ICRP *Publication 103* and Beyond

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Abstract
This paper focuses on ICRP *Publication 103*, the 2007 Recommendations of the International Commission on Radiological Protection, which lays out the system of radiological protection for all exposure situations and exposure types. In addition, subsequent ICRP publications which delve more deeply into specific aspects of this system are reviewed to some extent, including: ICRP *Publication 104* Scope of Radiological Protection Control Measures; ICRP *Publication 105*, Radiological Protection in Medicine; ICRP *Publication 108*, Environmental Protection — the Concept and Use of Reference Animals and Plants; ICRP *Publication 109*, Application of the Commission's Recommendations for the Protection of People in Emergency Exposure Situations; and an ICRP publication in press titled Application of the Commission's Recommendations to the Protection of People Living in Long Term Contaminated Areas After a Nuclear Accident or a Radiation Emergency.

Introduction
The International Commission on Radiological Protection (ICRP) is an independent, international organization that advances for the public benefit the science of radiological protection, in particular by providing recommendations and guidance on all aspects of protection against ionizing radiation.

ICRP was established in 1928 by the International Society of Radiology (ISR) to respond to growing concerns about the effects of ionizing radiation being observed in the medical community.

In preparing its recommendations, ICRP considers the fundamental principles and quantitative bases upon which appropriate radiation protection measures can be established, while leaving to the various national protection bodies the responsibility of formulating the specific advice, codes of practice, or regulations that are best suited to the needs of their individual countries.

ICRP offers its recommendations to regulatory and advisory agencies and provides advice the intended to be of help to management and professional staff with responsibilities for radiological protection. Although ICRP itself has no formal power to impose its recommendations, in fact legislation in most countries adheres closely to ICRP recommendations. In addition, the International Atomic Energy Agency (IAEA) International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources (commonly referred to as “the BSS”) is based heavily on ICRP recommendations, and the International Labour Organisation (ILO) Convention 115, Radiation Protection Convention, General Observation 1992, refers specifically to the recommendations of ICRP. Effectively, ICRP recommendations form the basis of radiological protection practice, programmes, regulations, and international standards and guidance worldwide.

ICRP has published well over one hundred publications on all aspects of radiological protection. Most address a particular area within radiological protection, but a handful of publications, the so-called fundamental recommendations, each describe the overall system of radiological protection. The system of radiological protection has been developed by ICRP based on (i) the current understanding of the science of radiation exposures and effects and (ii) value judgements. These value judgements take into account societal expectations, ethics, and experience gained in application of the system.

The 1990 Recommendations of ICRP (ICRP *Publication 60*) form the basis of the current IAEA BSS, and are also the foundation of most radiological protection practices, programmes and regulations worldwide. The 2007 Recommendations of ICRP (ICRP *Publication 103*) recently replaced the 1990 Recommendations. They are the result of nearly a decade of development and several major worldwide public consultations.

The 2007 Recommendations replace the 1990 Recommendations and update, consolidate, and develop additional guidance on the control of exposure from radiation sources issued since 1990. They reflect a more up-to-date understanding of the science behind radiological protection and evolving societal expectations.

The System of Radiological Protection

The system of radiological protection described in the 2007 Recommendations is an evolutionary change from that described in the 1990 Recommendations. This evolution is necessary in order for the system to remain current with our evolving understanding of the relevant scientific findings, and also to continue to reflect current societal norms. For example, the revised radiation and tissue weighting factors reflect updated scientific knowledge, while a greater emphasis on environmental protection reflects a heightened social awareness of the importance of this area. As well, practical application of the system can point out areas for improvement.

What follows is a brief review of the system of radiological protection as described in the 2007 Recommendations and subsequent publications. Much of this is, necessarily, taken almost directly from ICRP *Publication 103*.

