Workshop on
EU-BSS Directive Implementation
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DOSE COEFFICIENTS
– INTERNAL EXPOSURES –

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ICRP Committee 2

INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION

DOSE COEFFICIENTS – INTERNAL EXPOSURES

INTERNAL DOSIMETRY

- **Dosimetry of Internal Exposures**:
  - workers (intakes of radionuclides at the workplace)
  - members of the public (emergency situations)
  - patients (nuclear medicine)

- **Objective:** Assessment of **Committed Doses** due to the radionuclides incorporated into the body through
  - inhalation
  - ingestion
  - injection
  - skin/wounds

DOSE COEFFICIENTS – INTERNAL EXPOSURES

- The **doses due to intakes of radionuclides** can not be obtained directly 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 in excreta** samples M(Bqd^{-1}, $Bq\ L^{-1}$)
  - **Activity concentration in the air** M(Bqm^{-3})

  Or by a combination of these methods

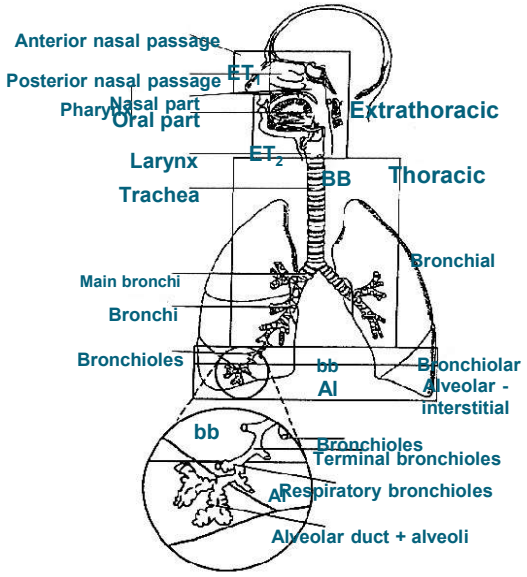


DOSE COEFFICIENTS – INTERNAL EXPOSURES

➢ The interpretation of the **monitoring data M(Bq, Bqd^{-1})** for the assessment of the

Intake I(Bq) and Committed Effective Dose E(50) Sv for adults, E(70) Sv for children:

- requires the application of **biokinetic and dosimetric models (ICRP)**
  - ✓ Metabolic behaviour of radionuclides inside the body
  - ✓ Irradiation of target organs due to the energy emitted from source organs
- requires the **characterization of the exposure:**
  - ✓ Type of intake (acute, chronic),
  - ✓ Route of intake (inhalation, ingestion, injection, intact skin, wound)
  - ✓ Time of intake (elapsed time from the exposure and the measurement)
  - ✓ Physical (particle size) and chemical properties of contaminant materials



DOSE COEFFICIENTS – INTERNAL EXPOSURES

➢ OCCUPATIONAL Exposures:

Total Effective dose, considering external and internal exposures of WORKERS:

E= $H_p(10)$ + E(50) Sv to demonstrate compliance with dose limits and constraints

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

$H_P(10)$ Sv: personal dose equivalent for External Exposures (uniform whole body exposure)

E(50) Sv: committed effective dose for Internal Exposures

- **I ing**: Intake (Bq) for ingestion
- **e(g) ing** : committed effective dose coefficient $SvBq^{-1}$ – ingestion
- **I inh**: Intake (Bq) for inhalation
- **e(g) inh**: committed effective dose coefficient $SvBq^{-1}$ – inhalation
- **g:** integration period= 50 years

DOSE COEFFICIENTS – INTERNAL EXPOSURES

➢ EVOLUTION OF INTERNAL DOSE COEFFICIENTS – Previous to 2007 Recommendations

✓ **ICRP Publication 30** - dose coefficients for inhalation and ingestion. Human gastrointestinal model.
1979-1988 - based on reference man of ICRP publication 23 and 1977 recommendations (**ICRP 26**)

✓ **ICRP Publication 68** - updated dose coefficients for inhalation and ingestión for workers
1994 - based on 1991 Recommendations (**ICRP Publication 60**),
- Human Respiratory Tract Model (HRTM, ICRP Publication 66),
- New skeletal data (ICRP Publication 70) and revised systemic biokinetic models..

