TIPS AND TRICKS FOR THE PRACTICE OF INTERNAL DOSIMETRY IN OCCUPATIONAL RADIATION PROTECTION
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Challenges of the dosimetry of internal exposures

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OCCUPATIONAL INTERNAL DOSIMETRY

- **Objective:** Assessment of **the Committed Effective Dose E(50) Sv** due to the radionuclides incorporated into the body through inhalation, ingestion, absorption trough intact skin or a wound at the workplace
- **Radiation protection frame:** individual monitoring of exposed persons to ionizing radiations. The assessment of **Effective Dose E (Sv)** to confirm compliance with dose limits:

$$E_t = H_P(10) + \sum_j I_{j,ing} e(g)_{j,ing} + \sum_j I_{j,inh} e(g)_{j,inh}$$

$H_P(10)$ Sv External Exposures -

E(50) Sv Internal Exposures -

- Iing: Intake (Bq) by ingestion
- e(g)ing: dose coefficient Sv/Bq – ingestion
- Iinh: Intake (Bq) by inhalation
- e(g)inh: dose coefficient Sv/Bq - inhalation

Occupational Internal Dosimetry: Challenges

- 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 organs, using whole/partial Body Counters
  - ✓ In-vitro measurements of the **activity concentration in excreta** samples M(Bqd^{-1}, BqL^{-1})
  - ✓ **Activity concentration in the air** M(Bqm^{-3})

Or by a combination of these methods

Occupational Internal Dosimetry: Challenges

- 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

Occupational Internal Dosimetry: Challenges

ICRP Reference documents

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

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

- New 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 progress

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

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

Occupational Internal Dosimetry: Challenges

General Approach:

A.- Characterization of internal exposure at the workplace

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

B.- Design of Routine Monitoring Programs

- Selection of the Monitoring Techniques + monitoring period

C.- Individual Monitoring of workers:

- Direct and Indirect techniques. Monitoring Data M(Bq), M(Bqd^{-1}, BqL^{-1})

D.- 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
- Available commercial software: IMBA,AIDE,IDEA-System,Taurus, Cador,…

Occupational Internal Dosimetry: Challenges

A.- Characterization of internal exposure at WORKPLACE

- Radionuclides: Type of radiation α/β/γ, Energy, Ie, $T_{1/2}$,...
  biokinetics (metabolic behaviour inside the body)

- Chemical compound of the radionuclide: Absorption Type (F, M, S) in case of inhalation, depending on the solubility of inhaled material:
  - ❑ Type F (Fast) – Short time of the radionuclides in the lungs
  - ❑ Type M (Moderate) – Medium time in lungs
  - ❑ Type S (Slow) – Long time in lungs
  - ❑ New ICRP/OIR Reports: also F/M and M/S materials (e.g. Uranium ICRP 137)

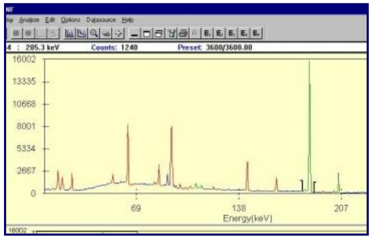
- Particle size of the inhaled aerosol: AMAD, AMATD

  AMAD: Activity Median Aerodynamic Diameter of inhaled aerosol
  Typically, default value: 5 µm (occupational exposures)

Occupational Internal Dosimetry: Challenges

B.- Design of Individual monitoring programs:

- ✓ Selection of technique and monitoring period
  - ▪ In vivo and in vitro bioassay will allow:
    - ❖ Identification of radionuclides
    - ❖ Quantification in terms of activity M (Bq) or M($Bq.d^{-1}$, BqL^{-1})



ISO20553: The objective of the monitoring of workers exposed to a risk of internal contamination is to guarantee the detection of the Committed Effective Dose of 1 mSv/year due to internal exposures

Occupational Internal Dosimetry: Challenges

C.- Individual monitoring of workers

- **Direct techniques using WBC (Whole Body Counters):**
  In vivo measurements of x-rays and gamma emitters internally deposited in the body, using γ spectrometry M (Bq)

- **Indirect techniques:**
  ✓In vitro measurements of activity concentration of alpha, beta and gamma emitters in excreta samples M ($Bq d^{-1}$, $Bq L^{-1}$)