Scope

The system of radiological protection applies to all exposures to ionising radiation from any source, regardless of its size and origin. However, the system can apply in its entirety only to situations in which either the source of exposure or the pathways leading to the doses received by individuals can be controlled by some reasonable means. Some exposure situations are excluded from radiological protection legislation, usually on the basis that they are unamenable to control with regulatory instruments, and some exposure situations are exempted from some or all regulatory requirements where such controls are regarded as unwarranted. ICRP *Publication 104* elaborates on the scope of radiological protection control measures.

Health effects of ionising radiation

An understanding of the health effects of ionising radiation is central to the system of radiological protection. Following a review of the biological and epidemiological information on the health risks attributable to ionising radiation ICRP concluded that the distribution of risks to different organs/tissues has changed somewhat since 1990. However, assuming a linear response at low doses, the combined detriment due to excess cancer and heritable effects remains essentially unchanged at around 5% per Sv (see Table 1). Embodied in this current estimate is the use of a dose and dose-rate effectiveness factor for solid cancers which is unchanged at a value of 2. In addition, following prenatal exposure, the cancer risk will be similar to that following irradiation in early childhood, and a threshold dose exists for the induction of malformations and for the expression of severe mental retardation.

The assumption of a linear dose–response relationship for the induction of cancer and heritable effects, according to which an increment in dose induces a proportional increment in risk even at low doses, continues to provide the basis for the summation of doses.

Table 1. Detriment-adjusted nominal risk coefficients (10^{-2} Sv^{-1}) for stochastic effects after exposure to radiation at low dose rate

Exposed population	Cancer	Heritable effects	Total
Whole	5.5	0.2	5.7
Adult	4.1	0.1	4.2

From ICRP *Publication 103*, Table 1.

Dose limits

The dose limits (see Table 2) remain unchanged from those recommended in 1990. However, it is recognized that further information is needed and revised judgements may be required particularly in respect of the lens of the eye. In addition, emerging data on possible excess risk in non-cancer diseases (e.g., cardiovascular disorders) are being watched closely.

Table 2. Dose limits in planned exposure situations

Type of Dose Limit	Occupational	Public
Effective dose	20 mSv per year, averaged over defined periods of 5 years, and 50 mSv in any single year[a]	1 mSv in a year
Annual eququivalent dose in:		
Lens of the eye	150 mSv	15 mSv
Skin	500 mSv	50 mSv
Hands and feet	500 mSv	–

[a] Additional restrictions apply to the occupational exposure of pregnant women.
From ICRP *Publication 103*, Table 6.

The use and calculation of equivalent and effective dose

Effective dose is intended for use as a protection quantity. The main uses of effective dose are the prospective dose assessment for planning and optimisation in radiological protection, and demonstration of compliance with dose limits for regulatory purposes.

Although the use of equivalent and effective dose remains unchanged, a number of revisions have been made to the methods used in their calculation. Reviews of the range of available data on the relative biological effectiveness of different radiations, together with biophysical considerations, have led to changes to some of the values of radiation weighting factors (see Table 3 and Figure 1). In addition, the distribution of risks to different organs/tissues has changed somewhat since 1990, particularly in respect of the risks of breast cancer and heritable disease, resulting in revised tissue weighting factors (see Table 4) intended to apply as rounded values to a population of both sexes and all ages.

Another change is that doses from external and internal sources will be calculated using reference computational phantoms of the human body based on CT images (the first appearing in ICRP *Publication 110*), replacing the use of various mathematical models. For adults, equivalent doses will be calculated by sex-averaging of values obtained using male and female phantoms.

Note that calculation of equivalent and effective dose use models and parameters selected from a range of experimental investigations and human studies through judgements, and meant to apply to a population rather than individuals. For individual retrospective dose and risk assessments, individual parameters and uncertainties have to be taken into account.

Collective effective dose is used for optimisation, predominantly in the context of occupational exposure. It is not intended as a tool for epidemiological risk assessment, and it is inappropriate to use it in risk projections. The aggregation of very low individual doses over extended time periods is inappropriate, and in particular, the calculation of the number of cancer deaths based on collective effective doses from trivial individual doses should be avoided.

