IAEA
International Atomic Energy Agency
Atoms for Peace and Development

ASSESSMENT OF OCCUPATIONAL EXPOSURE DUE TO INTERNAL RADIATION SOURCES

UNIT 8

UNCERTAINTIES IN INTERNAL DOSIMETRY

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CONTENTS OF LECTURE

- SOURCES OF UNCERTAINTY IN DOSE ASSESSMENTS
- MEASUREMENT UNCERTAINTY AND SCATTERING FACTORS
- UNCERTAINTY IN MONITORING PROGRAMS

UNCERTAINTIES IN INTERNAL DOSIMETRY

- **SOURCES OF UNCERTAINTY IN DOSE ASSESSMENTS**

  - ✓ The **measurement** of
    - the activity retained in the body (Bq in total-body or tissues/organs) at the time of monitoring,
    - the activity concentration (Bqd^{-1}, BqL^{-1}) in excreta samples at the collection time

    are subject to **type A** (e.g. counting statistics) and **type B uncertainties**

  - ✓ **Biokinetic and dosimetric models** used for the interpretation of monitoring data and the assessment of the intake I(Bq) and the Committed Effective Dose E(50) Sv, are simplified representations of human anatomy and physiology. It is assumed that the contaminated person has a similar retention/excretion behaviour as the ICRP reference retention/excretion models; individual variability may cause that the person differs from reference model in the 24h urinarya or fecal excretion.

  - ✓ The assessment of intake and dose requires to know or to make assumptions of the **internal exposure scenario** for the interpretation of monitoring data. Unknown time or pathway of intake and/or physicochemical form of incorporated radionuclides will result in uncertainties in assessed dose.

UNCERTAINTIES IN INTERNAL DOSIMETRY

- **SOURCES OF UNCERTAINTY IN DOSE ASSESSMENTS**

  ✓ **ICRP bioassay retention/excretion functions m(t) and ICRP dose coefficients e(50) $SvBq^{-1}$** (outcome of biokinetic and dosimetric models respectively) **are not subject to uncertainty.**

  ✓ The **sensitivity and accuracy of an individual monitoring program** should be evaluated to establish the reliability of an assessed dose.

UNCERTAINTIES IN INTERNAL DOSIMETRY

- **MEASUREMENT UNCERTAINTY AND SCATTERING FACTORS**

  ✓ **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 (EURADOS Report 03-2013)

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

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

This approximation is reasonable if $SF_A < 1.4$ (Type A uncertainties<34%)