  ✓Air Samplers: Personal (PAS) or Static (SAS) Air Samplers M ($Bq m^{-3}$)

Direct techniques using WBC (Whole Body Counters)

In-vivo monitoring – whole/partial body counting
NaI(Tl) and HPGe detectors. Gamma Spectrometry

(1) Shielded room	(2) WBC / Mobile Units
 CIEMAT WBC	 

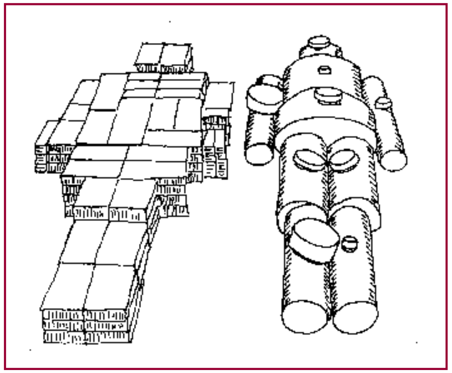
Direct techniques using WBC (Whole Body Counters)

In-vivo measurements of gamma emitters in total-body:

- Determination of fission and activation products and other radionuclides deposited in total body.
- **Calibration Phantom:** simulator of the human body, filled with a known radioactive source of radionuclides (e.g. ^{57}Co, ^{113}Sn, ^{137}Cs, ^{60}Co, ^{88}Y,…) covering the range of energy of interest (e.g. 100-3000 keV)

BOMAB Phantom (ANSI 13.35)

Brick Phantom



ICRU Report 69

Direct techniques using Body Counters: Lung Counting

- In vivo measurement of radionuclides with long residence times in the lung (e.g. U oxides, insoluble Pu and ^{241}Am).
- Detection of Xray, γ photons (E <200keV)
- HPGe detectors, Phoswich detectors

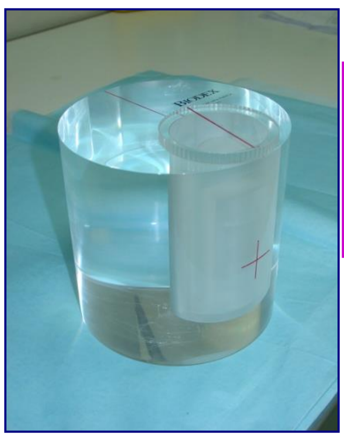
Lung Calibration:

- Livermore (LLNL, USA) phantom or JAERI (Japan) Phantom
- Lungs with radioactive sources
- Chest plates: ribs, muscle and fat
- Counting Efficiency mainly depending on Energy and chest wall thickness.

Thyroid Counting: determination of radioiodine in thyroid

- **^{131}I:** gamma emitter with a typical photopeak of 364.5 keV
  Calibration Source: ^{131}I or ^{133}Ba (mainly same emissions as ^{131}I)

- **^{125}I:** analysis of the X-ray typical emissions of 27.1 keV or/and using the low-energy gamma photopeak of 35.5 keV.
  Calibration Source: ^{125}I or ^{129}I (mainly same emissions as ^{125}I)



ANSI Thyroid Phantom, Bottle 20 ml with either ^{131}I or ^{125}I (CIEMAT, Spain)

Livermore Thyroid Phantom, IRSN (France)

INDIRECT TECHNIQUES: In vitro Monitoring of Excreta Samples (Urine and faeces)

Urine samples:

- ✓ Daily urinary excretion is 1.6 Ld^{-1} (reference man) and 1.2 Ld^{-1} (reference female)
- ✓ Creatinine is excreted at an average rate of 1.7 g d^{-1} (men) and 1.0 g d^{-1} (women) These values may be used for normalization (24h excretion)

Fecal samples: Reference faeces weight for male is 150 g and 120 g for female

Alpha Spectrometry

- ✓ ^{238}Pu, $^{239+240}$Pu, ^{241}Am, ^{244}Cm, ^{234}U, ^{235}U, ^{238}U, ^{228}Th, ^{230}Th, ^{232}Th,…
- ✓ Radiochemical separation is required
- ✓ Tc = 300000 s
- ✓ Results in 2-3 weeks

Liquid Scintilation Counting (LSC) - Beta emitters:

- ✓ ^{3}H (HTO, OBT),
- ✓ ^{14}C, ^{35}S, ^{32}P,
- ✓ ^{90}Sr (radiochemical separation)
- ✓ Tc = 60 - 120 min
- ✓ Results in 1 day (^{90}Sr in ~5 days)

INDIRECT TECHNIQUES: In vitro Monitoring of Excreta Samples (Urine And Faeces)

Mass Spectrometry **ICP-MS** (Inductively Coupled Plasma Mass Spectrometry)

- ✓ Uranium, ^{232}Th, ^{239}Pu,…
- ✓ Rapid alternative vs. Alpha Spec.
- ✓ Easy sample treatment, diluted Urine samples
- ✓ Results in 1-2 days

Mass Spectrometry **TIMS** (Thermal Ionisation Mass Spectrometry)

- ✓ uranium and plutonium isotopic measurements

Kinethic Phosphorescence Analyser (KPA) and **Fluorimetry**

- ✓ Methods for total uranium in urine.
- ✓ Rapid alternative vs Alfa Spectrometry but higher Detection Limits

Gamma Spectrometry

- ✓ Gamma emitters. Rapid method. No sample treatment. Results in 1 day
- ✓ HP Ge detectors

Comparison of methods for individual monitoring of intakes of radionucloides

Methods	Advantages	Limitations
In vivo monitoring of radionuclides in an organ or in total body	Rapid measurement of the activity retained and deposited in the body, especially important in case of RN emergencies Rapid intake and dose assessments	Mainly X_{ray} + γ emitter radionuclides Physical phantoms simulating internal contamination of organs or total body not always available Worse detection limit for actinide and NORM exposures when comparing with in vitro bioassay
In vitro radiobioassay of excreta samples	In vitro bioassay is the measurement technique of choice to quantify internal contamination of pure alpha and beta emitters. Alpha Spec. and ICP-MS: excellent detection limits	Alpha spectrometry: long time (~2 weeks) for estimating activity concentration in excreta samples. ICP-MS: better for NatU and Th in urine samples (and for other long lived radionuclides e.g. ^{239}Pu) but expensive technique
Workplace monitoring, Air Sampling	PAS and SAS may be useful when available *in vivo* and *invitro* techniques only quantify exposures reliably above 6 mSv, e.g. for monitoring actinides	High uncertainties may be associated when calculating intake, then difficult to use for dose assessment

Interpretation of Monitoring Data for the assessment of Intake I(Bq) and dose E(50)

D1.- Intake and Dose Assessments from a single monitoring data

- Date/Time of Intake T_0 (dd/mm/yyyy)
- Date/Time of Monitoring: t (days) after Intake
- In vivo monitoring data: M(Bq) Activity (from WBC)
  In vitro monitoring data: M(Bqd^{-1}) Activity concentration in excreta samples
- **Assessment of Intake I (Bq)** from a single monitoring data M(Bq):

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

M(Bq)= monitoring data (WBC or excreta)

m(t) = fraction of retained/excreted activity when Intake is 1 Bq (provided by ICRP reports)