✓ **ICRP Publications 54 and 78** - guidance on the design of monitoring programs and the interpretation of
1988, 1997 results to estimate doses to workers following inhalation or ingestion.
- provides reference bioassay retention/excretion functions and dose coefficients

✓ **ICRP Publications 56, 67, 69, 71 and 72 –** age-specific dose coefficients for inhalation and ingestion for 91
1989-1995 elements, using up-to-date models and ICRP60 recommendations

✓ **ICRP Publication 119** - **Compendium of Dose Coefficients based on ICRP Publication 60**
2011

✓ **ICRP Publications 88 and 95** - Dose to embryo/fetus and dose to infants from Ingestion of Radionuclides in
2001, 2004 Mothers' Milk

DOSE COEFFICIENTS – INTERNAL EXPOSURES

- **Internal Dose Coefficient e(τ) Sv Bq^{-1}** is the committed effective dose pero unit activity of intake, where τ (commitment period) is 50 years for adults and to the age of 70 years for children

- **Reference individuals:** A set of idealized males and females with anatomical and physiological characteristics defined by the ICRP for the purpose of radiological protection, defined in Publication 89.
  6 ages of each sex (Newborn, 1y, 5y, 10y, 15y, Adult)

- **Reference Person:** Sex-averaged conceptual person (from reference female and reference male) from whom the effective dose is defined

- **ICRP Publication 103:**
  - ✓ The dose coefficients used [to determine committed effective dose] are those specified by the ICRP with no departure from the anatomical, physiological, and biokinetic characteristics of the Reference Male and the Reference Female.
  - ✓ The effective dose assigned in the worker's record is that value which the Reference Person would experience owing to the radiation fields and activity intakes encountered by the worker.

- **Dose coefficient Adult** $e(50) = \sum_T w_T \left[\frac{h_T^{Male}(50) + hT^{Female}(50)}{2}\right]$ where w_T is the tissue weighting factor
  $h_T(50)$ is the committed equivalent dose coefficient

EFFECTIVE DOSE

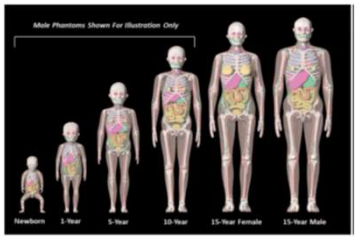
Reference voxel adult phantoms.
ICRP Publication 110

Reference Computational Phantoms

- **Adult** Reference Male and Female (**ICRP Publication 110**)
- **Children** of different ages: newborn, 1, 5, 10 and 15-years old (**ICRP Publication 143**)

- Phantoms are based on tomographic images. Voxels have been adjusted to approximate organ masses according to ICRP Publication 89

- **Dose Conversion Factors (external exposures)** and **dose coefficients (internal exposures)** are calculated using computational phantoms



Family of reference voxel pediatric phantoms for members of the public Figure 3.3 ICRP Publication 143

Figure 2. Sex averaging to obtain the Effective Dose. ICRP Publication 103

EFFECTIVE DOSE

➢ **Effective dose *E (Sv)*: Sex-averaged organ equivalent doses are used for its calculation**

$$E = \sum_T w_T \cdot \frac{(H_T^M + H_T^F)}{2}$$

- Sum over all organs and tissues considered to be sensitive to the induction of stochastic effects
- Remainder tissues:

arithmetic average of the 13 tissues/organs, for each sex

$$H_{\text{rmd}} = \frac{1}{13} \sum_1^{13} H_T$$

- **w_T averaged over both sexes and all ages**

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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

COMMITTED EFFECTIVE DOSE

Internal Exposures

Radiation sources (where incorporated radionuclides have accumulated) are inside the body and irradiation continues as long as the radionuclides remain inside the body, at a rate that changes with time.

The dose rate to the target region r_T delivered by each source region r_S is integrated over a given time period τ after intake:

$$H_T(\tau) = \int_0^{\tau} \dot{H}_T(t)dt = \sum_{r_S} \int_0^{\tau} A(r_S,t)\, S_w(r_T \leftarrow r_S,t)dt$$

where

$\dot{H}_T(t)$ equivalent dose rate in the **target organ or tissue r_T** at time *t;*

$A(r_S,t)$ activity (in Bq) in the **source region** r_S at time *t;*

$S_w(r_T \leftarrow r_S,t)$ *is the S- coefficient* = equivalent dose rate to target region r_T at time *t* per unit activity present in source region r_S, depending on w_R and Specific Absorbed Fractions (SAF)

Time-integrated quantity $H_T(\tau)$ Sv is the *committed equivalent dose* = dose to the target organ due to the initial intake and received over a time period τ = 50 years (adults) and to the age of 70 years (children).

