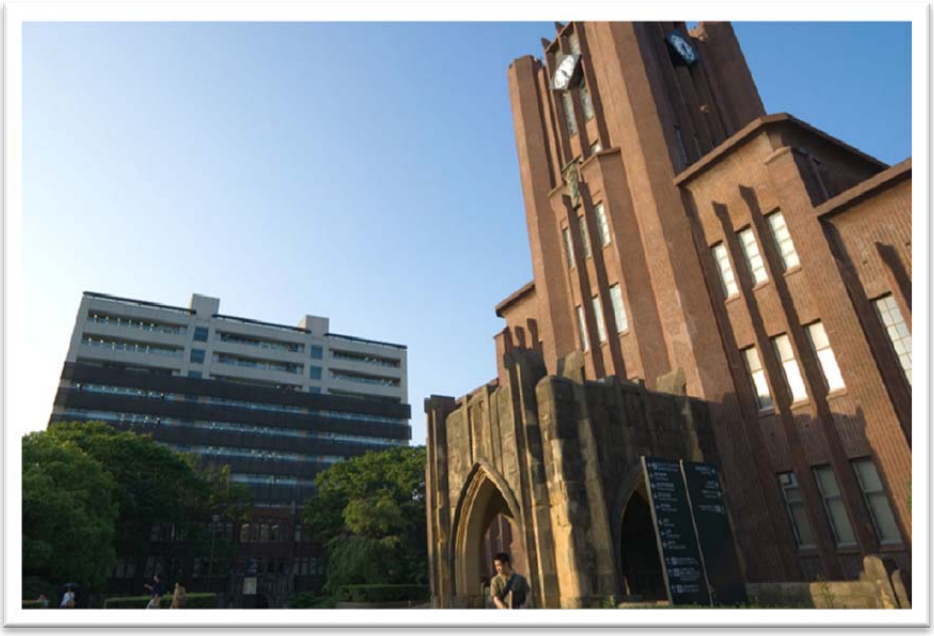
ICRP Symposium on Radiological Protection Dosimetry

Historical Review and Current Activities

The University of Tokyo
Thursday, February 18, 2016

Abstracts



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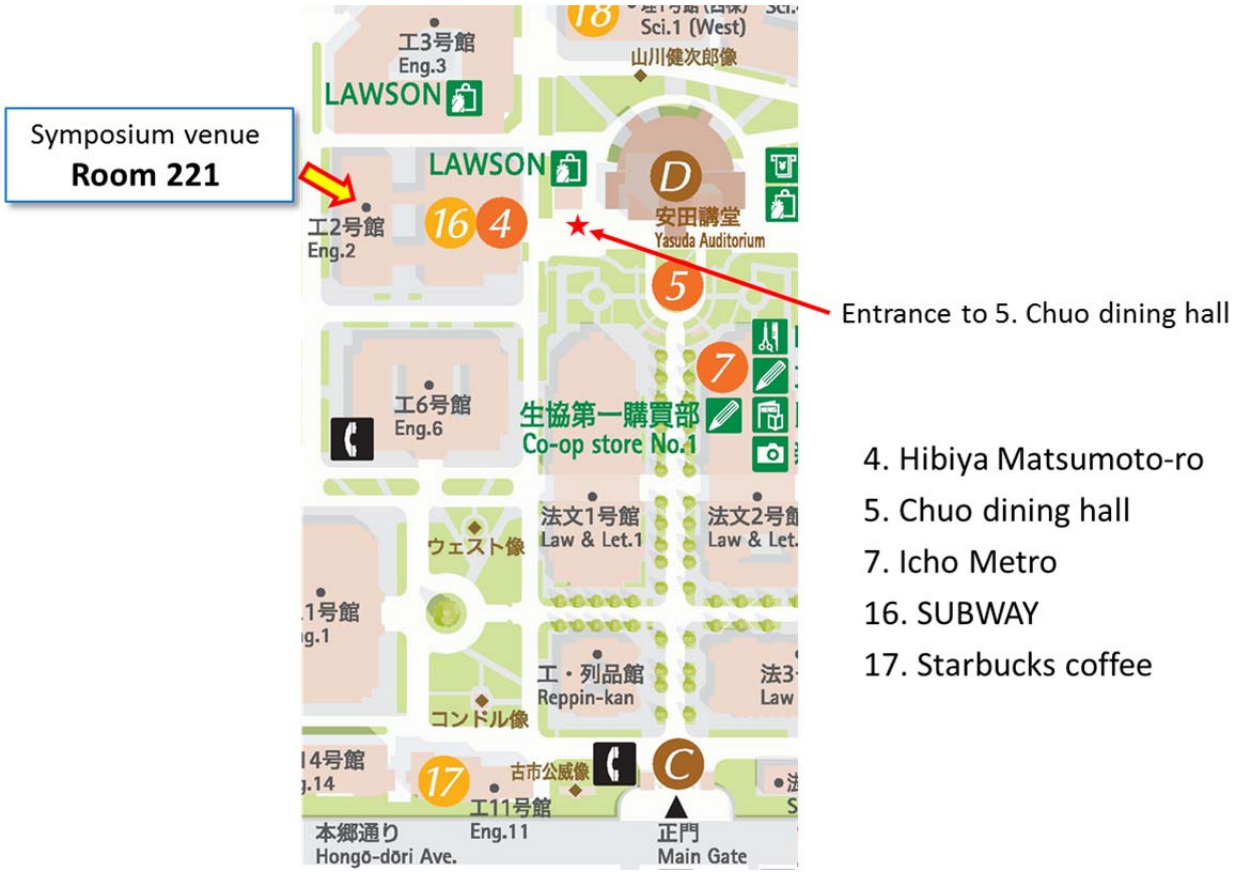
ICRP INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION

THE NIPPON FOUNDATION

Restaurants and shops in the campus



Photograph on the cover: Faculty of Engineering Building 2 (left, symposium venue) and the Yasuda Auditorium (right) in Hongo Campus, the University of Tokyo.
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Background

lCRP Committee 2 is engaged in the development of dose coefficients for the assessment of internal and external radiation exposures; development of reference biokinetic and dosimetric models, and reference data for workers and members of the public. The Committee and its Task Groups are currently engaged in a large program of work to provide revised dose coefficients that implement the 2007 Recommendations and introduce improvements in methodology.

ICRP Committee 2 works closely with the International Commission on Radiation Units and Measurements (ICRU). It also works with the other ICRP Committees, for example in current work to provide advice on the use of effective dose as a protection quantity.

Objectives of the symposium

ICRP Committee 2 welcomes this opportunity to discuss the current work with Japanese scientists and practitioners, covering topics including:

- Scientific bases of ICRP dose calculations
- Current status of the development of models and data
- Application of the models and data to dose assessments for workers and the public with focus on environmental exposures after accidental releases, risk assessment and radiation monitoring
- Use of equivalent and effective dose as protection quantities
- Research needs and future developments

Symposium venue

Room 221, Faculty of Engineering Building 2, Hongo Campus, the University of Tokyo

Coffee break and lunch

Coffee will be served during the morning and afternoon breaks.
Participants could visit for lunch the restaurants and cafeterias of the university campus.
Locations of restaurants and shops are found at the inside of the front cover.

Program

Registration starts at 9:30

Opening Address

10:00 – 10:10	Structure and Mission of the International Commission on Radiological Protection	John Harrison, C2 Chair

Session 1 – Introduction **Akira Endo, Session Chair**

10:10 – 10:30	Overview of the ICRP System of Internal and External Dosimetry	Wesley Bolch

Session 2 – Models and Data Used for the Calculation of Dose Coefficients **Michael Bellamy, Session Chair**

10:30 – 10:55	Computational Phantoms of the Reference Adults: Stylized and Voxel	Maria Zankl
10:55 – 11:20	Polygon Mesh Conversion of the ICRP Reference Phantoms	Chan Hyeong Kim
11:20 – 11:40	**Coffee Break**	
11:40 – 12:05	Methods of Dose Assessment to the Skeletal Tissues	Derek Jokisch
12:05 – 12:30	Computational Phantoms of Children and Pregnant Females	Choonsik Lee
12:30 – 13:00	Biokinetic Models and Dose Coefficients for Internal Exposures	John Harrison
13:00 – 14:00	**Lunch**	

