

# The new ICRP biokinetic and dosimetric models

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## 1. The use of the models

In internal dosimetry, no operational dose quantities have been defined which directly provide an assessment of equivalent dose or effective dose. Different methods are therefore applied to assess the doses due to radionuclides in the human body. They are mostly based on various activity measurements and the application of biokinetic and dosimetric models.

Biokinetic models that are developed for individual elements and their radioisotopes are used to calculate the total number of transformations occurring within specific tissues, organs or body regions (source regions) during a given period of time (usually 50 years for adults, or to age 70 years for children) by determining the time-integrated activity in each source region. Dosimetric models, based on Male and Female Reference computational phantoms and Monte Carlo radiation transport codes, are used to calculate the deposition of energy in all important organs/tissues (targets) for transformations occurring in each source region, taking account of the energies and yields of all emissions. At this stage, sex-specific absorbed doses in each target organ or tissue resulting from a nuclear disintegration in each source region are calculated. The radiation weighting factors are then applied to determine sex-specific committed equivalent doses to an organ or tissue, and the tissue weighting factors are finally applied to determine the sex-averaged committed effective dose.

## 2. New biokinetic and dosimetric models developed by ICRP

ICRP has been very active for many decades in providing models for the calculation of internal doses. The Human Respiratory Tract Model (HRTM) and the Human Alimentary Tract Model (HATM) were described in ICRP Publication 66 and ICRP Publication 100 [1-2]. Systemic models for individual elements were described in several publications providing also dose coefficients for workers and the members of the public for intakes of radionuclides by inhalation and ingestion (See section 3) [3-10]. Finally, the ICRP Publication 88 and 95 [11-12] described the biokinetic data for the transfer of radionuclides to milk and for the transfer of radionuclides to the embryo, fetus and newborn child. Since these publications, ICRP has continuously improved the accuracy of the models published. New models are being produced and will be used in the new series of ICRP publications (OIR Series and EIR Series). These new models are briefly described below:

### *Human Respiratory Tract Model*

The Human Respiratory Tract Model (HRTM) described in Publication 66 [1] has been updated in ICRP Publication 130 [13] to take account of data accumulated since its publication, although the basic features of the model remain unchanged. Inhaled particles containing radionuclides deposit in the ET airways (nose, larynx, etc.), the bronchial and bronchiolar airways of the lung and the AI region, with deposition in the different regions being mainly dependent on particle size [1]. Removal from the respiratory tract occurs mainly by dissolution and absorption to blood and the competing process of transport of particles to the throat followed by their entry into the alimentary tract. The proportions absorbed to blood or cleared by particle transport depend on the speciation and the

solubility of the material, and on the radioactive half-life of the radionuclide. The ICRP model for the respiratory tract is also applied to gases and vapours and to inhalation of radon and its radioactive progeny.

For absorption to blood, the main changes introduced in ICRP Publication 130 are:

- Redefinition of the Type F, M and S absorption defaults: larger rapid dissolution fraction ( $f_r$ ) values for M and S of 0.2 and 0.01, rather than 0.1 and 0.001, respectively, with lower rapid dissolution rate ( $s_r$ ) values of  $3 \text{ d}^{-1}$  for M and S, and  $30 \text{ d}^{-1}$  for F, rather than  $100 \text{ d}^{-1}$ ;
- Material-specific parameter values for  $f_r$ ,  $s_r$  and the slow dissolution rate ( $s_s$ ) in selected cases where sufficient information is available (e.g. forms of uranium);
- Element-specific values of  $s_r$  and the bound state parameters,  $f_b$  and  $s_b$ , where sufficient information is available; and
- Revised treatment of gases and vapours in which solubility and reactivity are defined in terms of the proportion deposited in the respiratory tract. The default assumption is 100% deposition (20% ET<sub>2</sub>, 10% BB, 20% bb and 50% AI), and Type F absorption. The SR-0, -1, -2 classification described in *Publication 66* has not been found to be helpful and is not used.

For clearance by particle transport, the main changes are:

- More realistic clearance from the nasal passage, including transfer from the anterior to the posterior region, based on recent human experimental studies;
- Revised characteristics of slow particle clearance from the bronchial tree based on recent human experimental studies. It is now assumed that it occurs only in the bronchioles rather than as a particle size dependent phenomenon throughout the bronchial tree; and
- Longer retention in the AI region of the lung, with a revised model structure, based on recent data including long-term follow-up of workers exposed to insoluble <sup>60</sup>Co particles, and plutonium dioxide.