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

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

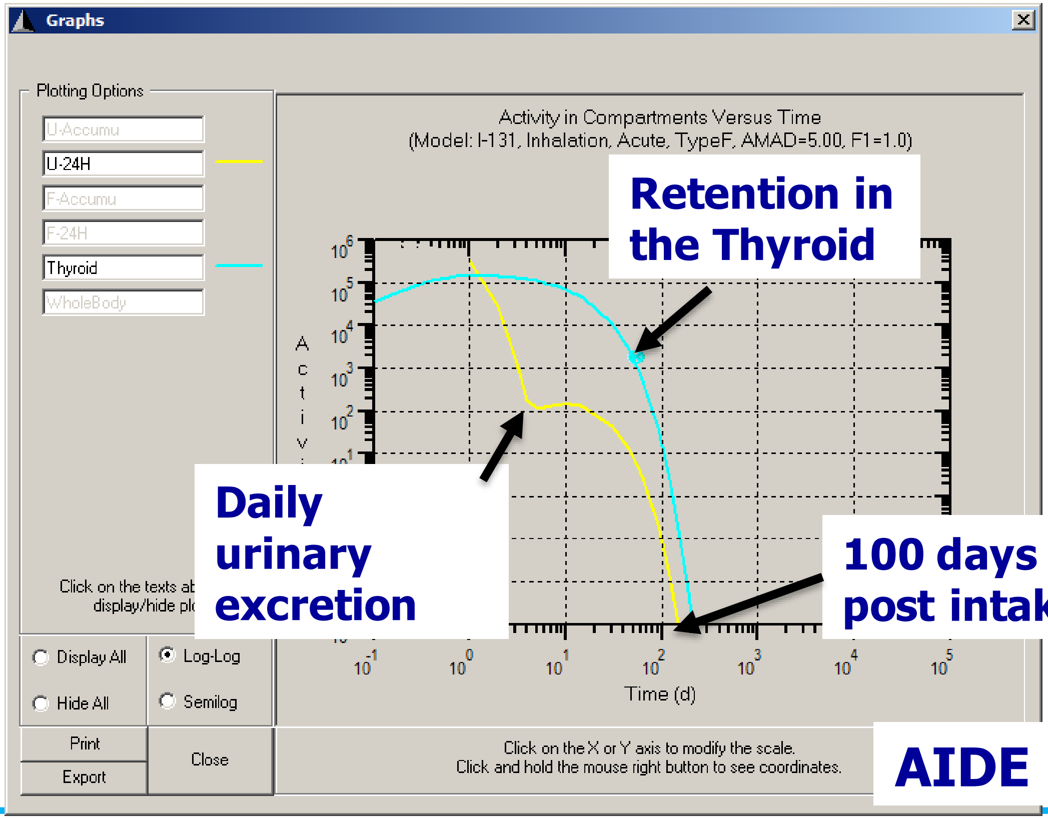
e(50) mSv/Bq: dose coefficient (provided by ICRP) = committed effective dose PER UNIT INTAKE

m(t): Retention and Excretion Functions (urine and feces)

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

ICRP provides m(t): retention/excretion functions.
Fraction in the body (direct measurement) or being excreted from the body (indirect measurement) PER UNIT INTAKE

ICRP: m(t) I-131 inhalation, type F, AMAD= 5 μm



AIDE Software

m(t) depends on:

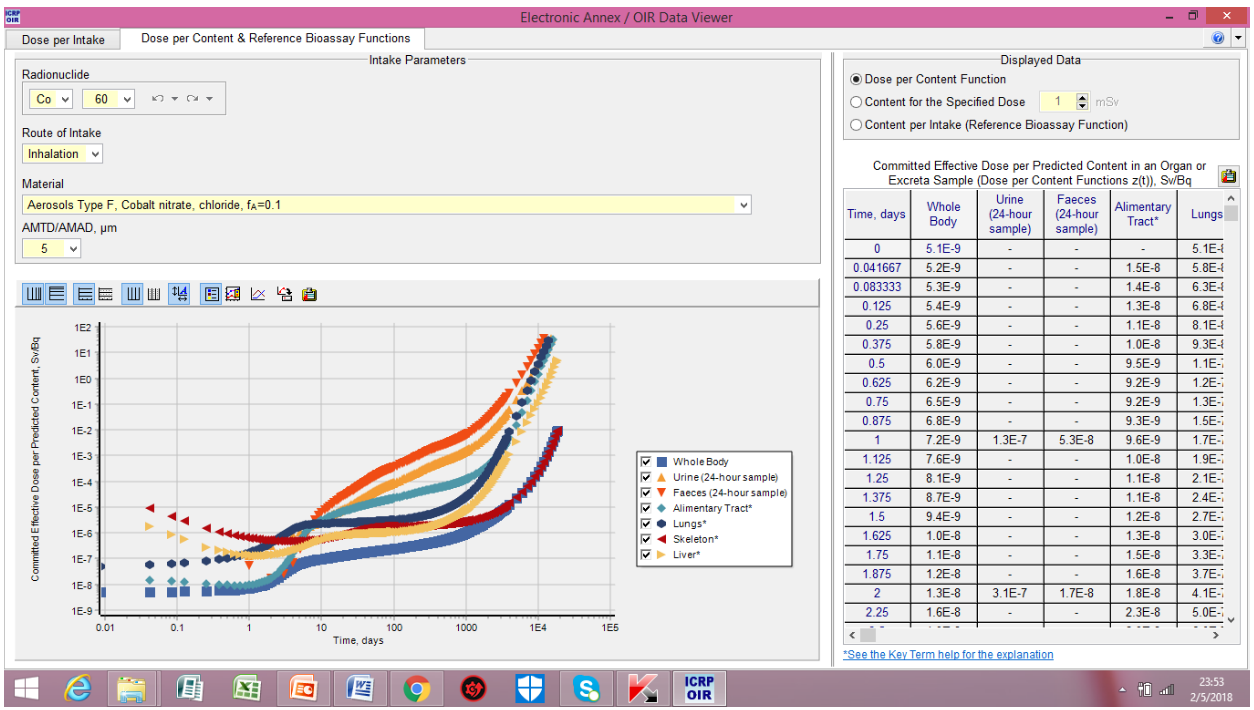
- Physical half-life
- Biokinetics of the radionuclide
- Is a function of the time since intake

