The International Commission on Radiation Units and Measurements (ICRU): Activities and Future Plans

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BRIEF HISTORICAL OVERVIEW

Mandate of the ICRU

Thirty years after Röntgen's discovery of the x-rays, the First International Congress of Radiology, at a meeting held in London, acknowledged the need for internationally accepted standards for units and measurements of exposure to ionizing radiation. The Congress appointed the *"International X-Ray Unit Committee"*, now the "*International Commission on Radiation Units and Measurements"* (ICRU), to provide scientific underpinnings and to investigate, develop, and establish such quantities, units, and measures pursuant to these goals. While medical applications of x-rays were initially the major impetus, the protection of individuals was included from the beginning. In 1928, at the Second International Congress of Radiology, an international agreement was achieved on the definition of a *unit* of x-ray dose, the röntgen, based on measurements with air-filled ionization chambers. In 1937, the ICRU recommended a definition of the röntgen applicable to x-rays as well as gamma rays.

Over the time, the field of activities of the ICRU expanded considerably to meet new and increasing needs. Today the objectives of the ICRU can be divided into four main areas:

(1) Quantities and Units,
(2) Radiation Protection and Radiation Ecology,
(3) Medical Applications of Ionizing Radiation,
(4) Basic Data for Radiation Interactions.

Recently, the ICRU decided to enter cautiously and progressively into the field of non-ionizing radiation. Here only the first two aspects of the ICRU program will be reviewed.

Initial steps in radiation measurement

The history of radiation measurements, in general, and for radiation protection purposes, in particular, is also the history of a succession of different quantities and, in fact, units. Soon after Röntgen's discovery of x-rays, many of the physical and, indeed, even biological effects induced by x-rays were used for radiation measurement purposes (Menzel and Feinendegen, 1995).

The radiation-induced blackening of photographic film, which Röntgen observed with x-rays, was one of the early methods suggested for measurements and definitions for units of radiation. Although film has never played a significant role in standardization, film dosimetry has been persuasive for personal monitoring of photon exposures and is still the medium of choice for diagnostic radiography.

Colour changes of chemicals, subsequent to x-ray exposures, led to popular units (e.g., the "pastille unit" (1904) for platino-barium cyanide capsules or the "Holzknecht" or "H" unit (1904) for mixtures of potassium chloride and sodium carbonate) for assessing exposure for a considerable period of time. Also, various photoluminescence effects were detected early in the history of radiation measurements, including thermo-luminescence, which Marie Curie reported as early as in 1904 in her doctoral thesis.

However, the most important physical effect for the initial phase of standardization was the ionization effect in gases. The first ionization chambers were built even before 1900. Many proposals were put forward for units based on radiation-induced ionization leading, finally, to the definition of the röntgen.

All originally proposed units were closely related to the underlying measurement principle. The fact that x-rays played a role predominantly in medical applications in that period explains why correlations to induced biological effects were established using "visible" observations, mainly reactions of skin. Not all of them were considered practical; for example, the proposal to use the depilatory effect of x-rays on hair did not find many supporters.

The radiation induced reddening of skin was used to define a unit called skin erythema dose (SED) which was used widely as a reference and was compared to the units based on physical measurements in an attempt to establish dose equivalencies between physical and biological phenomena.

Dosimetry in radiation protection

The development from the röntgen, the first internationally accepted unit of radiation measurements, to the currently practiced system of *quantities and units*, embedded into a general concept of radiation protection, is the result of the work of ICRU often in collaboration with its sister organization, the ICRP. This evolution was governed:

- by scientific progress in the underlying disciplines of radiation physics and radiation biology,

- by the rapid extension of the use of ionizing radiation and radioactive materials in medicine and in the power generation and other industries since the 1950's,

- by the recognition that hereditary damage and radiation carcinogenesis are the main risks associated with low dose exposures. (In addition, of course, non-stochastic effects are observed at high doses),

- and by the intention to generalize the applicability and to improve the scientific rigour and consistency of the definitions.