Table 3. Radiation weighting factors

Radiation type	**Radiation Weighting Factor, w_R**
Photons	1
Electrons and muons	1
Protons and charged pions	2
Alpha particles, fission fragments, heavy ions	20
Neutrons	A continuous function of neutron energy (See Figure 1)

From ICRP *Publication 103*, Table 2.

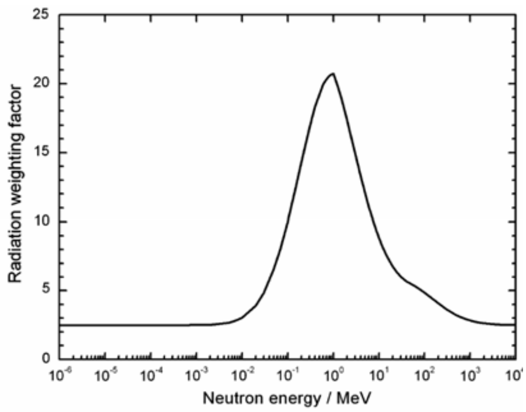

Fig. 1. Radiation weighting factor, w_R, for neutrons versus neutron energy (from ICRP *Publication 103*, Fig.1)

Table 4. Tissue weighting factors

Tissue	Tissue weigting factor, w_T	$\sum w_T$
Bone-marrow (red), Colon, Lung, Stomach, Breast, Remainder tissues*	0.12	0.72
Gonads	0.08	0.08
Bladder, Oesophagus, Liver, Thyroid	0.04	0.16
Bone surface, Brain, Salivary glands, Skin	0.01	0.04
	TOTAL	1.00

* Remainder tissues: Adrenals, Extrathoracic (ET) region, Gall bladder, Heart, Kidneys, Lymphatic nodes, Muscle, Oral mucosa, Pancreas, Prostate (male), Small intestine, Spleen, Thymus, Uterus/cervix (female). From ICRP *Publication 103*, Table 3.

Planned, existing and emergency exposure situations

The system of radiological protection described in the 2007 Recommendations recognises planned, existing and emergency exposure situations. These are intended to cover the entire range of exposure situations, and replace the previous categorisation into practices and interventions.

Planned exposure situations (which include situations previously categorised as practices) encompass sources and situations that have been appropriately managed within the system of radiological protection. Protection during medical uses of radiation is also included in this type of exposure situation. Recommendations for planned exposure situations are substantially unchanged from these provided previously.

Existing exposure situations include naturally occurring exposures as well as exposures from past events and accidents, and practices conducted outside the system of radiological protection. In this type of situation, protection strategies will often be implemented in an interactive, progressive manner over a number of years.

Indoor radon in dwellings and workplaces is an important existing exposure situation, and is the subject of current high-priority work for ICRP. In November 2009 ICRP issued a Statement on Radon. The intention is to publish this Statement in the Annals of the ICRP with an accompanying report on assessment of lung cancer risk from radon, after undertaking a public consultation on the two documents together.

The statement reaffirms that, for planned exposure situations, any workers' exposure to radon incurred as a result of their work, however small, shall be considered as occupational exposure. However, because of the ubiquity of radiation, the direct application of this definition to radiation would mean that all workers should be subject to a regime of radiological protection. Therefore the use of 'occupational exposures' is limited to radiation exposures incurred at work as a result of situations that can reasonably be regarded as being the responsibility of the operating management.

Emergency exposure situations include consideration of emergency preparedness and emergency response. Emergency preparedness should include planning for the implementation of optimised protection strategies which have the purpose of reducing exposures, should the emergency occur, to below the selected value of the reference level. During emergency response, the reference level would act as a benchmark for evaluating the effectiveness of protective actions and as one input into the need for establishing further actions.

Occupational, public and medical exposures

The system of radiological protection continues to distinguish among three categories of exposure: occupational, public, and medical. Table 5 shows these three categories of exposure, the three exposure situations, and the dose constraints and reference levels applicable in each circumstance.