Session 3 – Dose Coefficients Using ICRP Reference Models and Data **Kimiaki Saito, Session Chair**

14:00 – 14:25	Reference Dose Coefficients for Occupational External Exposure	Nina Petoussi-Henss
14:25 – 14:50	Reference Dose Coefficients for Environmental Exposure	Helmut Schlattl

Session 4 – Application of Effective Dose and Radiation Monitoring Practice **Kwang Pyo Kim, Session Chair**

14:50 – 15:15	Effective Dose and Risk Assessment	John Harrison
15:15 – 15:40	Revisions to ICRU Operational Quantities	Nolan Hertel
15:40 – 16:00	**Coffee Break**	

Session 5 – Research Needed for the ICRP System of Radiological Protection Dosimetry
Wesley Bolch, Session Chair

16:00 – 16:30	Issues on the Radiation Weighting Factor	Tatsuhiko Sato
16:30 – 17:00	Dose Assessment of Workers and the Public: Lessons Learned from Fukushima	Osamu Kurihara
17:00 – 17:25	General Discussion of Research Needs	

Concluding Remarks

17:25 – 17:30	Concluding Remarks	John Harrison, C2 Chair

Overview of the ICRP System of Internal and External Dosimetry

W.E. Bolch

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The system of protection established by the International Commission on Radiological Protection for both workers and members of the general public is based primarily upon the protection quantity *effective dose*. The effective dose is a doubly-weighted average of the radiation absorbed dose (energy imparted per unit mass) to various individual organs and tissues of the body. The first factor – the radiation weighting factor w_R – accounts for the radiobiological effectiveness of different radiation particle types. The second factor – the tissue weighting factor w_T – accounts for the relative risk of stochastic biological effect to the various exposed organs and tissues of the body. The effective dose is a non-measurable quantity and is thus must be given using various computational models. For internal exposures, models are invoked that account for the movement of the inhaled or ingested radionuclide through the respiratory or alimentary tract, respectively, to circulating blood. Next, systemic biokinetic models follow the radionuclide in blood as it is taken up both various sources organs of the body, released back to blood, and eventually eliminated via urinary or faecal excretion. Physics models of radionuclide decay are used to determine, at each location within the body, what types and energies of radiation particles emitted. Finally, anatomic and radiation transport models are used to follow these emitted particles as they travel through the body and deposit energy through both absorption or scattering events. The ultimate result of these computations is the *effective dose coefficient* – defined as the effective dose per activity inhaled or ingested. For external exposures, the very same anatomic and radiation transport models are employed, with the incident radiation coming from radioactivity or radiation sources found in either the occupational or natural environment. For external exposures, the *effective dose coefficient* relates the effective dose to computed or measured values of air kerma, particle fluence, or radioactivity concentration.

In this presentation, we will review the various dose quantities and computational models needed to determine dose coefficients for both internal and external radiation exposures. Further details are given the accompanying presentations of this symposium.

Computational Phantoms of the Reference Adults: Stylized and Voxel

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Phantoms simulating the human body or parts thereof play a central role in radiation dosimetry. The first computational body phantoms have been based upon mathematical expressions representing planes, cylindrical, conical, elliptical, and spherical surfaces describing the shape and position of idealized body organs. For this first generation of computational body phantoms, the organ masses and volumes were in accordance with the ICRP (International Commission on Radiological Protection) data of former Reference Man (ICRP *Publication 23*, 1975).

With the advent of more powerful computers in the 1980s, various groups have developed voxel phantoms as an extension and improvement to these earlier models. Being based on three-dimensional images of single individuals, they offer a more realistic replication of human anatomy. Various authors have shown that the organ shapes of the earlier mathematical phantoms present an over-simplification that has an influence on the energy distribution which may deviate for some cases systematically from that calculated for voxel phantoms. However, despite their obvious advantages compared to the previously used stylized phantom type, most of these phantoms do not represent the average Caucasian man or woman, due to being derived from a specific individual. Hence, the ICRP decided to construct voxel phantoms being representative of the adult Reference Male and Reference Female (ICRP *Publication 89*, 2002) with respect to their external dimensions, their organ topology, and their organ masses (ICRP *Publication 110*, 2009), for the update of organ dose conversion coefficients following the recent ICRP Recommendations (ICRP *Publication 103*, 2007).