New ICRP/OIR reports: **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

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



Dose per content function z(t) for ^{60}Co from ICRP DATA VIEWER

Last update: Electronic Annex OIR P4 (ICRP 141) www.icrp.org

Assessment of Intake and Dose E(50). Uncertainties.

ISO 27048: Dose Assessment for the monitoring of workers for internal radiation exposure

IDEAS Guidelines: General Guidelines for the Estimation of Committed Effective Dose from Incorporation monitoring data

"Measurements are assumed to be lognormally distributed with a given scattering factor (SF)"

$$SF_i = \exp\sqrt{[\ln(SF_A)]^2 + [\ln(SF_B)]^2}$$

Assessment of Intake and Dose E(50). Uncertainties.

ISO 27048 (Annex B, Table B.1.)

Sources of Uncertainties – In-vivo SCATTERING FACTOR (Log-normal)

Result of WBC: $A \pm 2\sigma_A$ Bq

Calculation of SF_A from σ_A → $SF_A = \exp(\sigma_A/A)$

Source of uncertainty (Type)	Log-normal scattering factor K_{SF}		
	Low photon energy E < 20 keV	Intermediate photon energy 20 keV < E < 100 keV	High photon energy E > 100 keV
Counting statistics (A)	1,5	1,3	1,07
Variation of detector positioning (B)	1,2	1,05	< 1,05
Variation of background signal (B)	1,5	1,1	< 1,05
Variation in body dimensions (B)	1,5	1,12	1,07
Variation of overlaying structures (B)	1,3	1,15	1,12
Variation of activity distribution (B)	1,3	1,05	< 1,05
Calibration (B)	1,05	1,05	1,05
Spectrum evaluation[1)] (B)	1,15	1,05	1,03

Assessment of Intake and Dose E(50). Uncertainties.

ISO 27048 (Annex B, Table B.2.)

Uncertainties – In-vivo monitoring, different ranges of energy

	Scattering Factor (Log-normal)		
	Low Energy Photons E < 20 keV	IntermediateEnergy Photons 20 keV < E < 100 keV	High Energy Photons E > 100 keV
Total Type A	**1.5**	**1.3**	**1.07**
Total Type B	**2.06**	**1.25**	**1.15**
Total	**2.3**	**1.4**	**1.2**

Assessment of Intake and Dose E(50). Uncertainties.

ISO 27048 (Annex B, Table B.3.)

Type B Uncertainties – In vitro monitoring – Default values for SF_B

Quantity	Type B Scattering factor SF_B
True 24 h urine	1.1
Activity concentration ^{3}H in urine	1.1
Simulated 24 h urine, creatinine or specific gravity normalised	1.7
Spot urine sample	2.0
Faecal 24 h sample	3.0
Faecal 72 h sample	1.9

Assessment of Intake and Dose E(50). Uncertainties

D2. Internal Dose Assessments from a set of n monitoring data M_i, i= 1...n

- Date/Time of Intake T_0 (dd/mm/yyyy)
- Date/Time of n Monitoring data: ti (days) post intake; i= 1,..., n
- Result of In-vivo monitoring: Mi (Bq) Activity (from WBC) or
  In-vitro monitoring: Mi (Bqd^{-1}) Activity concentration in excreta
- Assessment of the Intake I (Bq) from a set of n monitoring data

MAXIMUM LIKELIHOOD METHOD

$$\ln(I) = \frac{\sum_{i=1}^{n} \left(\frac{\ln(I_i)}{(\ln SF_i)^2} \right)}{\sum_{i=1}^{n} \frac{1}{(\ln SF_i)^2}}$$

✓ SF_i is the scattering factor (uncertainty) associated to monitoring value M_i

✓ I_i (Bq) is the value of intake obtained from M_i (Bq, Bq/d): $I_i = \frac{M_i}{m(t_i)}$

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

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

ISO 27048
IDEAS Guidelines

Reference Documents on Internal Dosimetry

- **ISO Reference documents - 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.

