IAEA
International Atomic Energy Agency
Atoms for Peace and Development

ASSESSMENT OF OCCUPATIONAL EXPOSURE DUE TO INTERNAL RADIATION SOURCES

UNIT 3

GENERAL PRINCIPLES OF THE DOSIMETRY OF INTERNAL EXPOSURES

GENERAL PRINCIPLES OF INTERNAL DOSIMETRY

CONTENTS OF LECTURE

- **EXPOSURES TO IONIZING RADIATIONS**
  - ✓External exposures
  - ✓Internal exposures

- **DOSE QUANTITIES**
  - ✓Absorbed Dose
  - ✓Radiation weighting factors $\mathbf{w_R}$
  - ✓Tissue weighting factors $\mathbf{w_T}$
  - ✓Equivalent Dose, Effective Dose
  - ✓Committed Equivalent Dose, Committed Effective Dose
  - ✓Annual doses

GENERAL PRINCIPLES OF INTERNAL DOSIMETRY

CONTENTS OF LECTURE (Cont.)

- **ASSESSMENT OF DOSES DUE TO INTERNAL EXPOSURES**
  - ✓ Definition of the reference person
  - ✓ ICRP Reference computational phantoms
  - ✓ Biokinetic Models
  - ✓ Dosimetric Models
  - ✓ Assessment of Intake and Committed Effective Dose

- **OCCUPATIONAL INTERNAL DOSIMETRY**

- **ICRP METHODOLOGY FOR INTERNAL DOSIMETRY**
  - ✓ OIR (Occupational Intakes of Radionuclides) Reports (Parts 1-5)
  - ✓ Other reference documents on internal dosimetry

GENERAL PRINCIPLES OF INTERNAL DOSIMETRY

- **EXPOSURES TO IONIZING RADIATIONS**

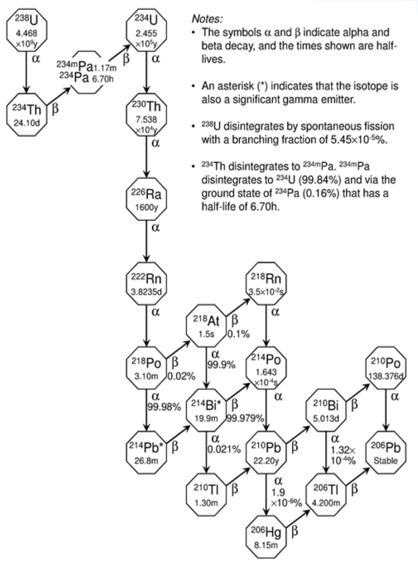
✓ **NATURAL SOURCES**

- **Cosmic Radiation**
- **Terrestrial Radioactive Sources** e.g. the **3 natural radioactive series** of **^{238}U, ^{235}U, ^{232}Th** (heavy elements, half-lives ~ the age of earth)

✓ **ARTIFICIAL SOURCES -** applications of ionizing radiations in:

- Medicine
- Industry
- Research
- Energy production
- Nuclear tests

and the residual materials of these activities.



Decay chain of ^{238}U
(OIR P1, ICRP Publication 130)

GENERAL PRINCIPLES OF INTERNAL DOSIMETRY

- **EXPOSURES TO IONIZING RADIATIONS**
  - ✓ **External exposures**
    - **External irradiation** - source of radiation is outside the body; radiation emitted by the source can interact with the human body (mainly gamma and beta radiations)
    - **External contamination** e.g. skin contamination
  - ✓ **Internal exposures**

    Radioactive material can be incorporated into the body by:
    - **Inhalation**
    - **Ingestion**
    - **Injection**
    - **Absorption though intact skin or through a wound**

    INTAKE: total activity (Bq) of a radionuclide entering the body from the external environment.

GENERAL PRINCIPLES OF INTERNAL DOSIMETRY

- **DOSE QUANTITIES**

✓ **Absorbed Dose**

- **Energy absorbed per unit mass** (joules kg^{-1} or **gray (Gy)**)
- **Internal dosimetry:** calculation of the absorbed dose in a target organ/tissue "T" caused by nuclear transformations (disintegrations) in a source region "S". The source region "S" contains the radionuclide after the intake.

$$D_T(Gy) = \frac{Average\ energy\ absorbed\ in\ organ\ T\ (J)}{Mass\ of\ organ\ T\ (kg)}$$

GENERAL PRINCIPLES OF INTERNAL DOSIMETRY

✓ Radiation weighting factors w_R

- w_R are established by ICRP for radiation protection purposes.
- Values of w_R are based on data for the Relative Biological Effectiveness (RBE) of different radiations.
- RBE: the ratio of absorbed doses of two types of radiation producing the same biological effect, where reference radiation is low LET radiation (gamma or x-rays)

Type of Radiation "R"	Radiation weighting factor "w_R" ICRP 60 (1990)	Radiation weighting factor "w_R" ICRP 103 (2007)
Alpha particles and heavy ions	20	20
Electrons β and muons	1	1
Gamma γ	1	1
Protons	5	2
Neutrons	5 - 20	$f(E_n)$

- w_R are used to derive the equivalent dose from the absorbed dose averaged over an organ/tissue

GENERAL PRINCIPLES OF INTERNAL DOSIMETRY

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- ✓ **Tissue weighting factors w_T** – representing the relative contribution of an organ/tissue “T” to the total health detriment resulting from uniform irradiation of the body.

w_T are used to derive the effective dose from the equivalent doses

Weighting factors represent mean values averaged over both sexes and all ages

Organ/Tissue “T“	w_T ICRP 60 (1990)	w_T ICRP 103 (2007)
Gonads	0.20	0.08
Bone marrow (red), Colon, Lung, Stomach	0.12	0.12
Bladder	0.05	0.04
Breast	0.05	0.08
Liver	0.05	0.05
Oesophagus	0.05	0.04
Thyroid	0.05	0.04
Skin	0.01	0.01
Brain	--	0.01
Salivary Glands	--	0.01
Bone surface	0.01	0.01
Remainder	0.05	0.08

GENERAL PRINCIPLES OF INTERNAL DOSIMETRY

- **DOSE QUANTITIES**
  - ✓**Equivalent Dose H_T** in an organ/tissue "T", in Sieverts:

$$H_T\ (Sv) = \sum_R w_R D_{T,R}$$

Some types of radiations are more harmful than others in causing stochastic effects.