Since the reference computational phantoms have a limited voxel resolution in the millimetre range, several organs and tissues having much smaller dimensions cannot be represented in detail. Hence, for selected calculations, additional stylized phantoms have been used. For the external irradiations of ICRP *Publication 116* (2010), stylized models of the eye and lens were used for estimating selected dose conversion coefficients. Similarly, for internal dosimetry, the fine structure of some of the target regions in the human respiratory tract and human alimentary tract could not be described by the voxel geometry of the reference phantoms, and thus stylized models of the airways and of individual segments of the alimentary tract were employed for the calculation of selected Specific Absorbed Fractions.

Polygon Mesh Conversion of the ICRP Reference Phantoms

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To overcome the limitations of the current voxel-type ICRP *Publication 110* reference phantoms, the ICRP Committee 2 is currently developing a set of mesh-type ICRP reference phantoms, by converting the current voxel-type *Publication 110* reference phantoms into a high-quality mesh format. The *Publication 110* reference phantoms are voxel phantoms based on whole-body computed tomography scans of adult male and female patients. The voxel resolutions are on the order of a few mm; therefore, smaller tissues such as the eye lens, skin or the walls of some organs cannot be properly defined in the phantoms. In addition, the voxel phantoms cannot represent the thin target tissues of the respiratory or alimentary tract organs, requiring additional simplified mathematical phantoms for dose coefficient calculations. The objective of the research in the ICRP Committee 2 is to produce a set of replica of *Publication 110* reference phantoms in a high-quality mesh-format to address the aforementioned limitations. The developed phantoms are expected to include continuous and fully-enclosed surfaces for all the organs and tissues in the phantoms, include the thin target layers in the alimentary and respiratory tract organs, and also include detailed and more accurate models for skeletal system, eyes, lymphatic nodes, blood vessels, and hands. The developed phantoms will be also deformable, which functionality will be useful when the ICRP Committee 2 calculates the dose coefficients for emergency exposure situations in the next term of ICRP (2017-2021).

The presentation will first introduce the research project in general, explaining the motivation and objective, and then explain the current progress and preliminary results, and finally conclude with the implication of the research outcomes in the ICRP and radiation protection society in general.

Methods of Dose Assessment to the Skeletal Tissues

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Estimating the amount of energy absorbed in skeletal tissues is complicated due to the relatively small sizes and interlacing structure of two contrasting media: bone and marrow. The two radiosensitive tissues of interest in the skeleton are the cells responsible for blood cell formation and the osteoprogenitor tissue. The former is called active (or red) marrow and resides in varying concentrations in the marrow spaces throughout the body. The sensitive osteoprogenitor tissue is considered to reside on the soft tissue side of the bone-marrow interface.

Charged particles originating within the skeleton have ranges such that they can traverse multiple segments of bone and marrow while depositing energy to the targets of interest, thus making explicit consideration of the skeletal microstructure desirable. Three dimensional imaging of human skeletal samples has been performed and used as a basis for computational dosimetry models for electrons, protons, and alpha particles. These models produce specific absorbed fractions which take into account the complex microstructure of the skeleton as well as the varied components of the marrow space (active marrow, adipose tissue, and the osteoprogenitor tissue). This presentation will briefly review a history of skeletal dosimetry before describing the latest methodologies and their application to effective dose coefficient calculations.