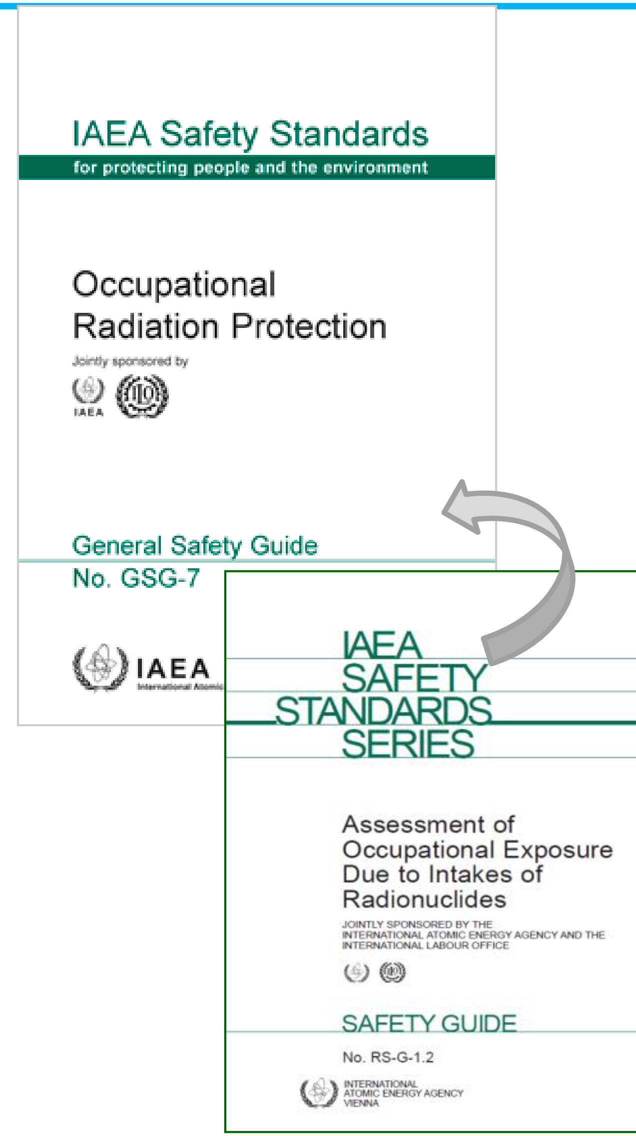
- **ISO 20031**: Monitoring and dosimetry for internal exposures due to wound contamination with radionuclides

Reference Documents on Internal Dosimetry

➢ IAEA Reference documents

- ❑ **GSG-7 - IAEA Safety Guide on Occupational Radiation Protection (2018)**

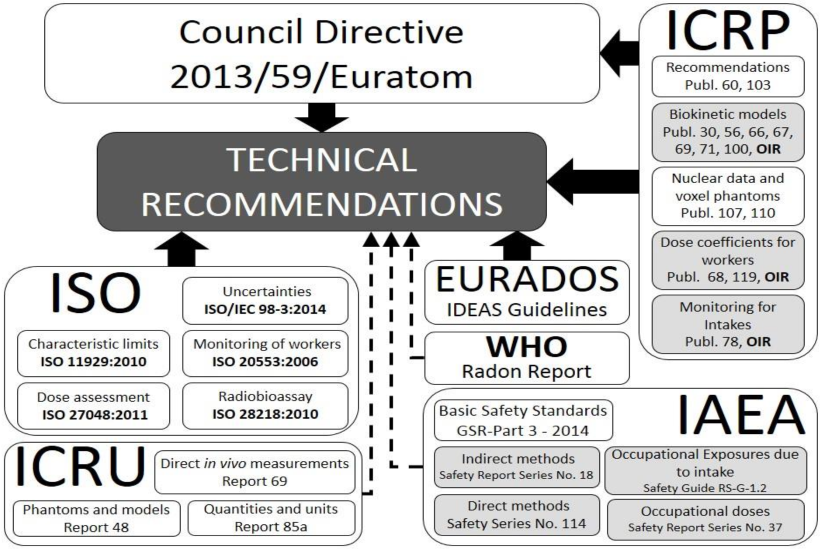
- ❑ It combines all the relevant safety guides on the protection of workers into a **single comprehensive safety guide, including the existing Safety Guide RS-G-1.2 Assessment of Occupational Exposure due to Intakes of Radionuclides (1999**) which was superseded when GSG-7 was published.