#### *Human Alimentary Tract Model*

The ICRP Publication 30 [3] model of the Gastrointestinal tract has been replaced by the HATM described in ICRP Publication 100 [2]. The main features of the HATM can be summarised as follows:

- Inclusion of all alimentary tract regions: oral cavity, oesophagus, stomach, small intestine, right colon, left colon and rectosigmoid (the sigmoid colon and rectum);
- A default assumption that absorption of an element and its radioisotopes to blood occurs exclusively in the small intestine, i.e. the total fractional absorption,  $f_A$  equals the fractional absorption from the small intestine,  $f_{SI}$ . A model structure that allows for absorption in other regions, where information is available;
- A model structure that allows for retention in the mucosal tissues of the walls of alimentary tract regions, and on teeth, where information is available; and
- Explicit specification of the location of target regions for cancer induction within each alimentary tract region.
- ICRP Publication 100 [2] gave preliminary values of electron and alpha particle absorbed fractions for stem cell layers in alimentary tract regions. ICRP Publication 133 [14] provided new calculations for both particle types and for both content and wall sources. For regions within the small intestine, new models of segment folding were also implemented.

#### *Systemic models*

A systemic model describes the time-dependent distribution and retention of a radionuclide in the body after absorption to blood and systemic circulation, and its excretion from the

body. In contrast to ICRP's current and past biokinetic models describing the behaviour of radionuclides in the respiratory and alimentary tracts, ICRP's systemic models have generally been element-specific with regard to model structure as well as parameter values. A single generic model structure that depicts all potentially important systemic repositories and paths of transfer of all elements of interest in radiation protection would be too complex to be of practical use. However, generic model structures have been used in previous ICRP documents to represent the systemic biokinetics of groups of elements, typically chemical families, known (or expected to have) qualitatively similar behaviour in the body. For example, ICRP Publication 20 [15] introduced a generic model formulation for the alkaline earth elements calcium, strontium, barium and radium, but provided element-specific values for most model parameters. In Parts 1-3 of ICRP Publication 30 [3-5], a model developed for plutonium, including parameter values as well as model structure, was applied to most actinide elements. The use of generic systemic model structures was increased in ICRP reports on doses to members of the public from intake of radionuclides [7-9] and is further expanded in recent ICRP Publications because it facilitates the development, description and application of systemic biokinetic models. An important development is that, as the availability of data allows, models have been made to be more physiologically realistic with regard to the dynamics of organ retention and excretion so that they can more reliably be applied to the interpretation of bioassay data as well as the calculation of dose coefficients.

### 3. From the models to the dose coefficients

Biokinetic and dosimetric models provide every data needed to calculate the dose from incorporation of the radionuclides. However, because of the complexity of the overall procedure when calculating internal dose, ICRP provided also sets of dose per intake coefficients that allow a direct estimate of the internal dose from knowledge of intake into the body. In addition, for occupational intakes, data are provided to allow intake and dose to be calculated from bioassay measurements. The current work of ICRP is to provide a new set of models and dose coefficients, to take into account the latest ICRP recommendations [16] and up-to-date knowledge in biology, physiology and dosimetry. They are going to be published in the Occupational Intake of Radionuclides (OIR) series and the Environmental Intakes of Radionuclides (EIR) series.

The OIR series replace the ICRP Publication 30 series [3-6] and ICRP Publication 68 [17] to provide revised dose coefficients for occupational intakes of radionuclides (OIR) by inhalation and ingestion. The revised dose coefficients have been calculated using the new biokinetic models described in section 2. The first of five reports in the OIR series, *Publication 130* (ICRP, 2015), includes chapters on control of occupational exposures, biokinetic and dosimetric models, monitoring methods, monitoring programmes and retrospective dose assessment. Subsequent reports provide data on individual elements and their radioisotopes, including biokinetic data and models, dose coefficients and data for bioassay interpretation. OIR Part 2 and Part 3 have been issued as Publication 134 and 137 [18-19], and OIR 4 is nearing completion. In these reports, each element section provides: dose coefficients (committed effective dose and committed equivalent doses to organs or tissues per Bq intake ( $\text{Sv Bq}^{-1}$ )) for inhalation and ingestion of all relevant radioisotopes; dose per content functions [committed effective dose per predicted activity content in the body or in a given organ or per daily excretion ( $\text{Sv Bq}^{-1}$ )]; reference bioassay functions [values of activity (Bq) retained in the body or specific organs, or excreted in urine or faeces, at various times after unit intake (i.e. 1 Bq) by inhalation or ingestion].

