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Overview of ICRP Committee 2 'Doses from Radiation Exposure'

J. Harrison
Public Health England, Centre for Radiation, Chemical and Environmental Hazards, Chilton, Didcot, Oxon OX11 0RQ, UK;
e-mail: john.harrison@phe.gov.uk

Abstract–Over many years, Committee 2 of the International Commission on Radiological Protection (ICRP) has provided sets of dose coefficients to allow users to evaluate equivalent and effective doses for intakes of radionuclides or exposure to external radiation for comparison with dose limits, constraints, and reference levels as recommended by ICRP. Following the 2007 Recommendations, Committee 2 and its task groups are engaged in a substantial programme of work to provide new dose coefficients for various conditions of radiation exposure. The methodology being applied in the calculation of doses can be regarded as state-of-the-art in terms of the biokinetic models used to describe the behaviour of inhaled and ingested radionuclides, and the dosimetric models used to model radiation transport for external and internal exposures. The level of sophistication of these models is greater than required for calculation of the protection quantities with their inherent simplifications and approximations, which were introduced necessarily, for example by the use of radiation and tissue weighting factors. However, ICRP is at the forefront of developments in this area, and its models are used for scientific as well as protection purposes. This overview provides an outline of recent work and future plans, including publications on dose coefficients for adults, children, and in-utero exposures, with new dosimetric phantoms in each case. The Committee has also recently finished a report on radiation exposures of astronauts in space, and is working with members of the other ICRP committees on the development of advice on the use of effective dose.

Keywords: Reference phantoms; Equivalent dose; Effective dose; Dose coefficients

This paper does not necessarily reflect the views of the International Commission on Radiological Protection.

1. INTRODUCTION

The remit of Committee 2 of the International Commission on Radiological Protection (ICRP) is: the development of dose coefficients for the assessment of internal and external radiation exposure; development of reference biokinetic and dosimetric models; and reference data for workers and members of the public. The current membership (2013–2017) is John Harrison (Chairman), François Paquet (Vice-Chairman), Wesley Bolch (Secretary), Mike Bailey, Volodymyr Berkovskyy, Doug Chambers, Marina Degteva, Akira Endo, John Hunt, Chan Hyeong Kim, Rich Leggett, Jizeng Ma, Dietmar Nosske, Nina Petoussi-Henss, and Frank Wissmann.

The Committee has four task groups that are responsible for the production of reports:

- Task Group on Dose Calculations, chaired by Wesley Bolch, is concerned with the development of computational models and reference data needed to assess organ and effective doses from both internal and external radiation sources to both occupational workers and members of the general public.
- Task Group on Internal Dosimetry, chaired by François Paquet, is currently engaged in the revision of biokinetic models, for use in the recalculation of dose coefficients for the inhalation and ingestion of radionuclides, first for workers and subsequently for members of the public.
- Task Group on Effective Dose, chaired by John Harrison, will produce a report to provide guidance on the use of the quantity 'effective dose', and its relation to risk, particularly in the context of applications in medicine but also more widely.
- Task Group on Dose Coefficients for External Environmental Exposures, chaired by Nina Petoussi-Henss, will provide conversion coefficients for the external exposure of members of the public to airborne sources and ground deposits.

Committee 2 works closely with the International Commission on Radiation Units and Measurements (ICRU); the Chairman of ICRU, Hans Menzel, is a member of the ICRP Main Commission. Committee members also support the work of the other ICRP committees, and are currently providing members for the task groups of Committees 1, 3, and 5.

Revisions of ICRP recommendations invariably require recalculation of dose coefficients because changes are made to the radiation and tissue weighting factors used in the calculation of equivalent and effective dose. In addition, improvements to the models used to calculate doses lead to revised values. Work is currently in progress to provide replacement dose coefficients based on the 2007 Recommendations (ICRP, 2007), incorporating a number of important methodological improvements. The following sections provide a short explanation of recent and forthcoming Committee 2 reports.

2. RECENT COMMITTEE 2 REPORTS (2009–2013)

2.1. Adult reference computational phantoms *(Publication 110)*

Menzel and Harrison 2012a gave an outline of the development of ICRP reference phantoms, and explained that *Publication 110* (ICRP, 2009), a joint report with ICRU, provides reference phantoms for the adult male and female derived from imaging data for individuals. The individuals were chosen for their similarity to the external dimensions and organ masses of the reference adult male and female (ICRP, 2002), and the models were subsequently adjusted for consistency with these data. The use of male and female phantoms will replace the use of stylised hermaphrodite phantoms developed by the Medical Internal Radiation Dose Committee of the Society of Nuclear Medicine (Cristy, 1980; Cristy and Eckerman, 1987). Thus, in future calculations, equivalent dose will be calculated separately for males and females, and averaged in the calculation of effective dose (ICRP, 2007).