  - ✓**Effective Dose E**, in Sieverts:

$$E\ (Sv) = \sum_T w_T H_T$$

Some organs/tissues are more radiosensitive than others for stochastic effects

Effective dose only applies to stochastic effects
Allows comparison with dose limits / dose constraints

GENERAL PRINCIPLES OF INTERNAL DOSIMETRY

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- **DOSE QUANTITIES - Internal Dosimetry**

  In case of intakes of radionuclides, internal doses are protracted over time and **committed doses** are calculated, over a certain period of time:

✓**Committed Equivalent Dose H_T** in an organ/tissue "T", in Sieverts:

$$H_T(50)\ Sv = \int_0^{50} \dot{H}_T\, dt$$

The dose rate is integrated over a period of 50 years for an adult.
The integration period is from age at intake to 70 years, for children

$$E\ (50)\ Sv = \sum_T w_T H_T(50)$$

✓**Committed Effective Dose E(50),** in Sieverts:

GENERAL PRINCIPLES OF INTERNAL DOSIMETRY

- **DOSE QUANTITIES - Internal Dosimetry**

  - ✓ **ANNUAL DOSES** from intakes of radionuclides

    Committed effective dose E(50) for a specified year is the effective dose committed (i.e. received) over 50 years arising from **all intakes in the specified year.**

  - ✓ **Committed effective dose E(50)** is a radiation protection quantity, is the dose to a **reference person** in a given exposure situation.

    If the effective dose complies to the limits, the exposed individual is protected adequately.

GENERAL PRINCIPLES OF INTERNAL DOSIMETRY

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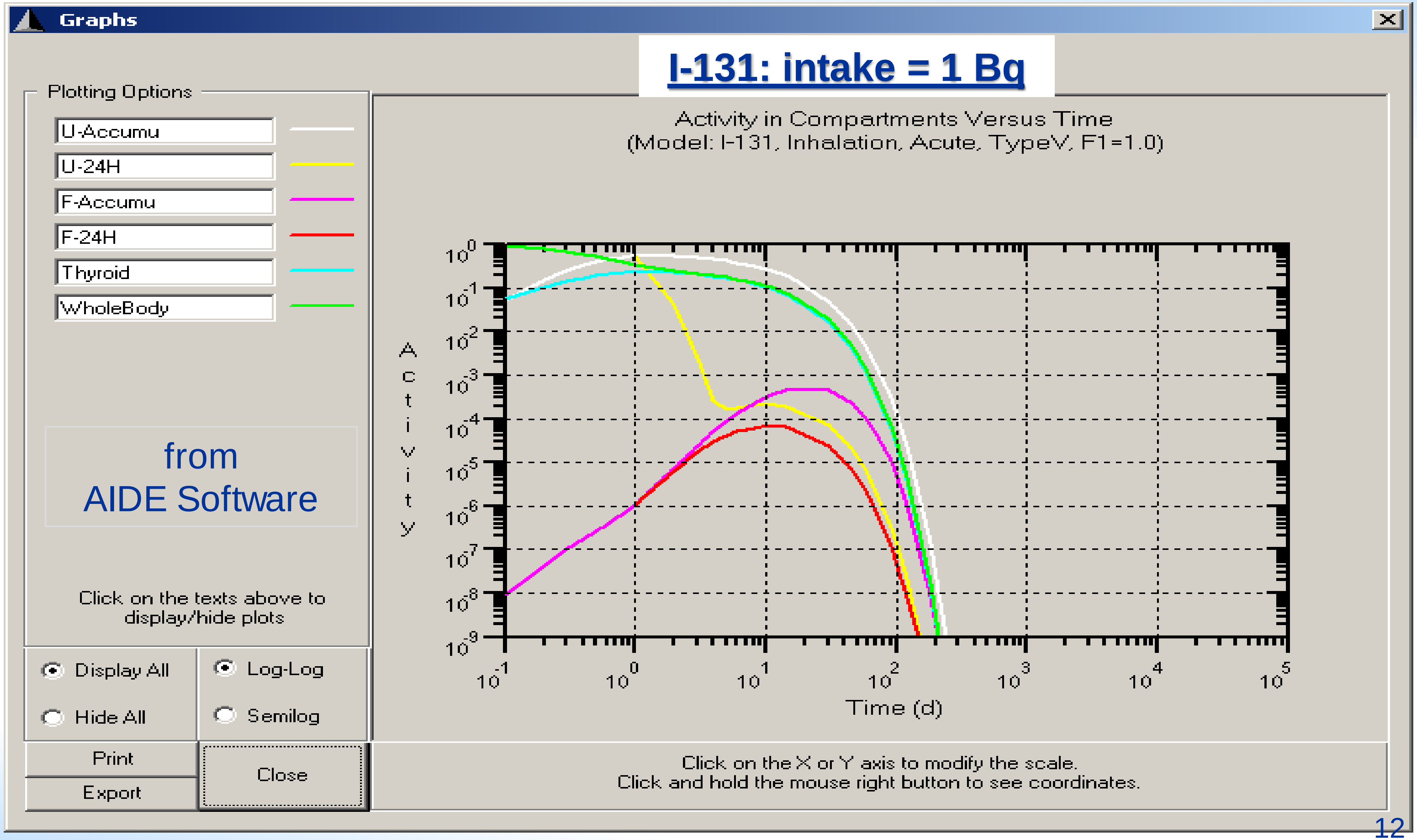
BIOKINETIC MODELS