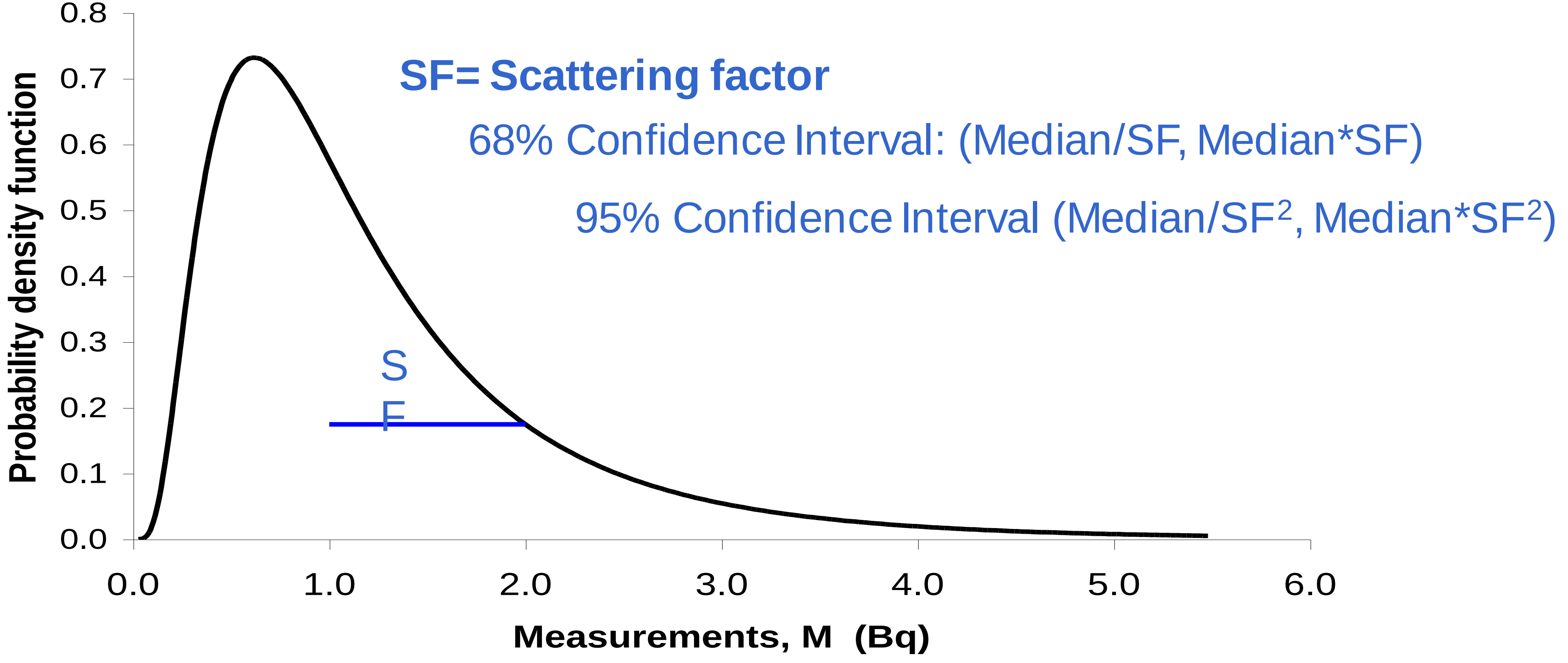
$SF_A = \exp(\sigma_M / M)$

Fractional error due to counting statistics (relative standard deviation)

UNCERTAINTIES IN INTERNAL DOSIMETRY

- **MEASUREMENT UNCERTAINTY AND SCATTERING FACTORS**

Measurements are assumed to be lognormally distributed with a given SF



UNCERTAINTIES IN INTERNAL DOSIMETRY

- **MEASUREMENT UNCERTAINTY AND SCATTERING FACTORS**
  - ✓ Activity counting is subject to random variation.
  - ✓ **Decision threshold (DT), Detection Limit (DL)** are set to define the **sensitivity of a bioassay method.** If the activity is close to the DT, the total measurement uncertainty is dominated by type A component. When the activity >> DL, type B component is dominant.
  - ✓ Monitoring data are also affected by the uncertainty on the activity of the calibration source, on the calibration count and on the measurement count. These uncertainties associated with **counting statistics** are defined as **"Type A" (**Poisson distribution).
  - ✓ **"Type B" sources of uncertainty** in monitoring data must be also taken into consideration:
    - Biological variability of excretion in in vitro measurement is reduced by **collection of samples over 24 hours** (or 72 hours for faecal samples).
    - The reliability of in vivo measurement depends on a **realistic calibration geometry, using a realistic calibration phantom**. The associated uncertainty increases at low photon energy.

UNCERTAINTIES IN INTERNAL DOSIMETRY

- **MEASUREMENT UNCERTAINTY AND SCATTERING FACTORS**

Type A uncertainties (Counting statistics)

$$M = \frac{C_{rn}}{T_S}\left(N_G - \frac{N_B}{R_B}\right), \qquad \sigma_A = \frac{C_{rn}}{T_S}\sqrt{N_G + \frac{N_B}{R_B^2}}$$

M measured activity, Bq

N_G gross counts

N_B background counts

R_B ratio of background count time to sample count time,

T_S time of the signal measurement

C_{rn} normalisation (i.e calibration) factor, Bq per count rate

UNCERTAINTIES IN INTERNAL DOSIMETRY

- **MEASUREMENT UNCERTAINTY AND SCATTERING FACTORS**

Type B uncertainties for *in-vivo* measurements

- ✓ Counting geometry
  - detector positioning and movement of person during measurement
- ✓ Differences between calibration phantom and subject
  - body dimensions
  - overlaying tissue
  - activity distribution
- ✓ Variation in background radiation
- ✓ Net peak assessment

UNCERTAINTIES IN INTERNAL DOSIMETRY

- **MEASUREMENT UNCERTAINTY AND SCATTERING FACTORS**

Type B uncertainties for excreta measurements

- ✓ Radiochemical analysis uncertainties
  - Tracer calibration
  - Weighing of tracer and sample
  - Chemical equilibrium between tracer and nuclide of interest
- ✓ Calibration errors associate with alpha or beta counting
- ✓ Uncertainty in collection period
  - depends on sampling procedures and the method used to normalise the data to 24 hours

UNCERTAINTIES IN INTERNAL DOSIMETRY

- **MEASUREMENT UNCERTAINTY AND SCATTERING FACTORS**

ISO 27048 (Annex B, Table B1)

Sources of Uncertainties – <u>In-vivo monitoring</u>,

Different ranges of energy. SCATTERING FACTOR SF (Log-normal)

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

Taken from ISO 27048, Annex B, Table B1

UNCERTAINTIES IN INTERNAL DOSIMETRY

- **MEASUREMENT UNCERTAINTY AND SCATTERING FACTORS**

ISO 27048 (Annex B, Table B2)
SCATTERING FACTORS SF – 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**

Taken from ISO 27048, Annex B, Table B2

UNCERTAINTIES IN INTERNAL DOSIMETRY

- **MEASUREMENT UNCERTAINTY AND SCATTERING FACTORS**

ISO 27048 (Annex B, Table B3) SCATTERING FACTORS SF type B – In-vitro monitoring

Typical values of Type B scattering factors for *in vitro* measurements are given in Table B.3.