2.2. Conversion coefficients for radiological protection quantities for external radiation exposures *(Publication 116)*

Publication 116 (ICRP, 2010) is a joint report with ICRU, presenting conversion coefficients for organ and effective doses, for external exposures in occupational settings, calculated using the *Publication 110* phantoms and in accordance with the 2007 Recommendations. The radiations considered are external beams of monoenergetic photons, electrons and positrons, neutrons, protons, pions (negative/positive), muons (negative/positive), and helium ions. The organ dose conversion coefficients tabulated in the report represent ICRP/ICRU recommended values. Comparisons of the protection quantities, equivalent and effective dose, with corresponding operational quantities show the latter to provide conservative estimates of dose in the majority of cases. Annexes and a CD provide detailed supporting information, including equivalent dose coefficients for the lens of the eye and skin.

2.3. Compendium of dose coefficients based on *Publication 60 (Publication 119)*

At the specific request of the International Atomic Energy Agency and European Commission, a compilation of dose coefficients has been provided as *Publication 119* (ICRP, 2012), based on the 1990 Recommendations (ICRP, 1991). These values will be used and referred to in International and European Basic Safety Standards, while new values based on the 2007 Recommendations are being calculated until their use is required.

Publication 119 includes committed effective dose coefficients for inhalation and ingestion intakes of radionuclides by workers, as compiled in *Publication 68* (ICRP, 1994b), calculated using the *Publication 66* (ICRP, 1994a) model of the human respiratory tract and the *Publication 30* (ICRP, 1979) model of the gastrointestinal tract. The biokinetic models used to describe the distribution, tissue retention, and excretion of individual elements and their radioisotopes following their absorption to blood were those developed for the *Publication 30* series (ICRP, 1979, 1980, 1981, 1988), except for cases for which updates were provided in *Publications 56, 67, 69* and

71 (ICRP, 1990, 1993, 1995a, 1995b). *Publication 119* also includes dose coefficients for intakes of radionuclides by members of the public, specifically 3-month-old infants; 1-, 5-, 10-, and 15-year-old children; and adults, as compiled in *Publication 72* (ICRP, 1995c). The biokinetic models used to describe the distribution, retention, and excretion of radionuclides were developed to consider age dependence in the case of radioisotopes of the 31 elements for which dose coefficients were given in *Publications 56, 67, 69*, and *71* (ICRP, 1990, 1993, 1995a, 1995b).

For external radiation exposures, *Publication 119* includes conversion coefficients for use in occupational radiological protection abstracted from *Publication 74* (ICRP, 1996), calculated assuming whole-body irradiation by monoenergetic photons, electrons, and neutrons in a number of idealised standard exposure geometries.

2.4. Assessment of radiation exposure of astronauts in space *(Publication 123)*

Astronauts are exposed to extremely complex radiation fields. The primary radiation field contains high-energy particles with unique high-linear energy transfer (LET) components that are very different from the typical low-energy electron, photon, and neutron radiation fields encountered in occupational exposure environments on earth. Radiation fields in space may arise from outside the solar system within supernova explosions, neutron stars, pulsars, or other high-energy phenomena. These galactic cosmic rays are composed of electrons, protons, alpha particles, and heavier nuclei. In addition, the sun emits particles continuously in the form of protons and electrons, as well as gamma rays, hard and soft x rays, and radiowaves. Solar particle events can be a significant source of high radiation exposure, particularly to astronauts performing extravehicular activities in deep space.

Publication 123 (ICRP, 2013) provides an assessment of radiation exposures in space, considers methods of dose estimation and detection for space radiations, and gives reference doses. The report and the accompanying CD provide an extensive set of organ dose conversion coefficients for a range of space radiation particles, calculated using the *Publication 110* reference computational phantoms and complementing the external dose conversion coefficients given in *Publication 116* (ICRP, 2010). In recommending the use of a radiation weighting factor (w_R) of 20 for all heavy ions of all energies for protection purposes, ICRP (2007) recognised that this may be unduly conservative in situations in which heavy ions make a major contribution to exposures, as experienced by astronauts. *Publication 123* discusses alternatives to the use of w_R, providing guidance on the use of quality factors as a function of either unrestricted LET [Q(L) functions from *Publication 60* (ICRP, 1991)] or particle charge and energy [Q(Z, E) functions defined by National Aeronautics and Space Administration (NASA): Cucinotta et al., 2011].