Table 5. Dose constraints and reference levels used in the system of radiological protection

Type of situation	Occupational exposure	Public Exposure	Medical Exposure
Planned exposure	Dose limit Dose constraint	Dose limit Dose constraint	Diagnostic reference level (Dose constraint[b])
Emergency exposure	Refrerence level	Reference level	n/a
Existing exposure	n/a[a]	Reference level	n/a

[a] Exposures resulting from long-term remediation operations or from protracted employment in affected areas should be treated as part of planned occupational exposure, even though the source of radiation is 'existing'.
[b] Comforters, carers, and volunteers in research only.
From ICRP *Publication 103*, Table 4.

Fundamental principles of radiological protection

The three key principles of radiological protection have remained unchanged in the 2007 Recommendations. The principles of justification and optimisation apply in all exposure situations. The principle of application of dose limits applies only for doses expected to be incurred with certainty as a result of planned exposure situations. These principles are defined as follows:

- The Principle of Justification: Any decision that alters the radiation exposure situation should do more good than harm.
- The Principle of Optimisation of Protection: The likelihood of incurring exposure the number of people exposed, and the magnitude of their individual doses should all be kept as low as reasonably achievable, taking into account economic and societal factors.
- The Principle of Application of Dose Limits: The total dose to any individual from regulated sources in planned exposure situations other than medical exposure of patients should not exceed the appropriate limits specified by the Commission.

Emphasis on optimisation

The 2007 Recommendations emphasise the key role of the principle of optimisation. This principle should be applied in the same manner in all exposure situations. Restrictions are applied to doses to a nominal individual (the Reference Person), namely dose constraints for planned exposure situations and reference levels for emergency and existing exposure situations. Options resulting in doses greater in magnitude than such restrictions should be rejected at the planning stage. Importantly, these restrictions on doses are applied prospectively, as with optimisation as a whole. If, following the implementation of an optimised protection strategy, it is subsequently shown that the value of the constraint or reference level is exceeded, the reasons should be investigated but this fact alone should not necessarily prompt regulatory action. This emphasis on a common approach to radiological protection in all exposure situations should aid application of the system of radiological protection in the various circumstances of radiation exposure.

Table 6. Framework for source-related dose constraints and reference levels with examples of constraints for workers and the public from single dominant sources for all exposure situations that can be controlled

Bands of constraints and reference levels[a] (mSv)	Characteristics of the exposure situation	Radiological protection requirements	Examples
Greater than 20 to 100	Individuals exposed by sources that are not controllable, or where actions to reduce doses would be disproportionately disruptive. Exposures are usually controlled by action on the exposure pathways.	Consideration should be given to reducing doses. Increasing efforts should be made to reduce doses as they approach 100 mSv. Individuals should receive information on radiation risk and on the actions to reduce doses. Assessment of individual doses should be undertaken.	Reference level set for the highest planned residual dose from a radiological emergency.
Greater than 1 to 20	Individuals will usually receive benefit from the exposure situation but not necessarily from the exposure itself. Exposures may be controlled at source or, alternatively, by action in the exposure pathways.	Where possible, general information should be made available to enable individuals to reduce their doses. For planned situations, individual assessment of exposure and training should take place.	Constraints set for occupational exposure in planned situations. Constraints set for comforters and carers of patients treated with radiopharmaceuticals. Reference level for the Highest planned residual dose from radon in dwellings.
1 or less	Individuals are exposed to a source that gives them little or no individual benefit but benefits to society in general. Exposures are usually controlled by action taken directly on the source for which radiological protection requirements can be planned in advance.	General information on the level of exposure should be made available. Periodic checks should be made on the exposure pathways as to the level of exposure.	Constraints set for public exposure in planned situations.

[a] Acute or annual dose.
From ICRP *Publication 103*, Table 5.