Computational Phantoms of Children and Pregnant Females

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In its *Publication 110*, the International Commission on Radiological Protection (ICRP) formally adopted two voxel-based computational reference phantoms representing the Reference Adult Male and Reference Adult Female. These models were subsequently used to establish external reference dose coefficients for worker occupational fields, aircrew exposures, and space radiation environments. They are presently being used by Committee 2 for establishing dose coefficients for internal exposures following radionuclide inhalation and ingestions, as well as external exposures to contaminated soil, water, and air. Moving forward, the ICRP is updating reference dose coefficients to members of the general public including infants, children, adolescents, and pregnant females. In keeping with the framework of *Publication 110*, a new series of reference voxel phantoms have been developed for the newborn, 1-year-old, 5-year-old, 10-year-old, and 15-year-old male and female. These phantoms are derived from a series of hybrid phantoms established jointly with the University of Florida (UF) and the National Cancer Institute (NCI). The UF/NCI pediatric hybrid phantoms are based on computed tomography (CT) images of patients and then adjusted to match the reference organ masses and body dimensions as reported in the ICRP *Publication 89*. Major changes to the UF/NCI hybrid phantoms include an adjustment of the organ identification system to mirror that for the adult phantoms of *Publication 110*. Additional tissues and substructures were modeled to include organ mucosa/lips/cheeks, glandular and adipose regions of the female breast, major blood vessels of the lungs, and the ureters. New tissue models were further developed for the lymphatic nodes and skeletal muscle. Detailed skeletal models are based upon microCT imaging of cored samples of newborn and 15-year cadaver spongiosa, coupled with pathlength distributions from the University of Leeds at ages of 1.7 and 9 years. The second phantoms series recently established is that of the adult pregnant female, developed at the University of Florida to support radiation epidemiology studies of in-utero exposures at the Techa River villages and Mayak Plutonium Production Facility. This series of phantoms include detailed fetal models based upon CT and MR imaging of preserved fetal specimens, and segmented CT-base anatomy of adult pregnant females. The final reference series include models at 8, 10, 15, 20, 25, 30, 35, and 38 weeks post-conception.

Biokinetic Models and Dose Coefficients for Internal Exposures

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Since the *Publication 30* series on occupational intakes of radionuclides, which followed from the *Publication 26* Recommendations (1977), ICRP has provided comprehensive information in support of the calculation of organ and effective doses for intakes of radionuclides by workers and members of the public. Dose coefficients (Sv Bq^{-1} intake) have been provided for workers, adult members of the public and children of different ages, considering intakes by ingestion and inhalation. Dose coefficients have also been provided for secondary exposures of the fetus and newborn child following intakes by the mother, considering placental transfer of radionuclides and transfer in breast milk.

The calculation of organ and effective doses following intakes of radionuclides into the body require biokinetic as well as dosimetric models. Biokinetic models describe the uptake and retention of radionuclides in body organs and tissues and are used to calculate the number of nuclear transformations occurring in each region. Dosimetric models are then used to calculate energy deposition in and dose to these organs and tissues and associated energy deposition and dose to other organs and tissues.

The construction of biokinetic models makes use of human data where these are available, supported by animal data and knowledge of physiological processes and biochemical interactions. Committee 2 is currently in the process of updating biokinetic models for the calculation of dose coefficients that are compliant with the latest ICRP Recommendations (*Publication 103*; 2007). Substantial revisions are being made to the model used for the human respiratory tract which describes the deposition of inhaled materials and their subsequent clearance from the lungs and absorption to blood. An updated model of the alimentary tract will also be implemented. Substantial efforts have also been made to improve the physiological realism of models used to describe the distribution, retention and excretion of radionuclides absorbed to blood, referred to as systemic models. Age-dependence of model parameter values is considered in the calculation of dose coefficients for children. Special models are required for the transfer of radionuclides to the fetus and breast-fed infant.

While the biokinetic models developed by ICRP are primarily for use in the calculation of reference dose coefficients in support of the system of protection, the models are also used for scientific purposes, including the calculation of organ doses in epidemiological studies of health effects. For protection purposes, ICRP provides dose coefficients for different particle sizes of inhaled materials and different chemical forms of inhaled and ingested radionuclides but otherwise specifies that no changes should be made to reference model parameter values. In other applications, it may be appropriate to make changes to adapt models to the characteristics of particular exposed population groups and also to consider uncertainties and variability between individuals.