3. FORTHCOMING COMMITTEE 2 REPORTS

3.1. Reference dosimetric phantoms and radiation transport calculations

Reference phantoms are being developed for children aged 3 months and 1, 5, 10 and 15 years, and for the fetus and pregnant female at gestational ages of 10, 15,

25, and 35 weeks. These dosimetric models, and those for adults provided in *Publication 110* (ICRP, 2009), are being used to provide reference radiation transport data in the form of specific absorbed fractions (SAFs) for radiations emitted from radionuclides retained in body organs and tissues. SAFs represent the deposition of energy in all important organs and tissues (target regions) following emissions from radionuclides retained in body organs and tissues (source regions). These data are used in the calculation of dose coefficients for the inhalation and ingestion of radionuclides by workers and members of the public (see below). They are also used in calculations of doses from radiopharmaceuticals, the responsibility of a task group led by Committee 3.

The calculation of SAFs involves Monte Carlo radiation transport of photons, electrons, and neutrons for an extensive set of source/target organ pairs. Additional work has focused on micro-computed-tomography-based models of electron and alpha particle dosimetry of skeletal tissues, and revisions to electron and alpha particle dosimetry in the dosimetric models of the human respiratory tract (ICRP, 1994a) and alimentary tract (ICRP, 2006).

Reports scheduled for the next few years in this series are:

- internal SAF values for the reference adult male and female;
- computational phantoms for the infant and children;
- internal SAF values for the infant and children;
- computational phantoms for the pregnant female, embryo, and fetus; and
- internal SAF values for the fetus and pregnant female.

3.2. Intakes of radionuclides by workers and the public

Work is in progress to replace *Publications 30* and *68* (ICRP, 1979, 1980, 1981, 1988, 1994b), that give biokinetic data and dose coefficients for occupational intakes of radionuclides by inhalation and ingestion, and *Publications 54* and *78* (ICRP, 1989, 1997), that give information for bioassay interpretation, with a single series of publications on occupational intakes of radionuclides (OIR series).

Part 1 of this series of reports is complete and provides a description of biokinetic and dosimetric methodology, including a summary of the *Publication 100* (ICRP, 2006) alimentary tract model, a detailed description of changes to the *Publication 66* (ICRP, 1994a) respiratory tract model, and an outline of approaches taken to the development of systemic models for elements. The use of bioassay data is also discussed. Subsequent parts will consist of element sections describing element-specific biokinetic models and providing dose coefficients and bioassay data. The series will have accompanying electronic annexes giving detailed information on organ doses and additional bioassay data. Planned publications are as follows:

- Part 2: hydrogen (H), carbon (C), phosphorus (P), sulphur (S), calcium (Ca), iron (Fe), cobalt (Co), zinc (Zn), strontium (Sr), yttrium (Y), zirconium (Zr), niobium (Nb), molybdenum (Mo), and technetium (Tc).

- Part 3: ruthenium (Ru), antimony (Sb), tellurium (Te), iodine (I), caesium (Cs), barium (Ba), iridium (Ir), lead (Pb), bismuth (Bi), polonium (Po), radon (Rn), radium (Ra), thorium (Th), and uranium (U).
- Part 4: lanthanides and actinides.
- Part 5: remaining elements to be considered.

The schedule of work for Committee 2 and its task groups includes replacement of all currently available dose coefficients for ingestion and inhalation of radionuclides by members of the public. Dose coefficients will be provided for:

- infants (3 months), children (1, 5, 10, and 15 years) and adults, replacing *Publications 56*, *67*, *69*, *71*, and *72* (ICRP 1990, 1993, 1995a, 1995b, 1995c).
- embryo/fetus and breast-fed infant following radionuclide intakes by the mother, replacing *Publications 88* and *95* (ICRP, 2001, 2004).

3.3. Dose coefficients for external environmental exposures

A new task group has been set up to develop age-dependent dose conversion coefficients for external radiation exposures, not previously provided by ICRP. Assessment of external exposures of members of the public, including infants and children, is important in the context of accidental releases from nuclear facilities, and more generally. Conversion coefficients for environmental exposures will be computed using ICRP reference dosimetric phantoms.