Retention Functions
- Thyroid
- Whole body
- Lungs
- …

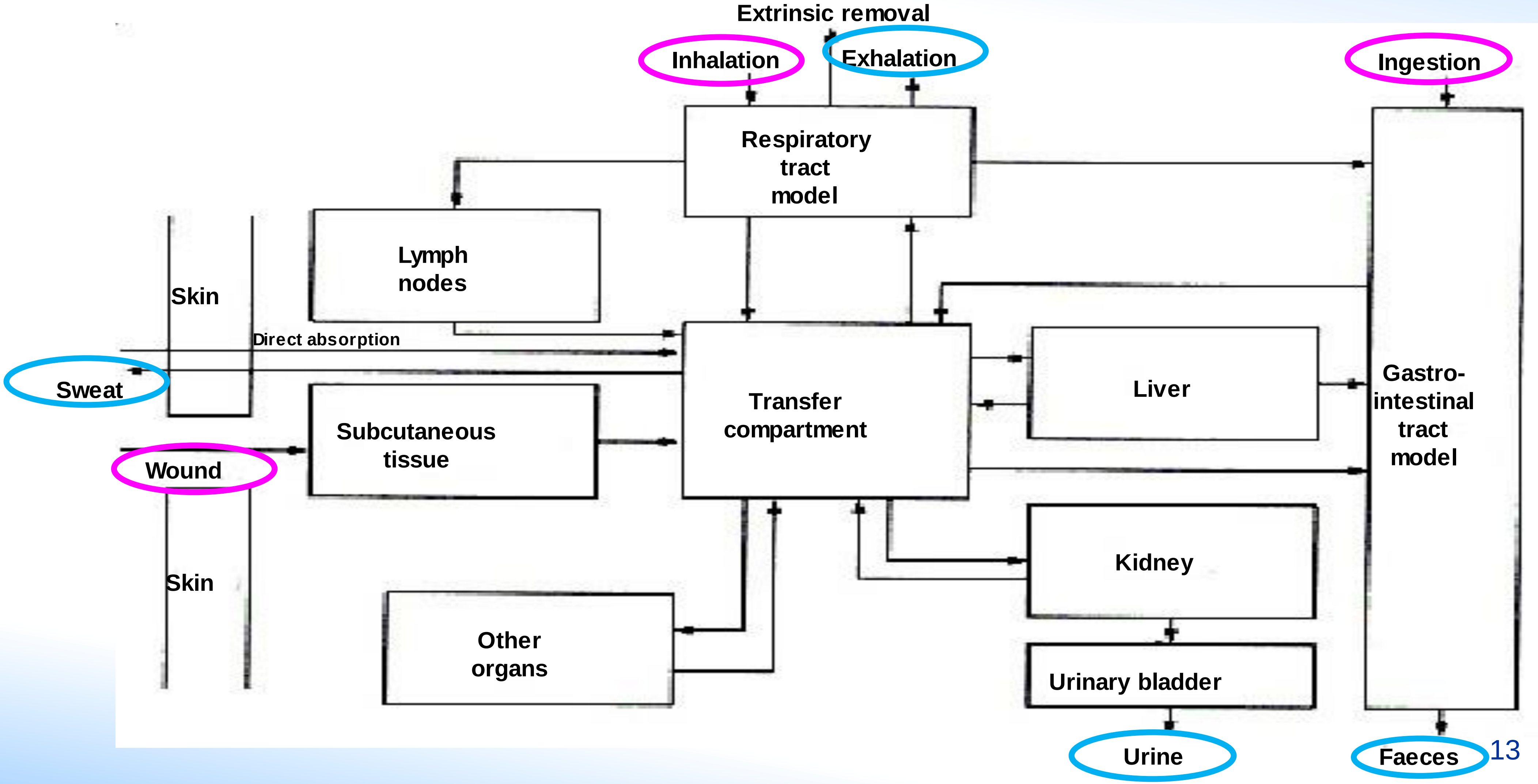
Excretion Functions
- Urine 24h
- Faeces 24 h

m(t): retention/excretion functions depending on time t (days) after intake



GENERAL PRINCIPLES OF INTERNAL DOSIMETRY

BIOKINETIC MODELS Routes of intake, transfers and excretion



BIOKINETIC AND DOSIMETRIC MODELS

- **BIOKINETIC AND DOSIMETRIC MODELS FOR INTERNAL DOSIMETRY**

Intake of radioactive material inside the body through **inhalation, ingestion, injection and through absorption from intact skin or a wound:**

Distribution of a radionuclide inside the body

Distribution of its **progeny** in the body with own biokinetics

Retention of radionuclides in organs/tissues of the body / **Excretion** mainly trough urine and feces