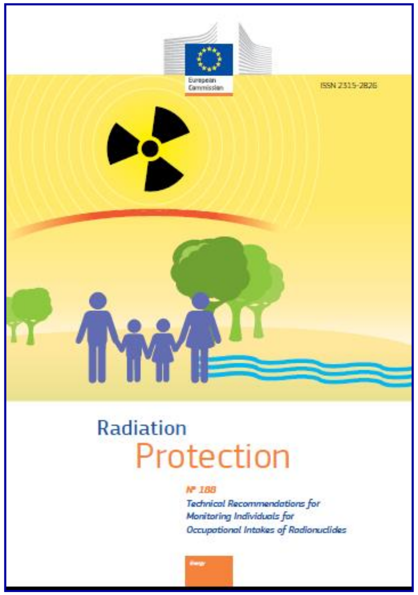


Reference Documents on Internal Dosimetry

➢ **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).

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

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)

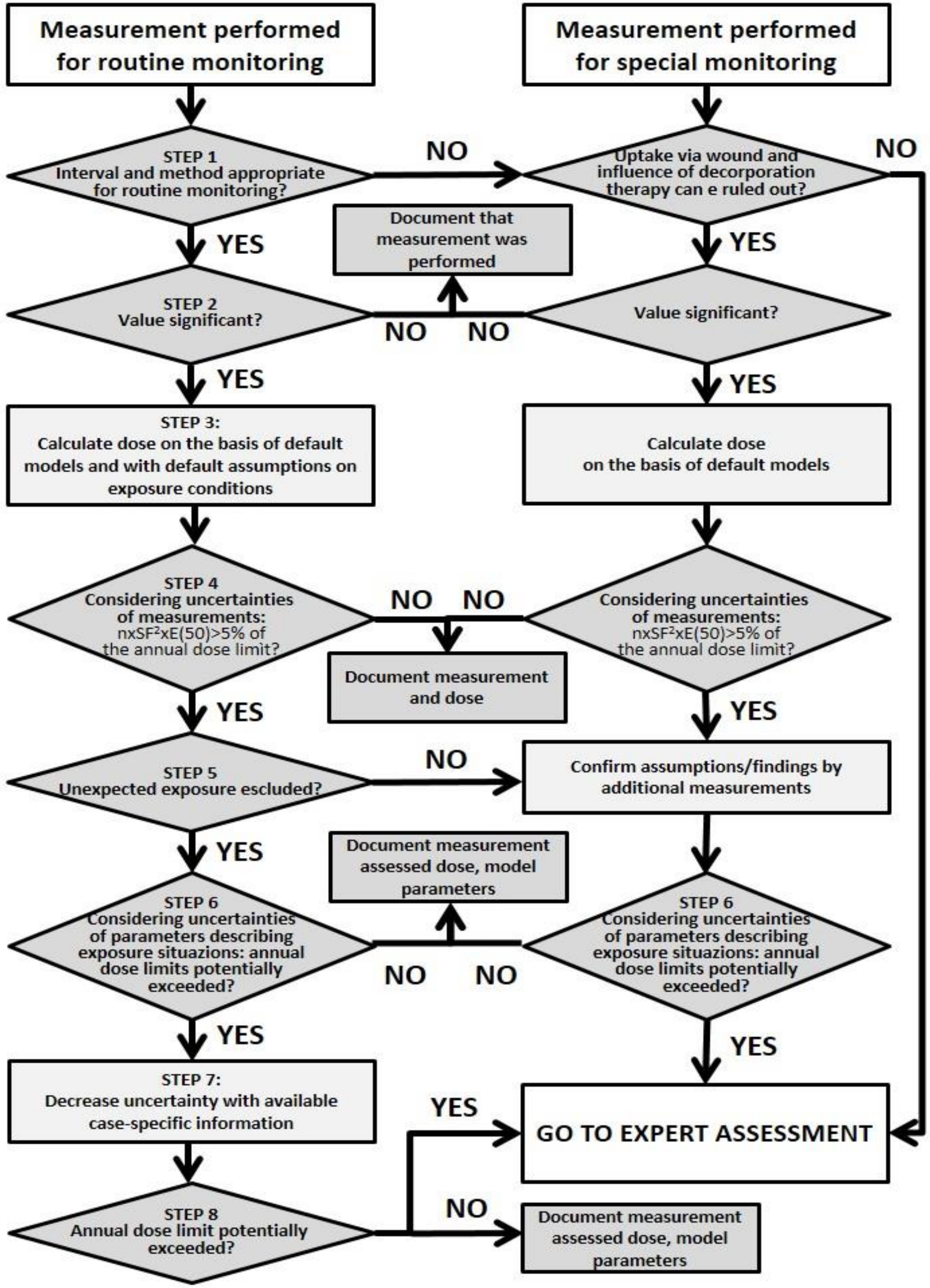
I – International (e.g. ICRP, ISO)