3.4. Use of effective dose

The task group on the use of effective dose led by Committee 2 has membership from Committees 1, 3, and 4 as well as external experts, in recognition of the central importance of this issue (Menzel and Harrison, 2012b). Experience has shown that 'effective dose', which has been defined and introduced by ICRP for risk management purposes (i.e. for risk limitation and optimisation), is widely used in radiological protection and related fields beyond its original purpose – incorrectly in some cases. Useful guidance on restrictions on the use of the quantity is provided by Committee 2 in Annex B to the 2007 Recommendations (ICRP, 2007). This guidance needs to be further expanded, and proposals made for the control of exposures and risk management in situations where 'effective dose' should not be used. An important focus of the report will be medical exposures (Balonov and Shrimpton, 2012; Harrison and Lopez, 2015).

4. DISCUSSION

ICRP Committee 2 has a large programme of work to provide new dose coefficients following the 2007 Recommendations (ICRP, 2007). Revisions of ICRP recommendations invariably require recalculation of dose coefficients because changes are made to the radiation and tissue weighting factors used in the calculation of

equivalent and effective dose. However, it is also important that the methodology used to calculate doses is examined and updated as necessary to ensure the appropriate use of developing scientific knowledge. Committee 2 is therefore in the process of developing a set of reference computational phantoms based on medical imaging data, and revising radiation transport calculations using these models. Biokinetic models used to describe the behaviour of inhaled and ingested radionuclides are being updated, also leading to changes in organ doses and effective dose coefficients. It can be argued that the level of sophistication of these models is greater than required for the calculation of the protection quantities, equivalent and effective dose, because the risk-related adjustments made using radiation and tissue weighting factors are necessarily broad judgements and approximations applied across all body organs and tissues of people worldwide. However, ICRP is at the forefront of developments in this area, and its biokinetic and dosimetric models are used for scientific as well as protection purposes. Thus, ICRP models can provide best estimates of organ and tissue absorbed dose for use in epidemiological studies and assessments of risk to individuals. Biokinetic and dosimetric models can be adjusted for application to individuals or specific population groups rather than ICRP reference persons. Furthermore, it is important that methodology is continually refined and improved to counter suggestions that the dose assessments underestimate risks, particularly for internal exposures.

Effective dose is a radiation protection quantity that is used to set limits, constraints, and reference levels that apply to reference workers or reference members of the public. It provides an elegant solution to the requirement for a single quantity that enables the summation of all radiation exposures, from external exposures and radionuclides entering the body by inhalation or ingestion. Effective dose is used as a risk-related quantity for the optimisation of protection below constraints and reference levels. As our scientific understanding of radiation dosimetry and the risks of radiation continue to develop, it will be important to examine the formulation and use of effective dose as the central quantity in the control of radiation exposure and its continued fitness for purpose.

The estimation of doses and risks to astronauts provides a good example of an application that goes beyond the scope of effective dose. As discussed in *Publication 123* (ICRP, 2013), use of a radiation weighting factor of 20 for heavy ions in the calculation of organ equivalent doses may be an unduly conservative risk adjustment; available evidence suggests peak values of around 10 with substantially lower values at higher energies. *Publication 123* discusses the alternative use of quality factors as a function of LET, and calculation of dose equivalent and effective dose equivalent as preferred risk-related quantities for space applications. An alternative energy-related function used by NASA is also discussed. However, the protection of astronauts is generally related to limits on stochastic risks in terms of radiation-exposure-induced death (REID) rather than effective dose. For example, a limit of 3% REID at the upper 95% confidence level is currently imposed on NASA flight crew. To calculate values of REID, age- and sex-specific risk factors are applied to radiation weighted doses. To obtain best estimates of organ doses, reference

phantoms of the type being developed by ICRP can be adjusted to the body dimensions of individual astronauts. The ICRP report on effective dose will explain the use of the protection quantities in the optimisation of protection, as distinct from dose and risk estimation.

REFERENCES

Balonov, M.I., Shrimpton, P.C., 2012. Effective dose and risks from medical x-ray procedures. Ann. ICRP 41(3–4), 129–141.

Cristy, M., 1980. Mathematical Phantoms Representing Children of Various Ages for Use in Estimates of Internal Dose. ORNL Report TM-367. Oak Ridge National Laboratory, Oak Ridge, TN.

Cristy, M., Eckerman, K.F., 1987. Specific Absorbed Fractions of Energy at Various Ages from Internal Photon Sources. ORNL TM-8381/VI-7. Oak Ridge National Laboratory, Oak Ridge, TN.