The replacement of all reference dose coefficients with *Publication 103* compliant values is a substantial scientific effort that will be completed over the next few years. Meanwhile, ICRP has provided, as *Publication 119* (ICRP, 2012), a compilation of dose coefficients based on the 1990 Recommendations of *Publication 60* (ICRP, 1991) for use while new values based on the 2007 Recommendations are being calculated.

Reference Dose Coefficients for Occupational External Exposure

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Practical radiological protection for workers uses dosimetric quantities which appropriately quantify the exposure of humans to ionising radiation for the implementation of the fundamental principles of limitation and optimization. Protection quantities, equivalent dose and effective dose, are not measurable and their values are assessed using their relationship to either physical radiation field quantities, e. g. air kerma free in air, K_a, or particle fluence, Φ, or operational dose quantities. Coefficients defined for a reference person provide numerical links between these quantities and it is very important that an internationally agreed set of coefficients is available for general use in radiological protection practice. One of the central focus of ICRP Committee 2 is the development of reference dose coefficients for radiation exposure to workers considering irradiation scenarios under occupational settings.

Revisions of ICRP recommendations, like the latest of *Publication 103* (ICRP, 2007), invariably require recalculation of dose coefficients because changes are made to the radiation and tissue weighting factors and to the phantoms used in the calculation of equivalent and effective dose. Dose coefficients for external radiation exposure of adults calculated using new reference computational phantoms were issued as *Publication 116* (ICRP, 2010) jointly with the International Commission on Radiation Units and Measurements (ICRU). Differences in the photon and electron dose coefficients from those of *Publication 74* (ICRP, 1996), still in use by several countries, do generally not exceed 20-30% and are largely attributable to specific aspects of the computational phantoms. Somewhat greater differences seen for low- and high-energy neutrons are attributable to the changes in their energy-dependent radiation weighting factors. Comparison of the effective doses with operational quantities revealed that the latter continue to provide a good approximation for photons, electrons and neutrons and for the energy ranges considered in ICRP *Publication 74* but not at the higher energies considered in ICRP *Publication 116*.

The presentation will highlight the computational framework, some of the main findings for photons and neutrons and the impact of new phantoms and updated weighting factors.

ICRP, 1996. Conversion coefficients for use in radiological protection against external radiation. ICRP Publication 74, Pergamon Press, Oxford, UK. Ann. ICRP 26(3/4)

ICRP, 2007. The 2007 Recommendations of the International Commission on Radiological Protection. ICRP Publication ICRP Publication 103, Elsevier, Oxford, UK. Ann. ICRP 37(2-4)

ICRP, 2010. Conversion Coefficients for Radiological Protection Quantities for External Radiation Exposures. ICRP Publication 116, International Commission of Radiological Protection, Oxford, UK. Ann. ICRP 40(2-5) (Japanese translation of ICRP Publication 116 is also available)

Reference Dose Coefficients for Environmental Exposure

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In the mid- and long-term period after nuclear accidents, and in large distances to the event, the external exposure is the major contribution to the radiation dose of the public. Thus, effective and organ dose conversion coefficients for adults and children exposed by a radioactive cloud (volume source in air) or to ground contamination after fall-out (plane source in ground) have been computed for electron and photon sources. In addition, the conversion coefficients for being in contaminated aquatic environment have been calculated. The calculations were performed with the Monte Carlo code PHITS using the ICRP reference adult models and forthcoming ICRP reference paediatric models representing newborns and 1, 5, 10 and 15 year old children. We also performed spot-check calculations using the Monte Carlo code EGSnrc to confirm the reliability of the calculation results of PHITS. The findings confirm the well-known fact that a smaller body mass yields to higher doses. Despite the moderately larger doses for children, it was found that, e.g., for ^{137}Cs in ground, the effective dose rate is still lower than the ambient-dose rate. Thus, the ambient-dose monitoring provides a conservative dose estimate not only for adults but also for children.