The *committed effective dose* -

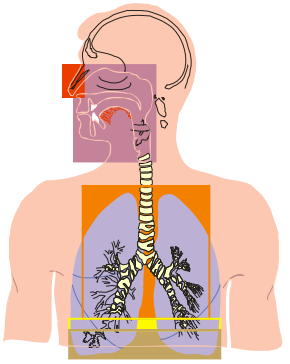
$$E(\tau) = \sum_T w_T \left[\frac{H_T^{Male}(\tau) + HT^{Female}(\tau)}{2}\right]$$

Sex-averaged organ committed equivalent doses

DOSE COEFFICIENTS – INTERNAL EXPOSURES

➢ **INTERNAL EXPOSURES OF <u>WORKERS</u>**

OIR Series – "Dose Coefficients for Occupational Intakes of Radionuclides" – Parts 1-5 consistent with recommendations of ICRP Publication 103



HRTM

❖ **IMPROVEMENTS – BIOKINETICS**

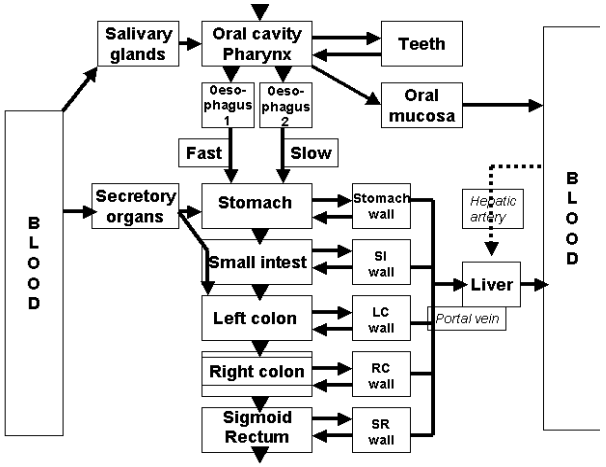
- Anatomical and physiological data of reference individuals according to ICRP Publication 89

- Update of the Human Respitarory Tract Model (HRTM) of ICRP Publication 66
  - Absorption Types (inhalation): F, F/M, M, M/S and S (e.g. uranium)
  - Higher doses for the most insoluble (Type S) materials

- Human Alimentary Tract Model (HATM) from ICRP Publication 100

- More realistic element-specific systemic models, physiologically based

- Independent biokinetics for the daughters of incorporated radionuclides



HATM

DOSE COEFFICIENTS – INTERNAL EXPOSURES

➢ INTERNAL EXPOSURES OF <u>WORKERS</u>

OIR Series – "Dose Coefficients for Occupational Intakes of Radionuclides" – Parts 1-5

❖ IMPROVEMENTS – DOSIMETRY

- Use of revised nuclear data from ICRP Publication 107
- Use of Reference Computational (voxel-type) phantoms for adults (male and female) according to ICRP Publication 110
- New skeletal dosimetry
- Change in radiation weighting factors w_R and tissue weighting factors w_T according to ICRP Publication 103
- New methodology (sex-averaging) for the calculation of the effective dose: consistent with ICRP Publication 103