The EIR series will replace the ICRP Publication 56 series [7-10] to provide revised age-dependent dose coefficients for members of the public for environmental intakes of

radionuclides by inhalation and ingestion. As for the OIR series, revisions have been made to use the updated HATM et HRTM and new systemic models, and considering the age-dependence of biokinetics. The first report in the EIR series will provide an introduction to the report series and include data on individual elements and their radioisotopes, including biokinetic data and models, and dose coefficients. As for the OIR series, each element section will provide dose coefficients: committed effective dose and committed equivalent doses to organs or tissues per Bq intake ( $\text{Sv Bq}^{-1}$ ) for inhalation and ingestion of all relevant radioisotopes.

## References

1. ICRP. Human Respiratory Tract Model for Radiological Protection. ICRP Publication 66, Ann. ICRP **24**, 1-3 (1994a)
2. ICRP. Human Alimentary Tract Model for Radiological Protection. ICRP Publication 100. Ann. ICRP, **36**, (1-2) (2006)
3. ICRP. Limits for intakes of radionuclides by workers. ICRP Publication 30, Part 1. Ann. ICRP, **2** (3/4) (1979)
4. ICRP. Limits for intakes of radionuclides by workers. ICRP Publication 30, part 2. Ann. ICRP, **4**, 3/4 (1980)
5. ICRP. Limits for intakes of radionuclides by workers. ICRP Publication 30, Part 3. Ann. ICRP, **6**, 2/3 (1981)
6. ICRP. Limits for intakes of radionuclides by workers. ICRP Publication 30, Part 4. Ann. ICRP **19**,4 (1988)
7. ICRP. Age-dependent dose to members of the public from intake of radionuclides: part 2: ingestion dose coefficients. ICRP Publication 67. Ann. ICRP **23**, 3-4. (1993)
8. ICRP. Age-dependent Doses to Members of the Public from Intake of Radionuclides: Part 3: Ingestion Dose Coefficients. ICRP Publication 69. Ann. ICRP, **25**,1 (1995a)
9. ICRP. Age-dependent Doses to Members of the Public from Intake of Radionuclides: Part 4: Inhalation Dose Coefficients. ICRP Publication 71. Ann. ICRP, **25**,3/4, (1995c)
10. ICRP. Age-dependent Doses to Members of the Public from Intake of Radionuclides: Part 5 Compilation of Ingestion and Inhalation Dose Coefficients. ICRP Publication 72. Ann. ICRP, **26**,1 (1996)
11. ICRP. Doses to the Embryo and Fetus from Intakes of Radionuclides by the Mother. ICRP Publication 88. Ann. ICRP **31**, 1-3 (2001)
12. ICRP. Doses to Infants from Ingestion of Radionuclides in Mothers' Milk. ICRP Publication 95. Ann. ICRP **34**,3/4, (2004)
13. ICRP. Occupational Intakes of Radionuclides, Part 1. ICRP Publication 130. Ann. ICRP **44** (2) ( 2015)
14. ICRP. The ICRP Computational Framework for Internal Dose Assessment for Reference Adults: Specific Absorbed Fractions. ICRP Publication 133. Ann. ICRP **45**, 2, (2016a)
15. ICRP. Alkaline Earth Metabolism in Adult Man. ICRP Publication 20. Ann. ICRP. (1973)
16. ICRP. The 2007 Recommendations of the International Commission on Radiological Protection. ICRP Publication 103. Ann. ICRP **37**, 2-4, (2007)
17. ICRP. Dose Coefficients for Intake of Radionuclides by Workers. ICRP Publication 68. Ann. ICRP, **24**, 4, (1994b)
18. ICRP. Occupational Intakes of Radionuclides: Part 2. ICRP Publication 134. Ann. ICRP **45**, 3/4, (2016b)
19. ICRP. Occupational Intakes of Radionuclides: Part 3. ICRP Publication 137. Ann. ICRP. **46**, 3/4, (2017)