✓**Biokinetic Model**

Radiation emitted by nuclear decay in **source organs**

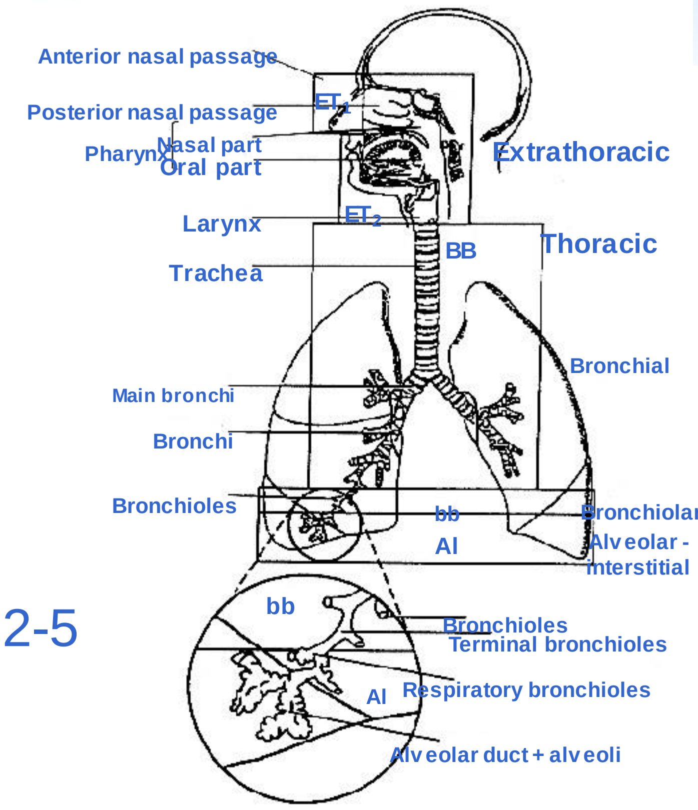
Energy absorbed in **target organs**

Absorbed Dose to target organs

✓**Dosimetric Model**

GENERAL PRINCIPLES OF INTERNAL DOSIMETRY

- **ASSESSMENT OF DOSES DUE TO INTERNAL EXPOSURES**
  - ✓ **BIOKINETIC MODELS**
    - **Human Respiratory Tract Model (HRTM).**
      ICRP Publications 66 and 130
    - **Human Alimentary Tract Model (HATM)**
      ICRP Publications 30 and 100
    - **Biokinetic and Dosimetric Models For Systemic Radionuclides.**
      ICRP/OIR (Occupational Intakes of Radionuclides) Publications Parts 2-5
    - **Absorption through Intact Skin and a Wound.**
      Wound Model of NCRP Report 156.



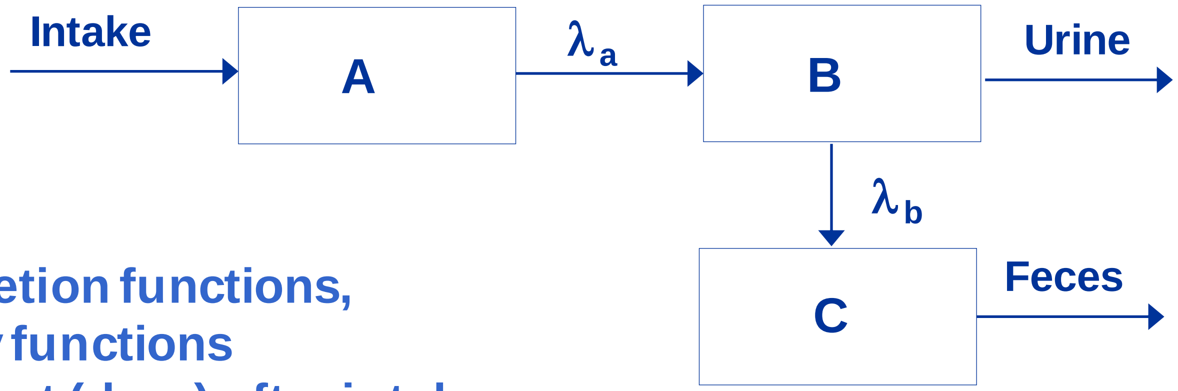
HRTM (ICRP Publication 66)

GENERAL PRINCIPLES OF INTERNAL DOSIMETRY

- ## ASSESSMENT OF DOSES DUE TO INTERNAL EXPOSURES

✓ **BIOKINETIC MODELS. Metabolic behaviour of contaminants inside the body.**

- **Modeling:** Mathematical description of the processes involved in the physical movement of radionuclides inside the body following intake, and the deposition of energy that constitutes exposure
- The deposition and movement of radioactive material inside the body depends on the intake mode, element, chemical form and physical form (e.g. particle size in case of inhalation)
- Tissues (including fluids) and organs are described as "Compartments"
  - Transfer routes
  - Transfer rates λ between compartments
  - Excretion routes



Output of the model: **m(t) retention and excretion functions,**
reference bioassay functions
depending with time t (days) after intake,
provided by ICRP

GENERAL PRINCIPLES OF INTERNAL DOSIMETRY

- **ASSESSMENT OF DOSES DUE TO INTERNAL EXPOSURES**

The **doses due to intakes of radionuclides** can not be obtained directly from measurements but must be assessed from:

✓ In-vivo measurements of the **retained activity M(Bq)** in total body or in specific organs, using Whole/Partial Body Counters

✓ In-vitro measurements of the **activity concentration in excreta** samples M(Bqd^{-1}, BqL^{-1})

✓ Workplace Monitoring (Air sampling) - Activity concentration in the air M(Bqm^{-3})

Or by a combination of these methods

GENERAL PRINCIPLES OF INTERNAL DOSIMETRY

- **ASSESSMENT OF DOSES DUE TO INTERNAL EXPOSURES**
  - ✓ Date/ **Time of Intake T_0**
  - ✓ Date/ **time of monitoring (in vivo)** or the **sample collection time (in vitro): t (days) after Intake**
  - ✓ **In vivo monitoring data: M(Bq)** is the retained activity in total-body or organs, at the time of monitoring
  - ✓ **In vitro monitoring data: M(Bqd^{-1}, BqL^{-1})** is the activity concentration in excreta samples at the sample collection time
  - ✓ **Assessment of Intake I (Bq)** from a single monitoring data:

$$I = \frac{M}{m(t)}$$

M= monitoring data (in vivo or in vitro measurements)

m(t) = retained/excreted fraction (reference bioassay functions are provided by ICRP)

  - ✓ **Assessment of the Committed Effective Dose E(50) mSv**:

E(50) mSv = I(Bq) * e(50)(mSv/Bq)

e(50) $SvBq^{-1}$: = dose coefficient (provided by ICRP) = committed effective dose PER UNIT INTAKE

GENERAL PRINCIPLES OF INTERNAL DOSIMETRY

- **ASSESSMENT OF DOSES DUE TO INTERNAL EXPOSURES**

The **interpretation of the monitoring data** for the assessment of the **intake I(Bq) and Committed Effective Dose E(50) (Sv):**

✓ requires the application of biokinetic and dosimetric models (ICRP)

✓ the evaluator needs to know or to make assumptions about:

- Type of intake (acute, chronic),
- Pathway of intake (inhalation, ingestion, injection, intact skin, wound)
- Time of intake (elapsed time from the exposure and the measurement)
- Physical (e.g. particle size) and chemical properties of internal contaminants

GENERAL PRINCIPLES OF INTERNAL DOSIMETRY

- **ASSESSMENT OF DOSES DUE TO INTERNAL EXPOSURES**

✓ **Dosimetric models**

- Micro and macro distribution of the radionuclide within the tissues or organs where significant deposition may occur
- Take into account the radiosensitivity of target tissues and organs – w_T
- Include consideration of quality of radiation - w_R, especially important for alpha emitters
- Depend on the decay properties of the radionuclide - particle type and energy

- **Allow the assessment of <u>dose coefficients</u> e(50) $SvBq^{-1}$ Committed Effective Dose PER UNIT INTAKE - provided by ICRP**

ICRP Reference Voxel Phantoms, ICRP Publication 110. Adult Male and female

GENERAL PRINCIPLES OF INTERNAL DOSIMETRY

- ## ICRP METHODOLOGY FOR OCCUPATIONAL INTERNAL DOSIMETRY

ICRP/OIR reports (Parts 1-5): **z(t) dose coefficient per measurement content**

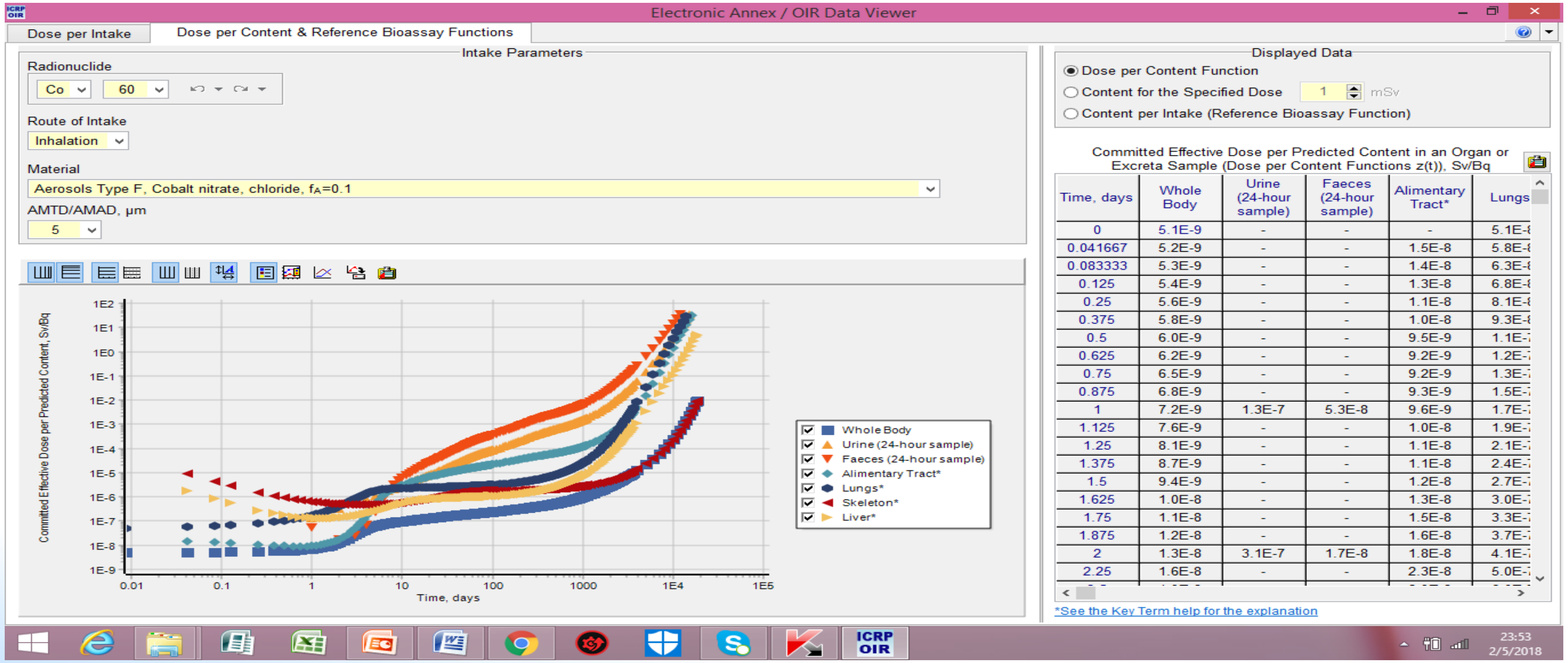
$$z(t) = \frac{e(50)}{m(t)} \, SvBq^{-1}$$

Values of **dose per unit content** functions ***Z(t)*** are provided by ICRP in its Occupational Intakes of Radionuclides (OIR) report series

$$\boldsymbol{E(50)\ Sv = M\ (Bq) \times Z(t)\ Sv\ Bq^{-1}}$$

where M(Bq)= monitoring data

Dose per content function z(t) for **^{60}Co**
from
ICRP DATA VIEWER
Last update:
Electronic Annex
OIR P4 (ICRP 141)
www.icrp.org



