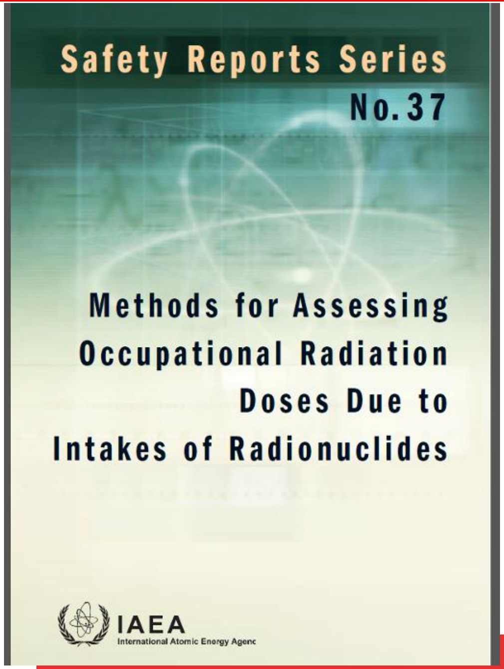
Safety Reports Series No. 37. Methods for Assessing Occupational Radiation Doses Due to Intakes of Radionuclides

http://www-pub.iaea.org/MTCD/Publications/PDF/Pub1190/Pub1190_web.pdf

GIVES e(50), FREE

Annexes : http://www-pub.iaea.org/MTCD/publications/PDF/Pub1190/tables.pdf

GIVES m(t), FREE



Download the annexes quickly, I cannot ensure that the link will work for long…

Documentation and software

How to select retention functions *“m(t)”* and dose coefficients *“e(50)”* ?

European Commission

COUNCIL DIRECTIVE 96/29/EURATOM of 13 May 1996 **GIVES e(50), FREE**

http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=OJ:L:1996:159:FULL&from=EN

Use this link, quick “google research” might drive you to an incomplete document.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Documentation and software

How to select retention functions *“m(t)”* and dose coefficients *“e(50)”* ?

- Reference documents
- **How to use them, selection of relevant parameters**

Documentation and software

ICRP Publication 119

ANNEX A. EFFECTIVE DOSE COEFFICIENTS FOR INGESTED AND INHALED PARTICULATES FOR WORKERS

Table A.1. Effective dose coefficients (e) for ingested and inhaled particulates (activity median aerodynamic diameters of 1 and 5 μm) for workers.

Nuclide	$T_{1/2}$	Inhalation				Ingestion	
		Type	f_1	e (Sv/Bq) (1 μm)	e (Sv/Bq) (5 μm)	f_1	e (Sv/Bq)
Hydrogen							
H-3	12.35 y	See Table B.1 for inhalation dose coefficients				1.0 OBT	4.2E−11
						1.0 HTO	1.8E−11
Beryllium							
Be-7	53.3 d	M	0.005	4.8E−11	4.3E−11	0.005	2.8E−11
		S	0.005	5.2E-11	4.6E−11		
Be-10	1.6E6 y	M	0.005	9.1E−09	6.7E−09	0.005	1.1E−09
		S	0.005	3.2E−08	1.9E−08		

1. Select inhalation or ingestion
2. Select Activity Median Aerodynamic Diameter (AMAD)

   5 μm : recommended for workers, 1 μm recommended for public members
3. Select « solubility », depending on chemical form

Documentation and software

ICRP Publication 119

ANNEX E. COMPOUNDS, LUNG CLEARANCE TYPES, AND f_1 VALUES USED FOR THE CALCULATION OF INHALATION DOSE COEFFICIENTS FOR WORKERS

Table E.1. Classification of inhaled particulate matter in the workplace.

Element	Type	f_1	Compounds
Cobalt	M	0.1	Unspecified compounds
	S	0.05	Oxides, hydroxides, halides, and nitrates
Uranium	F	0.02	Most hexavalent compounds [e.g. UF_6, UO_2F_2, $UO_2(NO_3)_2$]
	M	0.02	Less-soluble compounds (e.g. UO_3, UF_4, UCl_4, most other hexavalent compounds)
	S	0.002	Highly insoluble compounds (e.g. UO_2, U_3O_8)

The chemical form, if listed, gives a recommendation for type (F, M, S)