Effective Dose and Risk Assessment

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Effective dose (*E*) was originally introduced in the *Publication 26* Recommendations (ICRP, 1977) of the International Commission on Radiological Protection for the control of occupational and public exposures to external and internal sources of radiation at moderate and low levels of exposure. While the concept has remained essentially unchanged through the *Publication 60* (ICRP, 1991) and *Publication 103* Recommendations (ICRP, 2007), its use has been extended to members of the public of all ages, including *in utero* exposures of the embryo and fetus. *E* is accepted internationally as the central radiological protection quantity and has proved to be a valuable and robust quantity for use in the optimisation of protection and setting of control criteria: limits, constraints and reference levels. However, confusion has arisen in its practical application and communication of dose information to non-experts, particularly because of the number of different dose quantities. In addition, effective dose is increasingly used in medical applications, including a problematic and growing application to the assessment of risks to individuals. A task group is currently preparing advice on the use of the protection quantities; the presentation will summarise aspects of this advice, focusing on two key proposals that are under consideration by ICRP.

Confusion can arise in the use of the protection quantities, equivalent and effective dose (both in Sv), when they are not sufficiently well distinguished, and between equivalent dose and the operational quantity, dose equivalent (Sv), used in measurements of exposures to external radiation for the assessment of effective dose. Such difficulties would be avoided if organ and tissue doses are referred to in terms of mean absorbed dose (Gy), specifying low and high LET components as necessary. The unit Sv would then apply to the protection quantity, effective dose, and the corresponding operational quantity, dose equivalent. Limits to prevent deterministic effects to the lens of the eye, skin, and hands and feet would more appropriately be set in absorbed dose rather than equivalent dose. It is proposed, therefore, that consideration should be given to discontinuation of the use of equivalent dose as a separate protection quantity.

E is in widespread use in medical practice as a measure of risk, going beyond its intended purpose. While doses incurred at low levels of exposure may be measured or assessed with reasonable reliability, health effects have not been reliably demonstrated at such levels but are inferred. However, bearing in mind the uncertainties associated with risk projection to low doses or low dose-rates, it may be considered reasonable to use *E* as a rough indicator of possible risk, with the additional consideration of variation in risk with age, sex and population group.

Revisions to ICRU Operational Quantities

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The International Commission on Radiological Units and Measurements (ICRU) defines a set of operational dose quantities for the determination of external radiation exposure by measurement. The protection quantities recommended by the International Commission on Radiological Protection (ICRP) for the limitation of radiation exposure are generally not measurable. The ICRU operational quantities are used in practice to approximate the values of the ICRP protection quantities. The ICRU operational dose quantities for external irradiation in current use were defined 30 years ago.

The rationale for operational quantities has been examined in light of changes in the definitions of the ICRP protection quantities and changes in the fields of application of the operational and protection quantities. Current applications must cover a wider range of particle types and energies contributing to doses resulting from external irradiation of worker and members of the public. The relationship of the new operational quantities recommendations to the protection quantities has been investigated and will be covered in the proposed report. In addition the impact of changes on routine measurement practice, including instrument design and calibration, has been considered. The existing operational quantities were based on dose equivalent at a point in the ICRU sphere and on dose equivalent at a point in the body. The proposed operational quantities are particle fluence at a point in space multiplied by sets of values of conversion coefficients to the protection quantities, effective dose, absorbed dose to the lens of the eye, and absorbed dose to local skin.

Issues on the Radiation Weighting Factor

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It is well known that the risk of radiation exposure depends not only on dose and dose rate but also characteristics of radiation causing the dose. In the radiological protection system, this dependence is generally called “radiation quality”, and historically represented by linear energy transfer (LET) in water. The radiation quality factor as a continuous function of LET, $Q(L)$, was defined in ICRP *Publication 26*, and its form was revised in ICRP *Publication 60* by taking the reduced biological effectiveness of high-LET radiations into consideration. A similar concept, the radiation weighting factor, w_R, was also introduced in ICRP *Publication 60*, which simply expresses the radiation quality of organ doses by the type and energy of the radiation incident on the body. One reason to introduce this simplified concept was that $Q(L)$ was often interpreted to imply a spurious precision in spite of rather weak biological evidence to support its justification. However, the concept of radiation weighting factor is considered to be oversimplified in some situations such as radiation exposure in space as discussed in ICRP *Publication 123*.