Reference voxel adult phantoms.
ICRP Publication 110

DOSE COEFFICIENTS – INTERNAL EXPOSURES

ICRP TG 95 – Internal Dose Coefficients

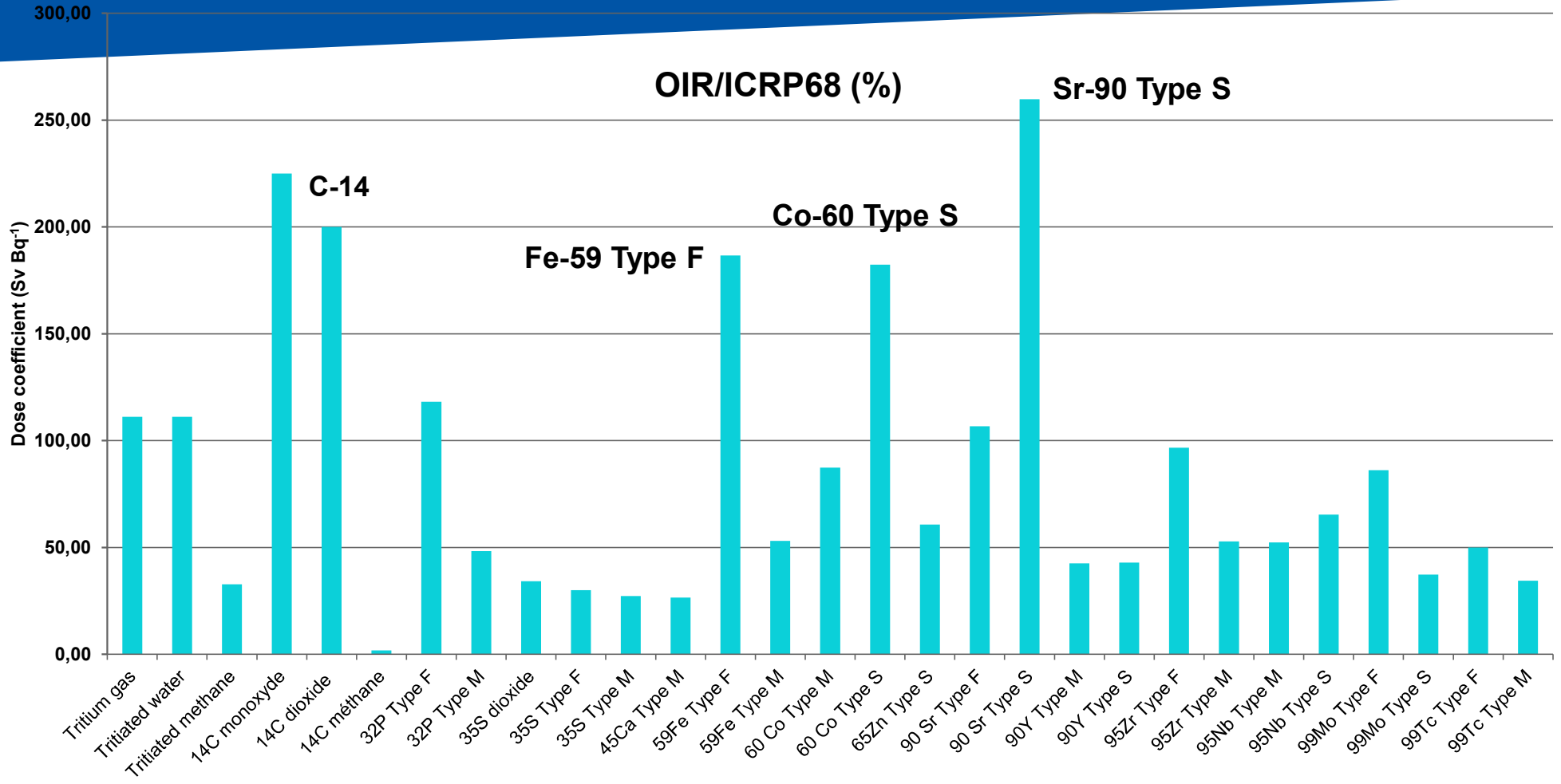
➢ **INTERNAL EXPOSURES OF <u>WORKERS</u>**

OIR Series – "Dose Coefficients for Occupational Intakes of Radionuclides" – Parts 1-5