GENERAL PRINCIPLES OF INTERNAL DOSIMETRY

- **OCCUPATIONAL INTERNAL DOSIMETRY**
  - ✓**Objective:** Assessment of **the Committed Effective Dose E(50) Sv** due to the radionuclides incorporated into the body through inhalation, ingestion, injection, absorption trough intact skin or a wound at the **workplace**
  - ✓Assessment of **Effective Dose E (Sv)** in a radiation protection frame to demonstrate compliance with dose limits, taking into account internal and external exposures:

DOSE OF RECORD: $$E = H_P(10) + \sum_j I_{j,ing} e(g)_{j,ing} + \sum_j I_{j,inh} e(g)_{j,inh}$$

$H_P(10)$ Sv External Exposures- *Personal Dose Equivalent*

E(50) Sv Internal Exposures – *Committed Effective Dose*

- I_{ing}: Intake (Bq) by ingestion I_{inh}
- $e(g)_{ing}$: dose coefficient $SvBq^{-1}$ – ingestion
- I_{inh}: Intake (Bq) by inhalation
- $e(g)_{inh}$: dose coefficient $SvBq^{-1}$ - inhalation

GENERAL PRINCIPLES OF INTERNAL DOSIMETRY

- **OCCUPATIONAL INTERNAL DOSIMETRY**
  - ✓ **General Approach:**

1.- Characterization of internal exposure at the workplace

- Information to be provided (e.g. by the Radiation Protection Officer)

2.- Design of Individual Monitoring Programmes – internal exposures
- Selection of the Monitoring Techniques + monitoring period
- Selection of the workers to be included in the monitoring programmes

3.- Individual Monitoring of workers:
- Direct and Indirect techniques.
- Identification and quantification of incorporated radionuclides.
- Monitoring Data M(Bq), M(Bqd^{-1}, BqL^{-1})

4.- Assessment of intake and committed effective dose E(50)
- Interpretation of Monitoring Data
- Step by step procedure: calculation Intake I (Bq) and dose E(50) Sv
- ICRP Data viewer and available commercial software

GENERAL PRINCIPLES OF INTERNAL DOSIMETRY

- **ICRP METHODOLOGY FOR OCCUPATIONAL INTERNAL DOSIMETRY**

  Assessment of **Committed Effective Dose E(50) Sv <u>for workers</u>** (Occupational exposures)

  ✓ ICRP Publications 78, 68, 119 (based on ICRP 60 recommendations)

  ✓ **ICRP OIR (Occupational Intakes of Radionuclides) reports, Parts I-V (based on ICRP 103 recommendations)**

  - OIR Part I - ICRP Publication 130
  - OIR Part II - ICRP Publication 134
  - OIR Part III - ICRP Publication 137
  - OIR Part IV - ICRP Publication 141
  - OIR Part V - In press

$$E(50)Sv = \sum_T W_T \left[\frac{H_T^M(50) + H_T^F(50)}{2} \right]$$

E(50) is calculated with the use of male and female committed equivalent doses to individual target organs or tissues T, and the integration time following the intake is taken to be 50 years

GENERAL PRINCIPLES OF INTERNAL DOSIMETRY

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- Other Reference Documents on Internal Dosimetry

✓ **ISO Standards –** developed by ISO TC85/SC2/WG13

- **ISO20553**: Monitoring of workers exposed to a risk of internal contamination
- **ISO28218:** Performance Criteria for Radiobioassay
- **ISO27048:** Dose Assessment for the monitoring of workers for internal radiation exposure

- **ISO 16637:** Monitoring and internal dosimetry for staff exposed to medical radionuclides as unsealed sources
- **ISO 16638-1:** Monitoring and internal dosimetry for specific materials Part 1: Inhalation of uranium compounds.
- **ISO 16638-2:** : Monitoring and internal dosimetry for specific materials Part 2: Ingestion of uranium compounds.
- **ISO 20031**: Monitoring and dosimetry for internal exposures due to wound contamination with radionuclides

GENERAL PRINCIPLES OF INTERNAL DOSIMETRY

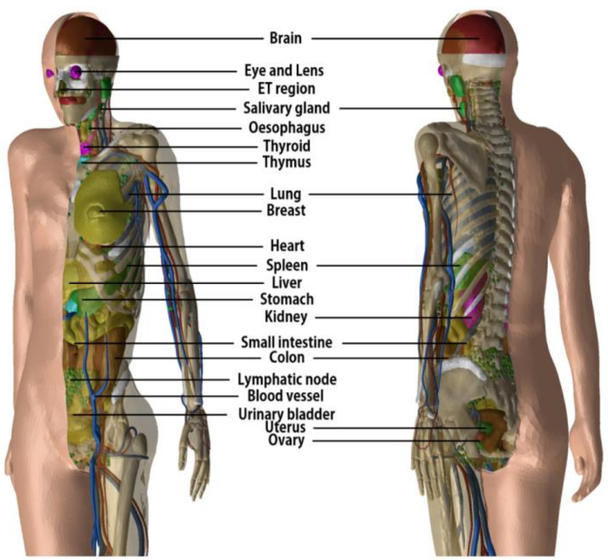
- **ASSESSMENT OF DOSES DUE TO INTERNAL EXPOSURES**

✓ **Definition of the reference person –**

ICRP Publication 89 “Basic anatomical and physiological data for use in radiological protection: reference values” (2001). The values apply to **workers** and **members of the public**

✓ **ICRP Reference computational phantoms**

- Sex and age dependent computational models representing reference individuals: adults, children, pregnant woman, embryo and foetus
- **ICRP Voxel-type Reference Computational Phantoms** (VRCPs)
  Calculation of dose coefficients
- **ICRP Mesh-type Reference Computational Phantoms** (MRCPs)
  Improved resolution comparing with voxel format