F: Fast, M: Medium, S: Slow

Documentation and software

ANNEXES of *AIEA Safety Reports Series No. 37*

Radionuclide: Cs-137
Intake: Inhalation Type F
Aerosol size: 1.0 micron AMAD
f1: 1.00000

Time (d)	Urine	Faeces	Tot. Body
1	5.7E-03	5.6E-04	4.0E-01
2	8.0E-03	1.4E-03	3.5E-01
3	6.3E-03	1.7E-03	3.3E-01
4	4.9E-03	1.6E-03	3.2E-01
5	3.9E-03	1.4E-03	3.1E-01
6	3.2E-03	1.1E-03	3.1E-01
7	2.7E-03	9.1E-04	3.0E-01
8	2.3E-03	7.6E-04	3.0E-01
9	2.1E-03	6.5E-04	3.0E-01
10	1.9E-03	5.7E-04	2.9E-01
20	1.4E-03	3.6E-04	2.8E-01
30	1.3E-03	3.3E-04	2.6E-01
40	1.2E-03	3.1E-04	2.4E-01
50	1.1E-03	2.9E-04	2.3E-01
60	1.1E-03	2.7E-04	2.1E-01
70	1.0E-03	2.5E-04	2.0E-01
80	9.5E-04	2.4E-04	1.9E-01

Three days after acute inhalation of ^{137}Cs in vivo measurement gives a retained activity of 300 Bq.

The intake is thus 300/3.3E-01~909 Bq

Documentation and software

How to select retention functions *"m(t)"* and dose coefficients *"e(50)"* ?

- Reference documents
- How to use them, selection of relevant parameters

Software

- **Computation of *m(t)* and *e(50)***
- Intake assessment from a series of measurements

Software : computation of *m(t)* and *e(50)*

MONDAL (NIRS, Japan)

FREE & IN LINE

Please select [Intake route & Subject] and [Radionuclide]

Intake route & Subject	Radionuclide (Pull down menu)
○ Inhalation by workers ◉ Ingestion by workers ○ Inhalation by members of the public ○ Ingestion by members of the public	Co-60

Continue

Start Page, request a PC version

http://www.nirs.go.jp/db/anzendb/RPD/mondal3.php

In line software

http://www.nirs.go.jp/db/anzendb/RPD/gpmd1.php

Co60 Ingested by workers.

Please select [Chemical Form] and [Retention/Excretion].

Chemical Form

◉ Oxides, hydroxides and inorganic compounds : f1=0.05
○ Unspecified compounds : f1=0.1

Retention/Excretion

◉ Whole-body retention
○ Daily urinary excretion
○ Daily faecal excretion

Which graph do you want?

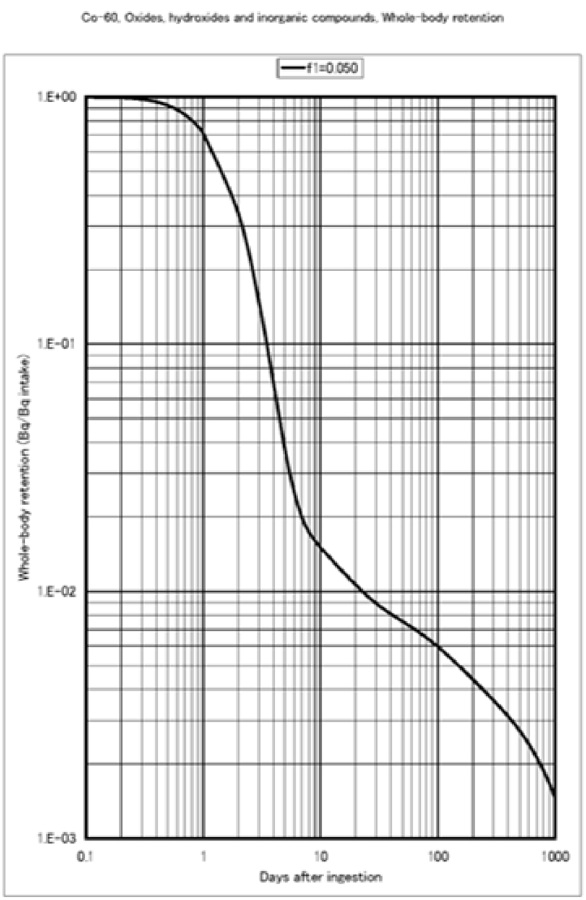
◉ Predicted values of the retention or excretion of radionuclides
○ Committed effective dose(CED) per measured radioactivity