consistent with recommendations of ICRP Publication 103

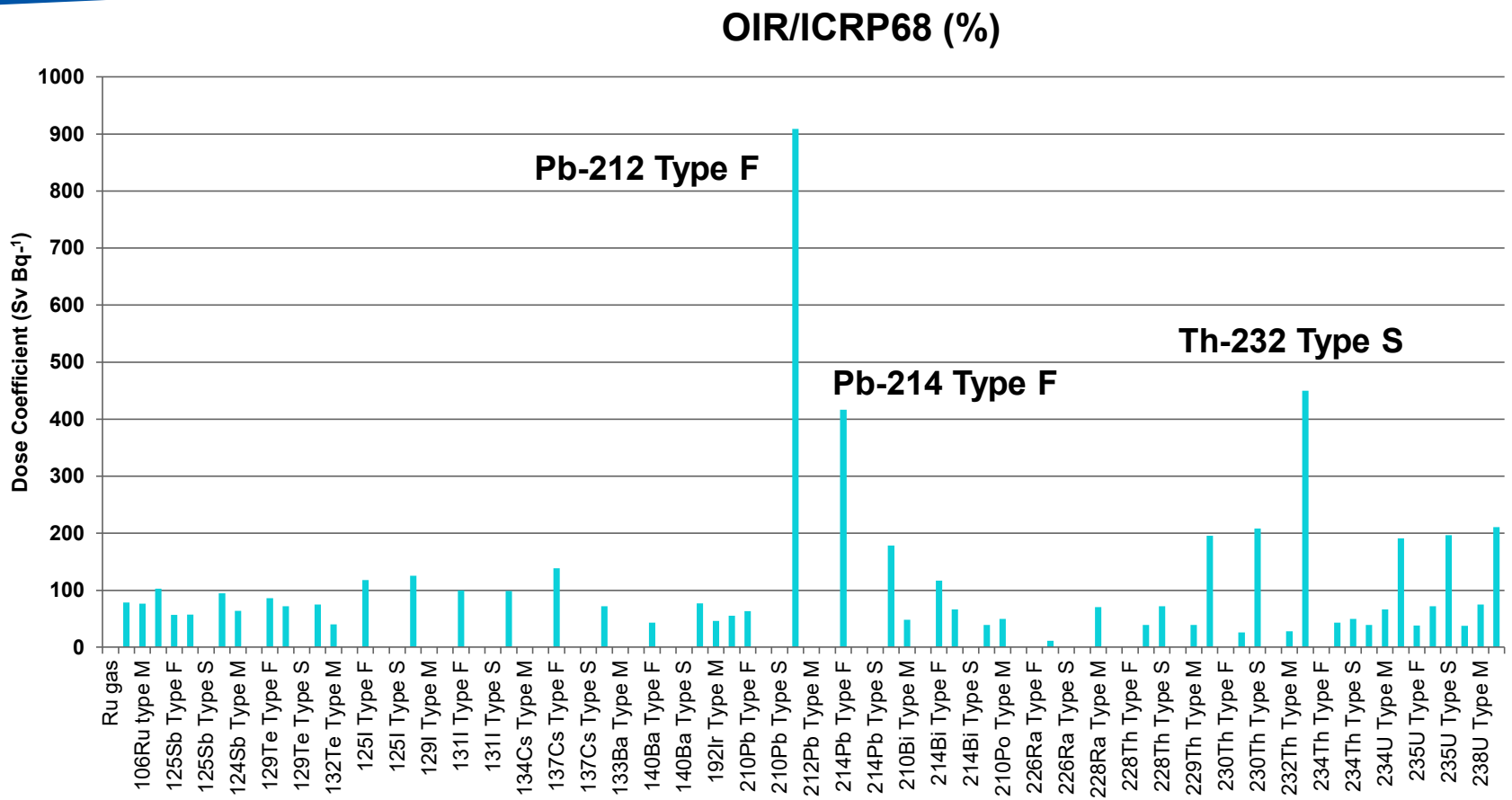
- **Publication 130** – OIR Part 1 (2015): - Methodology for the evaluation of doses due to occupational intakes
  - Update of Human Respiratory Tract Model of ICRP Publication 66
  - Human Alimentary Tract Model of ICRP Publication 100
  - New systemic models
  - Anatomic data of reference individuals according to ICRP Publication 89
- **Publication 134** – OIR Part 2 (2017): H, C, P, S, Ca, Fe, Co, Zn, Sr, Y, Zr, Nb, Mo, Tc
- **Publication 137** – OIR Part 3 (2017): Ru, Sb, Te, I, Cs, Ba, Ir, Pb, Bi, Po, Ra, Th, U, Rn
- **Publication 141** – OIR Part 4 (2019): La, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Ac, Pa, Np, Pu, Am, Cm, …
- **Publication 151** – OIR Part 5 (2022): Be, F, Na, Mg, Al, Si, Cl, K, Sc, Ti, V, Cr, Mn, Ni, Cu, Ga, Ge, … and noble gases Ne, Ar, Kr, Xe