Reference Mesh-type adult female phantom, ICRP publication 145

GENERAL PRINCIPLES OF INTERNAL DOSIMETRY

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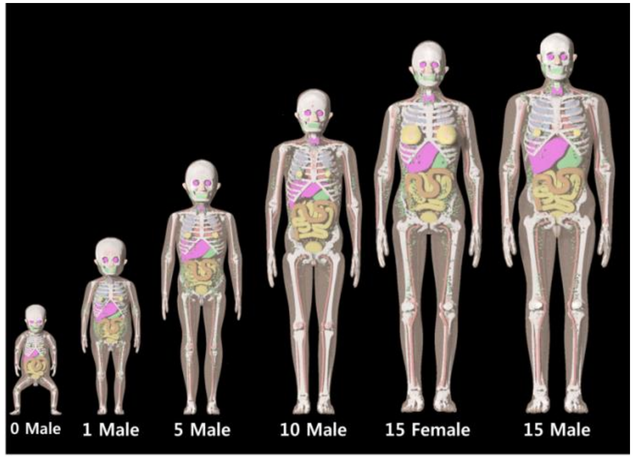
- **ASSESSMENT OF DOSES DUE TO INTERNAL EXPOSURES**

  ✓ **ICRP Reference computational phantoms**

  - **Male and female adult reference voxel phantoms** are described in **ICRP Publication 110**. They were generated from CT images of real persons and modified to be adapted to the ICRP reference person
  - **Paediatric Computational Reference Phantoms** are described in **ICRP Publication 143**
  - **Adult Mesh-type Reference Computational Phantoms** are described in **ICRP Publication 145**
  - Monte Carlo calculations using computational phantoms allow simulation of external or internal exposure situations e.g. **for the assessment of dose coefficients**

Reference adult phantoms, ICRP publication 110



Reference paediatric phantoms, ICRP publication 143

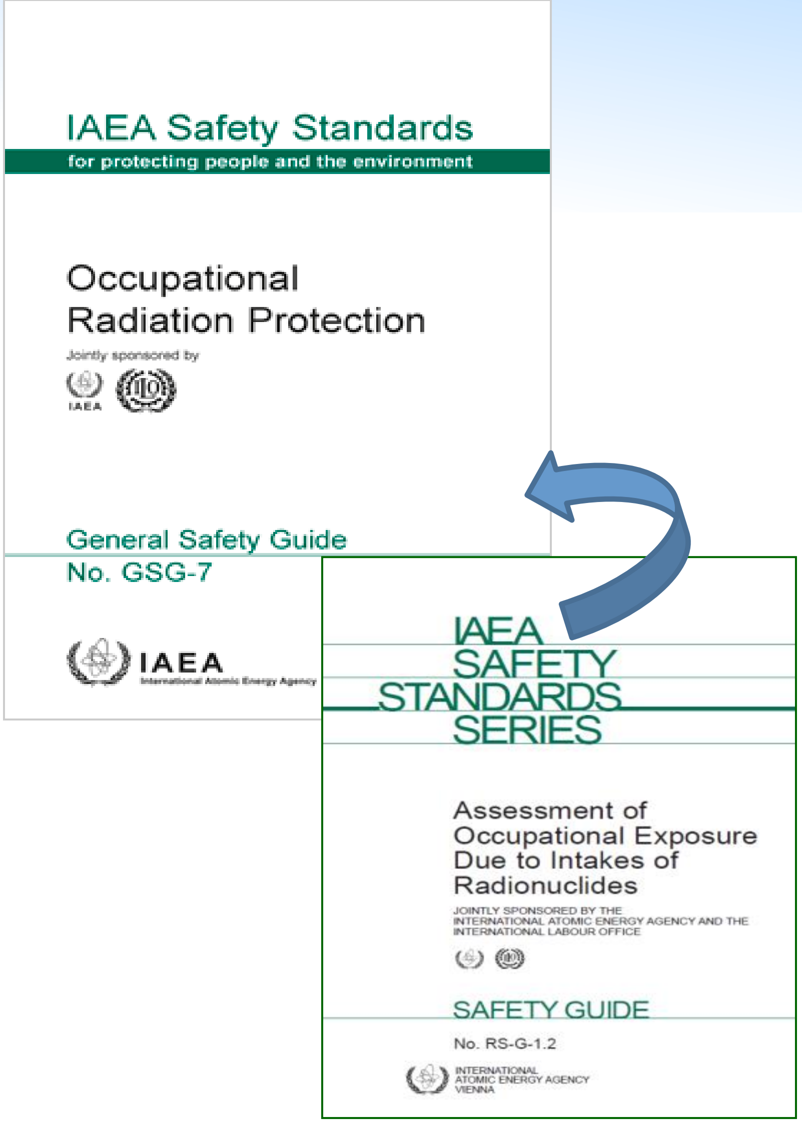
GENERAL PRINCIPLES OF INTERNAL DOSIMETRY