Get Graph

Software : computation of *m(t)* and *e(50)*

MONDAL (NIRS, Japan)

| Higher quality graph (PDF file)|
| Numerical data|



Access to numerical data (tables)

Access to committed effective dose (CED) per measured activity, *i.e.* directly takes into account e(50) and retention

Software : computation of *m(t)* and *e(50)*

DCAL (K. Eckerman et al. , ORNL) **FREE**

Includes 800 radionuclides

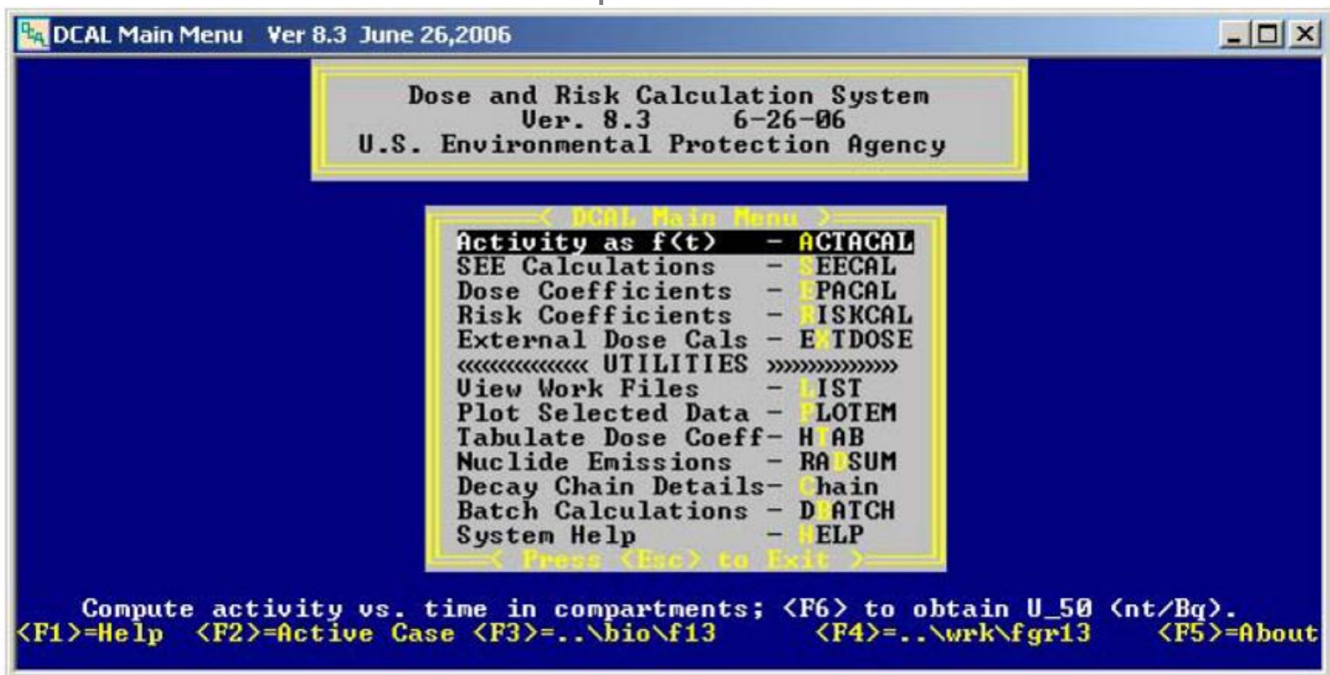
Compute e(50), retention/excretion functions

Compute about everything you want

Can vary most of parameters (biokinetic, AMAD, age)

MS-DOS based

Not so user friendly



http://www.epa.gov/radiation/assessment/dcal.html

Documentation and software

How to select retention functions *"m(t)"* and dose coefficients *"e(50)"* ?