Comparison of dose coefficients between ICRP 68 and OIR Part 2



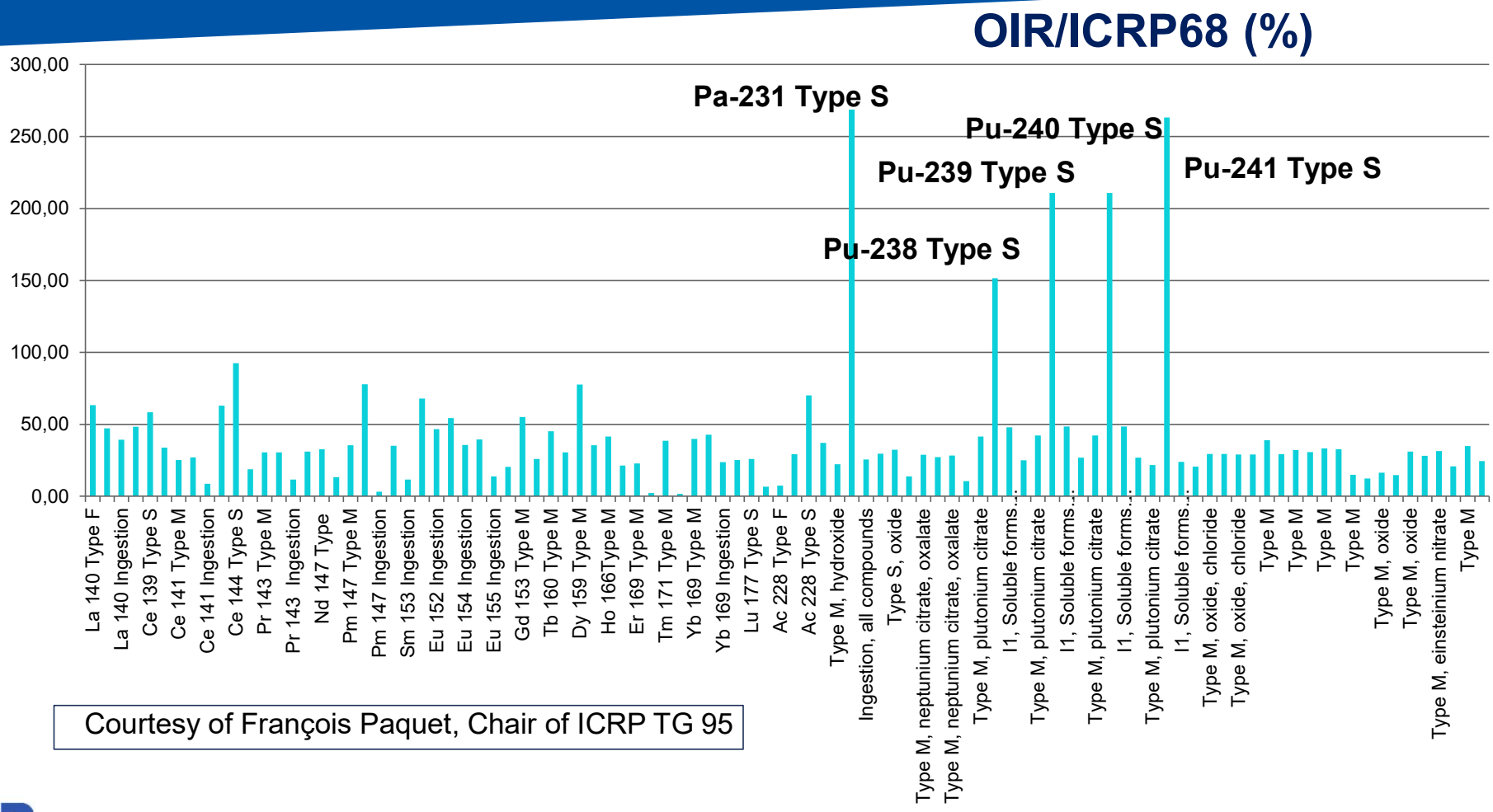
Courtesy of François Paquet, Chair of ICRP TG 95

Comparison of dose coefficients between ICRP 68 and OIR Part 3



Courtesy of François Paquet, Chair of ICRP TG 95

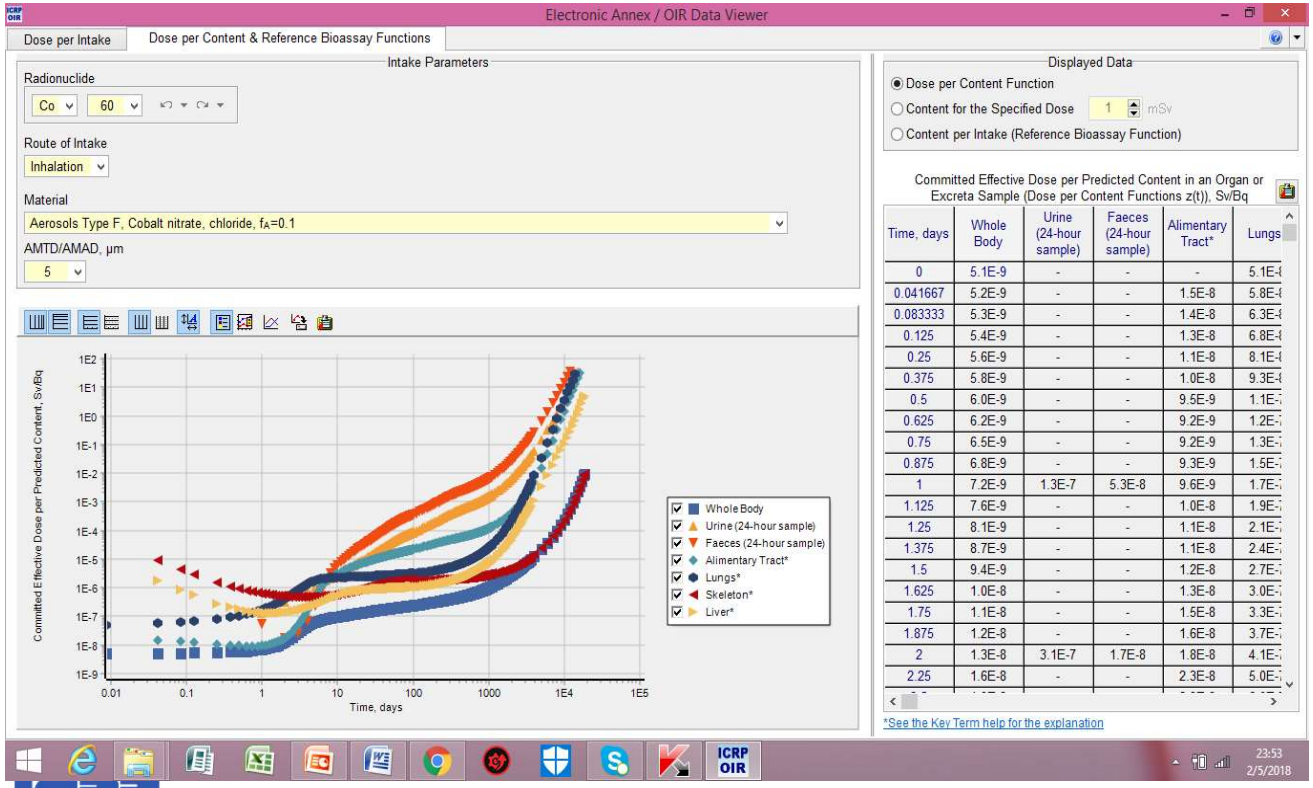
Comparison of dose coefficients between ICRP 68 and OIR Part 4