At the symposium, I would like to discuss the possibility to introduce the radiation quality factor as a function of specific energy, z, which represents absorbed dose in microscopic sites such as cells and intracellular structures. A similar concept has already been proposed by a few decades ago when ICRU defined the quality factor as a function of lineal energy, y, in ICRU Report 40. The microdosimetry-based quality factor is advantageous in comparison to $Q(L)$ and w_R because it can consider:

1. difference in RBE among photons of different energies,
2. difference in RBE among ion species at the same LET,
3. dose effect due to stochastic variation of absorbed doses in each cell, which is particularly important at low dose, and
4. recent radiobiological findings such as non-targeted effect.

The last 2 items are feasible only when z instead of y is adopted as the index. On the other hand, its disadvantages are that:

1. the concept as well as the numerical relation of the radiation quality factor becomes complicated,
2. definitions of z and y are hard to understand for non-specialist of microdosimetry,
3. appropriate site sizes related to the radiation exposure risk must be determined, and
4. evaluation of dose distributions as a function of z or y, $d(z)$ or $d(y)$, for various exposure situation is difficult.

The 1st item seems to be crucial, but it does not directly result in abandoning the simplicity of the radiological protection system itself. This is because the radiation quality factor is mainly used for calculating the fluence to effective dose conversion coefficients, and once they are evaluated, people can use the values without considering the difficulty of their evaluation process. Of course, these disadvantages cannot be overcame within a few years, but I believe that it is worthwhile to try to establish a new microdosimetry-based radiation quality factor as a long term project. The more details of each advantage and disadvantage will be presented at the symposium.

Dose Assessment of Workers and the Public: Lessons Learned from Fukushima

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Almost five years have passed since an unprecedented nuclear accident at the Tokyo Electric Power Company's (TEPCO's) Fukushima Daiichi Nuclear Power Plant (FDNPP). An enormous amount of radionuclides was released into the environment as a consequence of this accident, which caused radiation exposure to workers in charge of emergency operations at the site of the accident and the general public. The dose assessment of the exposed individuals is indispensable although the doses are generally low considering the published information. However, there exist many difficulties in this, in particular in estimating internal doses due to the intake of short-lived radionuclides represented by ^{131}I with a physical half-life of 8 days.

Regarding the workers, the individual exposure monitoring could not be sufficiently performed shortly after the accident. Personal dosimeters were mostly lost by tsunamis and whole-body counters (WBCs) were disabled because of the elevated radiation levels at the site of the accident. The monitoring for internal exposure was finally started after the Japan Atomic Energy Agency (JAEA) sent their mobile WBC unit to Onahama town located about 60 km south of the FDNPP, but its monitoring capability was not enough for a large number of the workers to be measured. As a result, the largest contributing radionuclide to the internal dose, ^{131}I, could not be detected in most subjects although only the workers whose internal doses were relatively high were examined in detail at the JAEA's center located in Ibaraki Prefecture. According to TEPCO, six workers received the doses over 250 mSv in effective dose (the maximum: 680 mSv), the temporal dose limit set for the emergency operations at the FDNPP.

The same problem has also existed in the dose assessment of residents of Fukushima Prefecture. It was also difficult to perform direct measurements of the residents shortly after the accident. As a result, there have been only 1,300 data on which the estimation of thyroid doses due to intake of ^{131}I is directly based. Most of these data were from a screening survey for examining thyroid exposure to 1,080 children at three places: Kawamata town, Iwaki city and Iitate village. The National Institute of Radiological Sciences (NIRS) thus estimated the internal thyroid doses to the residents in the whole area of Fukushima Prefecture using a combination of the results of the screening survey, late WBC measurements of ~3,000 adults from various places, and atmospheric transport and dispersion model (ATDM) simulations of the radionuclides. As a result, the highest internal thyroid equivalent doses were expected to affect residents of Futaba town, Iitate village and Iwaki city, and their doses were estimated to be around 30 mSv at most. A large discrepancy between the estimations by the NIRS and UNSCEAR occurred because the UNSCEAR method included the ingestion dose that should be trivial for most residents, whereas the NIRS method did not.

The presentation provides an overview of the dose assessment related to the FDNPP accident, and also the remaining issues to be solved in the further studies.