- Reference documents
- How to use them, selection of relevant parameters

Software

- Computation of m(t) and e(50)
- **Intake assessment from a series of measurements**

Documentation and software

Intake assessment from a series of measurements

Retention/Excretion measurements do not follow exactly the biokinetic model:

* Normal (daily) variation
* Inter-individual variations
* Model and measurement uncertainties

It's thus **better to use a series of measurements** especially if :

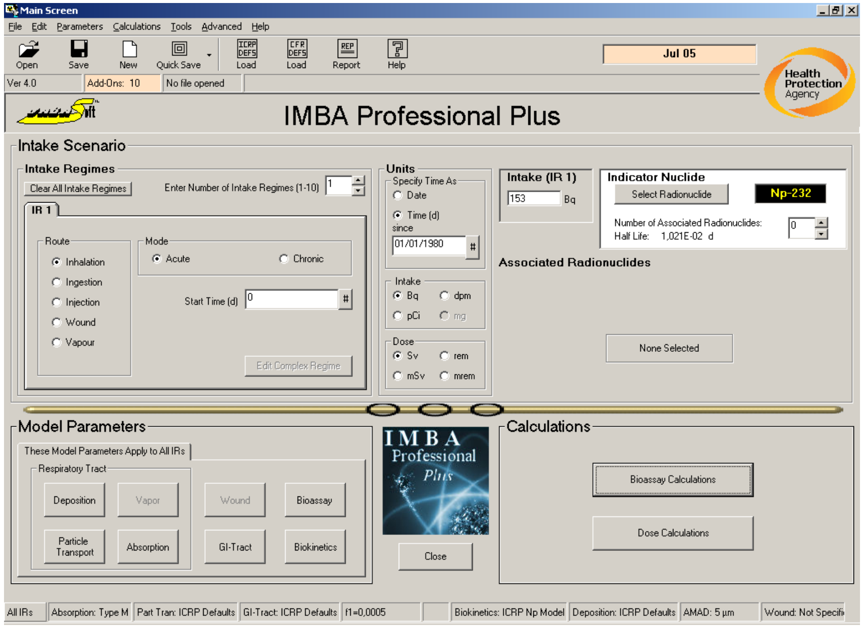
* the first dose assessment gives a rather high dose
* the time of intake is unknown

Intake assessment from a series of measurement can be done "by hand", however it is easier and safer to use a validated and **devoted software**.

Intake assessment from a series of measurements

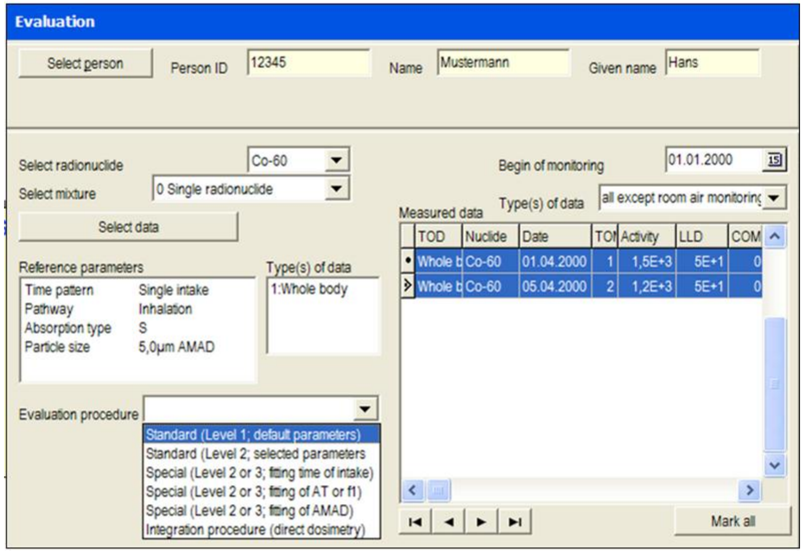
IMBA (PHE, England)

https://www.phe-protectionservices.org.uk/imba



IDEA System (IDEA-System GmbH, Germany)

http://www.idea-system.com/



Practical case

The « occupational physician » ask you to assess the dose, following a contamination incident with ^{131}I of a worker in a nuclear medicine department. The incident is poorly described but probably due to a catheter leakage.

Incident date: September 24th

Urine measurements: October 1st, 16 Bq/24h.

Practical case

Tables from ICRP 78

Ingestion is unlikely.

Iodine is highly volatile : vapor is a good choice (SR-1 used for reactive or soluble compound).

If not sure, take the most conservative dose assessment, i.e. test different hypotheses. The highest e(50) WILL NOT necessarily give the highest estimate, m(t) also plays its role.