The relevant national authorities will often play a major role in selecting values for dose constraints and reference levels. Guidance on the selection process is provided by recommending bands of constraints and reference levels (see Table 6).

Emphasis on optimisation using reference levels in emergency and existing exposure situations focuses attention on the residual level of dose remaining after implementation of protection strategies. This residual dose should be below the reference level, which represents the total residual dose as a result of an emergency, or in an existing situation, that the regulator would plan not to exceed. These exposure situations often involve multiple exposure pathways so protection strategies involving a number of different protective actions will have to be considered. However, the process of optimisation will continue to use the dose averted by specific countermeasures as an important input into the development of optimised strategies.

Radiological protection of the environment

In the past, ICRP concerned itself with the environment primarily with regard to the transfer of radionuclides through it because this directly affects the radiological protection of human beings. In the 1990 Recommendations ICRP stated that “the standard of environmental control needed to protect man ... will ensure that other species are not put at risk. Occasionally, individual members of non-human species might be harmed, but not to the extent of endangering whole species or creating imbalance between species.”

However, in its 2007 Recommendations, ICRP acknowledges that that it is now necessary to demonstrate, directly and explicitly, that the environment is being protected. Therefore, it is necessary to develop a clearer framework to assess the relationships between exposure and dose, and between dose and effect, and the consequences of such effects, for non-human species, on a common scientific basis. This is further developed in ICRP *Publication 108*.

Recent ICRP Publications which Further Elaborate the System of Radiological Protection

ICRP *Publication 104*: Scope of Radiological Protection Control Measures

In principle the system of radiological protection applies to all exposures to ionizing radiation. However, in practice the measures undertaken to control these exposures must be limited based on practical considerations. ICRP *Publication 104* discusses the scope of radiological protection control measures, and describes certain tools (e.g. exemption, exclusion and clearance) that can be used to manage the scope.

ICRP *Publication 108*: Environmental Protection - the Concept and Use of Reference Animals and Plants

The 2007 Recommendations acknowledge that that it is now necessary to demonstrate, directly and explicitly, that the environment is being protected, rather than simply assume that adequate protection of humans is sufficient to protect the environment. Therefore, it is necessary to develop a clearer framework to assess the relationships between exposure and dose, and between dose and effect, and the consequences of such effects, for non-human species, on a common scientific basis.

To this end, ICRP *Publication 108* sets out some high-level ambitions with regard to environmental protection. To aid in demonstrating whether these ambitions are being achieved, and help optimise the level of effort that might be expended on environmental protection, and ICRP has developed a set of Reference Animals and Plants (RAPs) and derived consideration reference levels (DCRLs). ICRP does not propose the application of dose limits to Reference Animals and Plants.

Recent ICRP Publications Elaborating on Specific Exposure Categories and Situations

One of the first publications following the 2007 Recommendations was ICRP *Publication 105* on Radiological Protection in Medicine. This publication describes the application of the system of radiological protection for medical exposures, an exposure category quite different from occupational and public exposures by virtue of the fact that most of the time, most of the benefit and the detriment apply to a single individual: the patient. In the other two exposure categories, typically one group receives most of the detriment (e.g. the workers in a facility), while another group receives most of the benefit (e.g. the public at large receiving electrical power).

Two publications each examine one of the three exposure situations: ICRP *Publication 109* examines emergency exposure situations, and the ICRP publication in press titled Application of the Commission's Recommendations to the Protection of People Living in Long Term Contaminated Areas after a Nuclear Accident or a Radiation Emergency examines the system of radiological protection as applied to existing exposure situations.

Other Current Initiatives and Future Work

For more information on current and future work of ICRP the reader is referred to another paper prepared for this congress by the same author titled “International Commission on Radiological Protection – recent publications, current initiatives and future work”.

Acknowledgements

Preparation of this paper drew extensively on the hard work of ICRP members through several ICRP publications shown in the references section. The author would like to acknowledge the dedication of those ICRP members who contributed to these publications, and thus recognize their important contribution to this paper.

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