Courtesy of François Paquet, Chair of ICRP TG 95

DOSE COEFFICIENTS – INTERNAL EXPOSURES

OIR Data Viewer, Electronic Annex of ICRP Publication 151



OIR Data Viewer can show:

- ✓Classification of incorporated materials according to chemical form (inhalation: Type F, M, S, F/M, M/S; ingestion: f_A)
- ✓Reference bioassay retention/excretion functions m(t)
- ✓Dose coefficients e(50) $SvBq^{-1}$ for inhalation, ingestion, injection

  "Z(t) Dose per content" functions

DOSE COEFFICIENTS – INTERNAL EXPOSURES

ICRP TG 95 – Internal Dose Coefficients

- **INTERNAL EXPOSURES OF WORKERS**
  OIR Series – "Dose Coefficients for Occupational Intakes of Radionuclides" – Parts 1-5

Z(t) "dose per content function" – NEW -

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

e(50): dose coefficient Sv Bq^{-1}
m(t): reference bioassay retention/excretion function
t: time (days) after intake

Direct assessment of committed effective dose, using in vivo M(Bq) or in vitro M(Bqd^{-1}, BqL^{-1}) monitoring data

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

DOSE COEFFICIENTS – INTERNAL EXPOSURES

➢ INTERNAL EXPOSURES OF MEMBERS OF THE PUBLIC

- **Internal exposures**: inhalation of airborne radionuclides from a cloud, inhalation of resuspended radionuclides and by ingestion of contaminated food or water

- **Effective Dose** may be obtained by environmental measurements, habit data and modelling.

  Information on concentrations of radionuclides in effluents and the environment are used together with radioecological modelling (pathway analysis of environmental transport, trough air, water, soil, sediments, plants and animals to humans).

DOSE COEFFICIENTS – INTERNAL EXPOSURES

ICRP TG 95 – Internal Dose Coefficients

- **INTERNAL EXPOSURES OF MEMBERS OF THE PUBLIC**

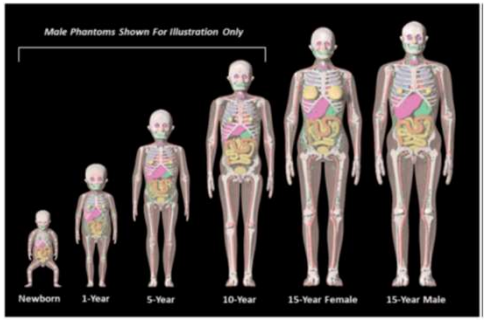
  EIR Series – "Dose Coefficients for Intakes of Radionuclides by members of the PUBLIC"
  Physiological data specific to the public, depending with age (tissue masses, transfer rates,…)
  Age groups according to ICRP Publication 89: 3-months, 1 year, 5 years, 10 years, 15 years, adult
  Age dependent biokinetic models and data. No bioassay retention/excretion functions.

  EIR Part 1: 29 elements of OIR Parts 1-3 – **ICRP Publication 159 - *in press***
  EIR Part 2: elements of OIR Part 4 – ***public consultation until August 2nd***

  EIR Part 3: elements of OIR Part 5 - 2025

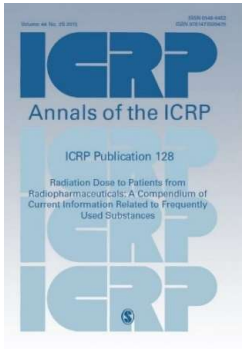
  EIR Part 4: Transfer to milk and child 2026-2027
  EIR Part 5: Transfer to the embryo and foetus 2026-2027