A –Advisory (e.g. TECHREC team)

EC RP 188

ROUTINE MONITORING

SPECIAL MONITORING



EURADOS e. V. a sustainable network (www.eurados.org)

European Radiation Dosimetry Group

EURADOS was founded in 1981 by scientists involved in contracts with the European Commission.

Main EURADOS bodies:

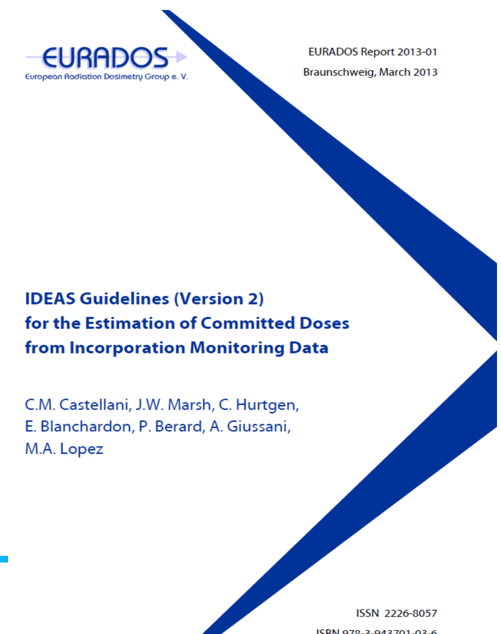
- ✓ The General Assembly , composed by **80 Voting Members** (Feb 2020)
- ✓ The Executive Board
- ✓ The Council
- ✓ The Working Groups, with the involvement of **> 500 scientists** in different fields of the dosimetry of ionizing radiations
- ✓ **40 Sponsor institutions**

EURADOS e. V. a sustainable network (www.eurados.org)

EURADOS Working Groups
WG2 Harmonisation of individual monitoring
WG3 Environmental dosimetry
WG6 Computational dosimetry
WG7 Internal dosimetry
WG9 Radiation dosimetry in radiotherapy
WG10 Retrospective dosimetry
WG11 High energy radiation fields
WG12 Dosimetry in medical imaging

EURADOS actions

- Annual Meetings
- Winter Schools
- Workshops
- **Intercomparisons: EIVIC** (WBC)
  ICIDOSE (E(50))
- Training Courses
- Young scientist support
- Newsletter
- EURADOS Reports & publications


EURADOS
European Radiation Dosimetry Group e. V.

EURADOS Report 2013-01
Braunschweig, March 2013

IDEAS Guidelines (Version 2)
for the Estimation of Committed Doses
from Incorporation Monitoring Data

C.M. Castellani, J.W. Marsh, C. Hurtgen,
E. Blanchardon, P. Berard, A. Giussani,
M.A. Lopez

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- Recent **EC Projects**: EIVIC, EJP CONCERT, CONFIDENCE, Cathymara, Shamiseng, TECHREC,…
- Member of MEENA Network – Joint reseach for radiological protection in Europe

Thanks for your attention

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