Table A.6.1. Compounds, absorption types and f_1 values

Intake	f_1	Compounds
Ingestion	1.0	All compounds
Inhalation, Class SR-1	1.0	Iodine vapour
Inhalation, Type F	1.0	All other compounds

Table A.6.2. Dose coefficients

				Inhalation		Ingestion	
Nuclide	$t_{1/2}$	Type	Class	f_1	$e(50)$,Sv Bq^{-1}	f_1	$e(50)$,Sv Bq^{-1}
I-125	60.1 d	F	—	1.0	7.3E–09	1.0	1.5E–08
		F	SR–1[a]	1.0	1.4E–08		
I-129	1.57E+07 y	F	—	1.0	5.1E–08	1.0	1.1E–07
		F	SR-1	1.0	9.6E–08		
I-131	8.04 d	F	—	1.0	1.1E–08	1.0	2.2E–08
		F	SR-1	1.0	2.0E–08		

[a]The model for iodine vapour is described in *Publication 68* (ICRP, 1994)

Practical case

Table A.6.17. Special monitoring: predicted values (Bq per Bq intake) for inhalation of ^{131}I

	Type F		Vapour	
Time after intake (d)	Thyroid	Daily urinary excretion	Thyroid	Daily urinary excretion
1	1.2E–01	2.8E–01	2.3E–01	5.3E–01
2	1.2E–01	2.3E–02	2.2E–01	4.3E–02
3	1.1E–01	1.4E–03	2.0E–01	2.5E–03
4	9.9E–02	1.5E–04	1.9E–01	2.7E–04
5	9.0E–02	8.9E–05	1.7E–01	1.7E–04
6	8.2E–02	9.6E–05	1.5E–01	1.8E–04
7	7.4E–02	1.0E–04	1.4E–01	1.9E–04
8	6.8E–02	1.1E–04	1.3E–01	2.0E–04
9	6.2E–02	1.1E–04	1.2E–01	2.1E–04
10	5.6E–02	1.1E–04	1.1E–01	2.1E–04

$$Intake = \frac{MEASURED\ Daily\ Urinary\ Excretion}{m(t)}$$

$$= \frac{16\,[Bq/24h]}{1.9E-4} = 8.4\ 10^{4}\ Bq$$

Committed effective dose=8.4 10^{4}*2 10^{-8}~**1.7 mSv**

Practical case

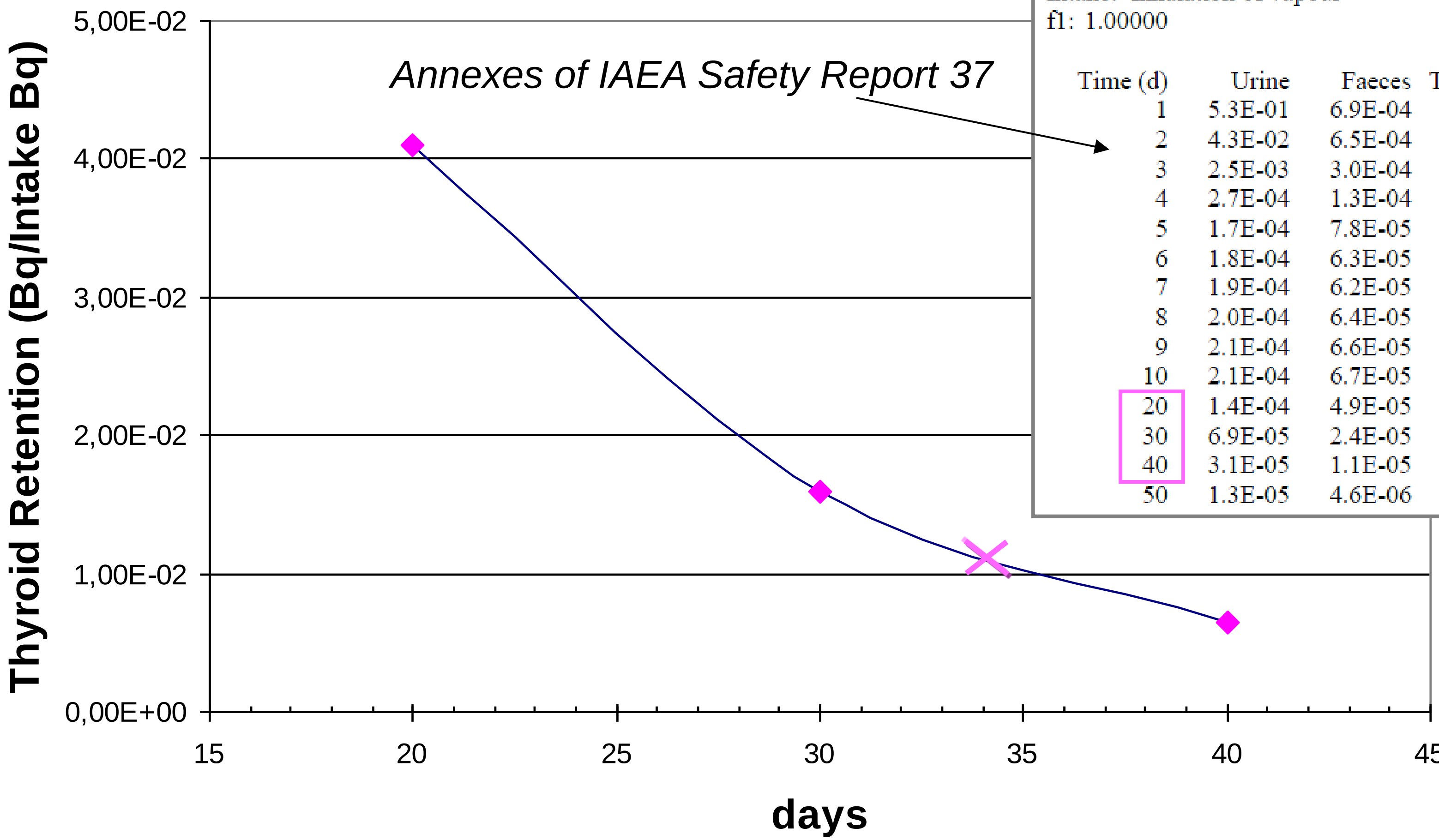
The « occupational physician » ask you to assess the dose, following a contamination incident with ^{131}I of a worker in a nuclear medicine department. The incident is poorly described but probably due to a catheter leakage.