  EIR Data Viewer (v1): electronic annex of Publication 159



Family of reference voxel pediatric phantoms for members of the public Figure 3.3 ICRP Publication 143

DOSE COEFFICIENTS – INTERNAL EXPOSURES



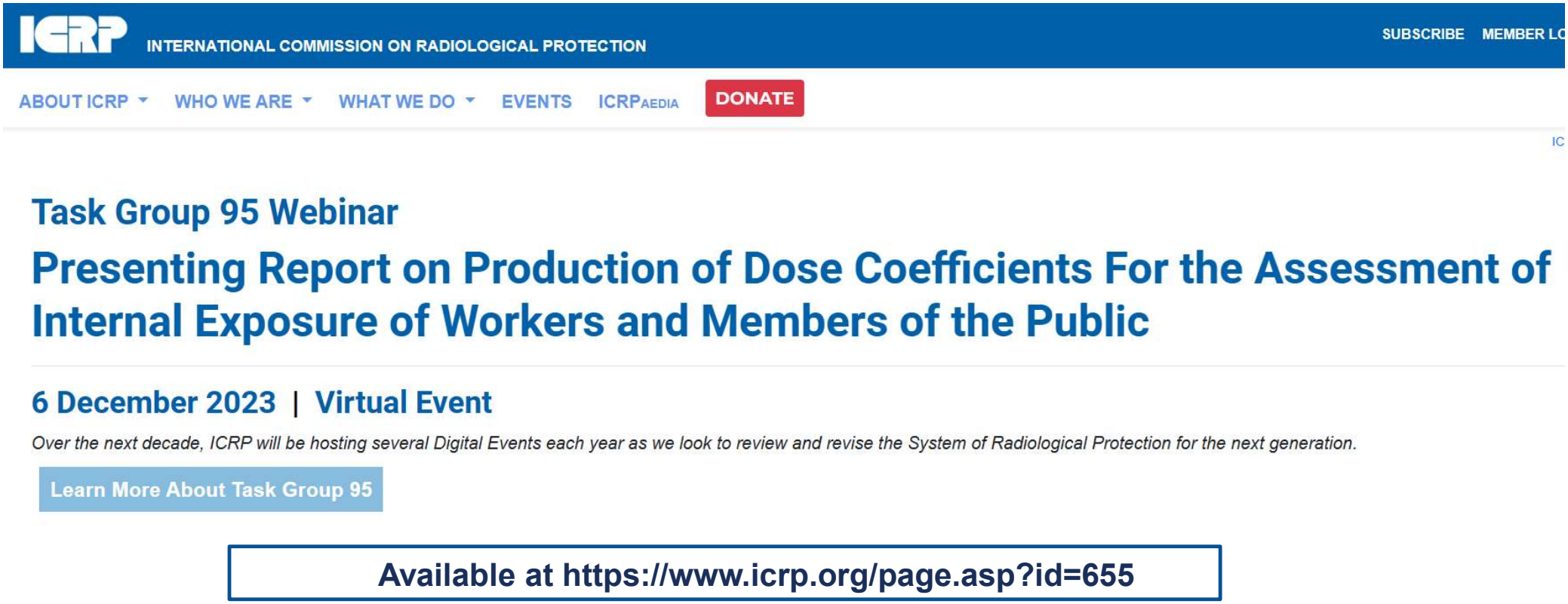
TG 36 – Radiopharmaceutical Dosimetry – *A. Giussani y M. Andersson*

Update of ICRP Publication 128 *"Radiation Dose to Patients from Radiopharmaceuticals: A Compendium of Current Information Related to Frequently Used Substances"*

- **Assessment of dose coefficients for radiopharmaceuticals (DIAGNOSIS)**
  - ✓ Development of new compartmental models for new substances and improvement/updating of currently available models
  - ✓ **Age-dependent dose coefficients, for both sexes: Absorbed Organ Dose (mGy/MBq) and Effective Dose (mSv/MBq)**
  - ✓ Development and QA with software IDAC (Univ. Gothenburg), DOSAGE (BfS), DCAL (ORNL).
  - ✓ Validation of models with real patient data.

- **Full draft of the report is completed**. After approval by ICRP Main Commission the report will be available for **public consultation by the end of 2024**

ICRP Committee 2 - *TG 95*



Available at https://www.icrp.org/page.asp?id=655

ICRP Committee 2 - *TG 95*

Joint EURADOS-ICRP Training Course on the Theory and Practical Application of Codes for the Determination of Dose After Internal Contamination
(organised in cooperation with IRSN)

14 - 18 October 2024

Fontenay aux Roses, France

https://www.icrp.org/admin/EURADOS-ICRP_2024-Training-Course_RegistrationForm.pdf

Thanks for your attention