Cucinotta, F.A., Myung-Hee, Y.K., Chappell, L.J., 2011. Space Radiation Cancer Risk Projections and Uncertainties – 2010. NASA/TP-2011 – 216155.

Harrison, J.D., Marsh, J.W., 2012. Effective dose from inhaled radon and its progeny. Ann. ICRP 41(3/4), 378–388.

Harrison, J.D., Lopez, P.O., 2015. The use of effective dose in medicine. Ann. ICRP 44(1S), 280–287.

ICRP, 1979. Limits for intakes of radionuclides by workers. ICRP Publication 30 (Part 1). Ann. ICRP 2(3/4).

ICRP, 1980. Limits for intakes of radionuclides by workers. ICRP Publication 30 (Part 2). Ann. ICRP 4(3/4).

ICRP, 1981. Limits for intakes of radionuclides by workers. ICRP Publication 30 (Part 3). Ann. ICRP 6(2/3).

ICRP, 1988. Limits for intakes of radionuclides by workers: an addendum. ICRP Publication 30 (Part 4). Ann. ICRP 19(4).

ICRP, 1989. Individual monitoring for intakes of radionuclides by workers. ICRP Publication 54. Ann. ICRP 19(1–3).

ICRP, 1990. Age-dependent doses to members of the public from intake of radionuclides – Part 1. ICRP Publication 56. Ann. ICRP 20(2).

ICRP, 1991. 1990 Recommendations of the International Commission on Radiological Protection. ICRP Publication 60. Ann. ICRP 21(1/3).

ICRP, 1993. Age-dependent doses to members of the public from intake of radionuclides – Part 2. Ingestion dose coefficients. ICRP Publication 67. Ann. ICRP 23(3/4).

ICRP, 1994a. Human respiratory tract model for radiological protection. ICRP Publication 66. Ann. ICRP 24(1–3).

ICRP, 1994b. Dose coefficients for intakes of radionuclides by workers. ICRP Publication 68. Ann. ICRP 24(4).

ICRP, 1995a. Age-dependent doses to members of the public from intake of radionuclides – Part 3. Ingestion dose coefficients. ICRP Publication 69. Ann. ICRP 25(1).

ICRP, 1995b. Age-dependent dose to members of the public from intake of radionuclides – Part 4. Inhalation dose coefficients. ICRP Publication 71. Ann. ICRP 25(3/4).

ICRP, 1995c. Age-dependent doses to members of the public from intake of radionuclides – part 5. Compilation of ingestion and inhalation coefficients. ICRP Publication 72. Ann. ICRP 26(1).

ICRP, 1996. Conversion coefficients for use in radiological protection against external radiation. ICRP Publication 74. Ann. ICRP 26(3/4).
ICRP, 1997. Individual monitoring for internal exposure of workers. ICRP Publication 78. Ann. ICRP 27(3/4).
ICRP, 2001. Doses to the embryo and fetus from intakes of radionuclides by the mother. ICRP Publication 88. Ann. ICRP 31(1/3).
ICRP, 2002. Basic anatomical and physiological data for use in radiological protection reference values. ICRP Publication 89. Ann. ICRP 32(3).
ICRP, 2004. Doses to infants from ingestion of radionuclides in mothers' milk. ICRP Publication 95. Ann. ICRP 34(3/4).
ICRP, 2006. Human alimentary tract model for radiological protection. ICRP Publication 100. Ann. ICRP 26(1/2).
ICRP, 2007. The 2007 Recommendations of the International Commission on Radiological Protection. *ICRP Publication* 103. Ann. ICRP 37(2–4).
ICRP, 2009. Adult reference computational phantoms. ICRP Publication 110. Ann. ICRP 39(2).
ICRP, 2010. Conversion coefficients for radiological protection quantities for external radiation exposures. ICRP Publication 116. Ann. ICRP 40(2–5).
ICRP, 2012. Compendium of dose coefficients based on ICRP Publication 60. ICRP Publication 119. Ann. ICRP 41(Suppl.).
ICRP, 2013. Assessment of radiation exposure of astronauts in space. ICRP Publication 123. Ann. ICRP 42(4).
Menzel, H.-G., Harrison, J.D., 2012a. Doses from radiation exposure. Ann. ICRP 41(3/4), 12–23.
Menzel, H.-G., Harrison, J.D., 2012b. Effective dose: a radiation protection quantity. Ann. ICRP 41(3/4), 117–123.