Incident date: September 24th

Urine measurements: October 1st, 16 Bq/24h.

Thyroid measurement: October 28th, 40 Bq.

Practical case



Radionuclide: I-131
Intake: Inhalation of vapour
f1: 1.00000

Time (d)	Urine	Faeces	Tot. Body	Thyroid
1	5.3E-01	6.9E-04	3.3E-01	2.3E-01
2	4.3E-02	6.5E-04	2.4E-01	2.2E-01
3	2.5E-03	3.0E-04	2.1E-01	2.0E-01
4	2.7E-04	1.3E-04	1.9E-01	1.9E-01
5	1.7E-04	7.8E-05	1.8E-01	1.7E-01
6	1.8E-04	6.3E-05	1.6E-01	1.5E-01
7	1.9E-04	6.2E-05	1.5E-01	1.4E-01
8	2.0E-04	6.4E-05	1.3E-01	1.3E-01
9	2.1E-04	6.6E-05	1.2E-01	1.2E-01
10	2.1E-04	6.7E-05	1.1E-01	1.1E-01
20	1.4E-04	4.9E-05	4.6E-02	4.1E-02
30	6.9E-05	2.4E-05	1.8E-02	1.6E-02
40	3.1E-05	1.1E-05	7.4E-03	6.4E-03
50	1.3E-05	4.6E-06	2.9E-03	2.5E-03

Read thyroid retention : **$1\ 10^{-2}$**

Intake = 40 Bq/($1\ 10^{-2}$)=4 000 Bq

Dose = 4 000*2 10^{-8}=**80 µSv**

Practical case

The « occupational physician » ask you to assess the dose, following a contamination incident with ^{131}I of a worker in a nuclear medicine department. The incident is poorly described but probably due to a catheter leakage.

Incident date: September 24th

Urine measurements: October 1st, 16 Bq/24h.

Thyroid measurement: October 28th, 40 Bq.

Urine measurement → 1.7 mSv

Thyroid measurement → 0.08 mSv

?!?!

Discussion with the occupational physician, worker, staff, etc :

** date of contamination sure ?*

** possibility of small intakes (chronic exposure) ?*

** continue follow-up ?*

Such cases are not exceptional.

GEOMETRIC AVERAGE

$$Dose = \sqrt{1.7 \times 0.08} \approx 0.37\ \mathrm{mSv}$$

CONCLUSION

It's not as difficult as it seems to be.

Do not work alone.

Be as conservative as reasonably reasonable †.

† *This is a personal advice, not an official recommendation of IRSN*

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