Table B.3 — Default values for the lognormal scattering factor K_{SF} for various types of measurement from different studies (Type B errors) (derived from [21][24])

Quantity	Type B scattering factor, K_{SFB}
True 24 h urine	1,1[a]
Activity concentration of ^{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
Faecal 72 h sample	1,9
Chest count	2

[a] Value given by [28].

Taken from ISO 27048, Annex B, Table B3

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✓ **EXAMPLE of the application of Scattering Factors: Accidental ingestion of ^{137}Cs**

Assessment of Intake I(Bq) and dose E(50) from in-vivo monitoring data: $A_i \pm \sigma_{Ai}$ of ^{137}Cs

In vivo measurements in the Whole Body Counter (WBC) at t=1, 8, 17 y 30 days after intake.

Calculation of Scattering Factor Type A SF_A from σ_{Ai}. SF_B from Annex B of ISO27048, **in-vivo E>100keV**

WBC

t(days post Intake)	A_i Bq of Cs-137	Genie 2000 Err_A_i (%)	σA_i (Bq)
1	8.80E+04	10	8800
8	6.00E+04	10	6000
17	9.30E+04	10	9300
30	8.30E+04	10	8300

A_i Bq of Cs-137	SFA	SFB	SF
8.80E+04	1.11	1.15	1.19
6.00E+04	1.11	1.15	1.19
9.30E+04	1.11	1.15	1.19
8.30E+04	1.11	1.15	1.19
		(Tabla SFB, E>100 keV)	

$$SF_A = \exp\left(\frac{\sigma A}{A}\right)$$

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

UNCERTAINTIES IN INTERNAL DOSIMETRY

- **UNCERTAINTY IN MONITORING PROGRAMS**

  ✓ **The monitoring program is appropriate:**

  - The bioassay method has the **sensitivity (DL) to detect potential annual doses E(50) $\leq$1 mSv** due to the inhalation of the radionuclides at the workplace

  - **The underestimation due to unknown time of intake is less than 3.**

    Monitoring program: selection of a bioassay method and a **monitoring interval = ΔT days**

    Typical assumption: **time of intake T_o at the half point of a monitoring interval** $T_o = \Delta T/2$ days.
    Intake at the half point of the monitoring period: I (Bq)= M (Bq) / m(ΔT/2)

    Maximum underestimation:
    Intake occurred the day after the last measurement: $T_o = \Delta T$ days, Î (Bq)= M (Bq) / m(ΔT)
    Intake half point / Intake after last measurement = I / Î = **m(ΔT/2)/ m(ΔT) $\leq$ 3**

UNCERTAINTIES IN INTERNAL DOSIMETRY

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- **UNCERTAINTY IN MONITORING PROGRAMS**

✓ **Uncertainty sources contributing to overall uncertainty**

- **Unknown time or period of intake**
  Default assumption: acute intake at the half point of a monitoring period

- **Unknown pathway of intake:**
  Default assumption: Inhalation

- **Uncertainty in monitoring data M (Bq) -** Type A and Type B uncertainties. Assessment of Scattering Factor SF. Confidence interval (95%) $(M/SF^2, MxSF^2)$

- **Unknown particle size distribution (AMAD)**
  Default values: AMAD= 5 μm for occupational exposures. AMAD= 1 μm for public exposures

- **Unknown absorption type** in case of inhalation (F, M, S, F/M, M/S) and **gastro-intestinal absorption factor (f_A).** Default Absorption type and f_A recommended by ICRP/OIR

REFERENCES - UNIT 8 - UNCERTAINTIES IN INTERNAL DOSIMETRY

EUROPEAN COMMISSION - RADIATION PROTECTION REPORT SERIES No.188 - Technical Recommendations for Monitoring Individuals for Occupational Intakes of Radionuclides (ec.europa.eu/energy/sites/ener/files/rp_188.pdf). EC RP 188 (2018).

EUROPEAN RADIATION DOSIMETRY GROUP [EURADOS] - IDEAS Guidelines (Version 2) for the Estimation of Committed Doses from Incorporation Monitoring Data. EURADOS Report 2013-01 ISBN 978-3-943701-03-6 (2013).

INTERNATIONAL ORGANIZATION FOR STANDARDIZATION. RADIATION PROTECTION – *Monitoring of Workers Occupationally Exposed to a Risk of Internal Contamination with Radioactive Material*. ISO 20553:2006. (ISO:Geneva) (2006)

INTERNATIONAL ORGANIZATION FOR STANDARDIZATION. RADIATION PROTECTION – Dose assessment for the monitoring of workers for internal radiation exposure ISO 27048:2011 (ISO: Geneva) (2011).