- **Other Reference Documents on Internal Dosimetry**

  ✓ **IAEA Reference documents**

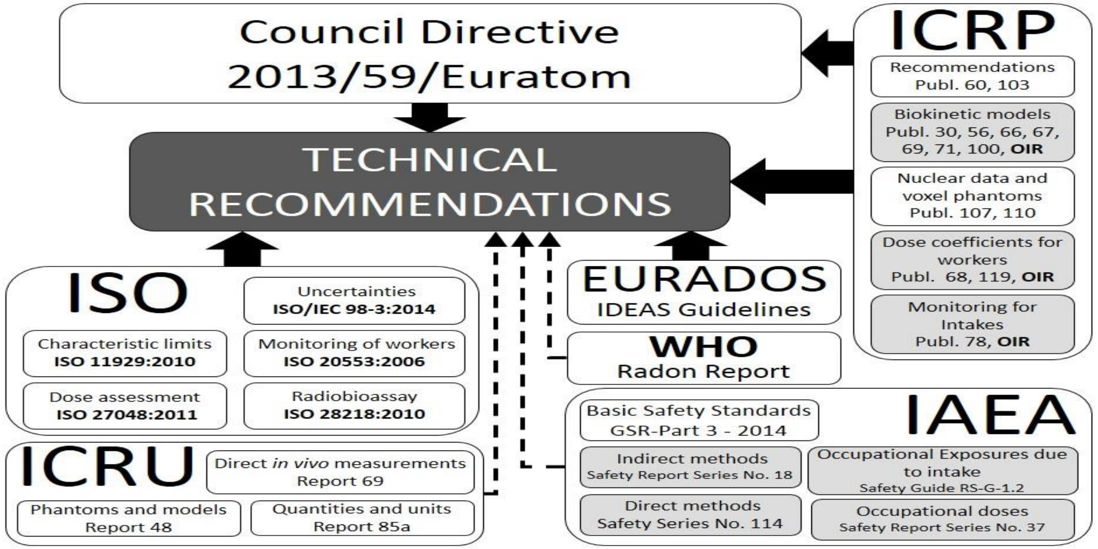
    - **IAEA Safety Guide on Occupational Radiation Protection**

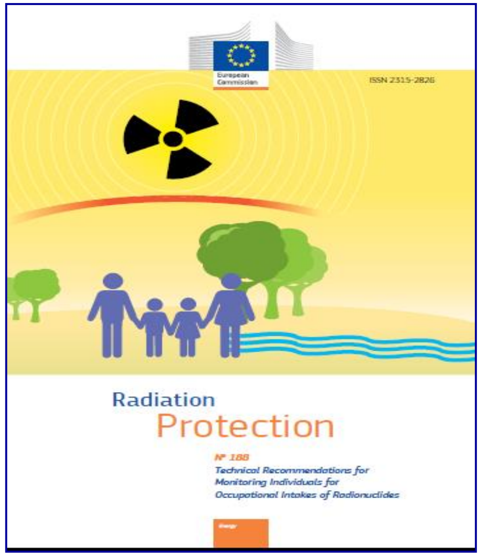
    - It combines all the relevant safety guides on the protection of workers into a **single comprehensive safety guide, including the existing Safety Guide RS-G-1.2 Assessment of Occupational Exposure due to Intakes of Radionuclides (1999)** which is superseded once the draft was approved for publication.



GENERAL PRINCIPLES OF INTERNAL DOSIMETRY

- **Other Reference Documents on Internal Dosimetry**
  - ✓ **EURADOS Reference documents:**
    - **EC RP 188 -** Technical Recommendations for Monitoring Individuals for Occupational Intakes of Radionuclides (ec.europa.eu/energy/sites/ener/files/rp_188.pdf) *European Commission's Radiation Protection Report Series*





- **IDEAS Guidelines:** General Guidelines for the Estimation of Committed Effective Dose from Incorporation monitoring data. Eurados Report 01-2013 (www.eurados.org).

GENERAL PRINCIPLES OF INTERNAL DOSIMETRY

EC RP 188 - Technical Recommendations for Monitoring Individuals for Occupational Intakes of Radionuclides

A. Purpose, Context and Scope, and Implementation by Internal Dosimetry Services (5 recommendations)
B. General Principles of Monitoring Individuals for Occupational Intakes of Radionuclides
C. Monitoring Programmes (19 recommendations)
D. Methods of Individual and Workplace Monitoring (39 recommendations)
E. Routine and Special Dose Assessment (29 recommendations)
F. Accuracy Requirements and Uncertainty Analysis (8 recommendations)
G. Quality Assurance and Criteria for Approval & Accreditation (14 recommendations)
H. Radon Measurement and Dosimetry for Workers (15 recommendations)

ANNEXES

- ✓ Reference Biokinetic and Dosimetric Models
- ✓ Examples of Monitoring Programme Design and Internal Dose Assessment
- ✓ Monitoring and Internal Dosimetry for First Responders in a Major Accident
- ✓ Internal Dosimetry for Assessment of Risk to Health
- ✓ Compilation of the Recommendations

GENERAL PRINCIPLES OF INTERNAL DOSIMETRY

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EC RP 188 - Technical Recommendations for Monitoring Individuals for Occupational Intakes of Radionuclides

Each relevent topic: a question, a technical explanation and list of recommendations

- **Chapter D, Methods of Individual and Workplace Monitoring:**

Q2: How should *in vivo* bioassay of the activity of radionuclides retained in the body that emit penetrating radiation be performed?		
D02	I	***In vivo* measurement** of radionuclides in the body should be employed **for radionuclides emitting penetrating radiation** that can be detected outside of the body (mainly high energy X-ray and gamma emitting radionuclides) wherever feasible [ICRU 2003; IAEA 1996]. Methods should satisfy the **performance criteria** for radiobioassay set by **ISO 28218:2010** [ISO 2010b].
D03	I	For radionuclides that are X/gamma emitters (>100 keV) and are rapidly absorbed from the respiratory tract into the body (e.g. ^{137}Cs, ^{60}Co), **whole body monitoring** using **NaI(Tl)** scintillation detectors and/or **HPGe** semiconductor detectors should be performed [ICRU 2003; IAEA 1996]
D04	I	**Monitoring of specific organs** using NaI(Tl) scintillation detectors and/or HPGe semiconductor detectors should be performed for X/gamma emitting radionuclides that concentrate in particular organs or tissues (e.g. ^{131}I in the thyroid) [ICRU 2003; IAEA 1996]

Types of Recommendations
M –Mandatory (e.g. EURATOM Directive)
I – International (e.g. ICRP, ISO)
A –Advisory (e.g. TECHREC team)

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