The objectives of radiation dosimetry are to provide procedures, techniques and concepts for the determination of the "amount" of ionizing radiation that is quantitatively related to the potential biological effect. In radiation protection, dosimetry is thus concerned with the practical aspects of developing internationally accepted concepts, quantities and methods which are suitable for radiation risk assessment, and can be used for controlling exposures and specifying exposure limits for radiation workers and the public.

QUANTITIES AND UNITS

One of the main objectives of the ICRU is to develop a universally accepted set of quantities and units for radiation and its interaction with biological matter. Only with a set of scientifically sound, easily understood, and well implemented quantities and units can ionizing radiation be safely employed to meet society’s needs in medical care and industrial applications.

The ICRU has developed and recommended a set of fundamental quantities and units which has been in wide use for decades and has been vital to the successful exchange of information, and comparison of results.

However the field is not static and the expanding uses of radiation and radiation-producing processes demand further development and elaboration of quantities which, in turn, implies development and understanding of new concepts that will facilitate meeting the new needs.

The ICRU organization includes a standing committee on "Quantities and Units". As new concepts, instruments, and techniques emerge from the radiation science community, this committee serves to refine the definitions of quantities and units and include and expand them in response to these involving needs.

Development of concepts, quantities and units

Several milestones can be identified in the development of concepts, quantities and units for dosimetry in radiation protection:

- in 1953, at the 7th International Congress of Radiology in Copenhagen, the ICRU introduced the *absorbed dose* in a irradiated material, by any type of ionizing radiation, as the fundamental *quantity* correlated to the induced biological effect. The special *unit* introduced was the rad; now this special unit in the "Système International" (SI) is the gray (Gy).

- in 1962, the ICRU introduced -for radiation protection purposes- the quantity dose equivalent as a product of the absorbed dose and various modifying factors, the most important of which is the quality factor. This factor accounts for differences in the relative biological effectiveness of different types of ionizing radiations atlow doses. The special unit introduced was the rem; now the SI-based special unit is the sievert (Sv).

- in 1977, the ICRP introduced (ICRP Report 26) the effective dose equivalent, based on the dose equivalent in various organs of an individual and the weighted sum of these, as a limiting quantity for all types of exposure. In 1991, the ICRP modified its approach and introduced effective dose.

in 1985, the ICRU (ICRU Report 39) introduced operational quantities for the specification of dose equivalent, for area and individual monitoring in the case of external radiation sources.

Physical quantities, protection quantities and operational quantities

Determination of radiation protection quantities often involves significant uncertainties. In addition, a variety of approximations must be made to relate physical measurements to the biological effects caused by radiation. Therefore, although the requirements for accuracy in radiation protection measurements may not always be high, it is essential that the quantities employed be defined unambiguously, and that any approximations be clearly stated.

The ICRU's currently recommended system of radiation protection quantities and units fulfills these requirements and has beenadopted by most national and international regulatory bodies. The system can be described as a hierarchy of quantities composed of physical quantities (including fluence, kerma and absorbed dose), protection quantities (effective dose, organ doses) and operational quantities (ambient dose equivalent, directional dose equivalent, and personal dose equivalent).

ICRU Report 51, *Quantities and Units in Radiation Protection Dosimetry* (1993) summarizes all current definitions and takes account of the new formulations of protection quantities contained in ICRP Publication 60 (1990). More recently, ICRU Report 60 (1998), "Fundamental Quantities and Units for Ionizing Radiations", provides specifics regarding all quantities and units underlying physical determinations ultimately used in protection dosimetry. The ICRU will expand the definitions into area of radioecology and publish a new report, Report 65, "Quantities, Units and Terms in Radioecology".

To support and promulgate these physical quantities, numerous national standards (as well as secondary standards) laboratories maintain a range of well-defined radiation standards. The ICRU works closely with these organizations to ensure that optimal execution of the standards base is maintained. These laboratories provide a network of services for instrument and dosimeter calibration in terms of operational and base units. ICRU Report 64, *"Dosimetry of High-Energy Photon Beams Based on Standards of Absorbed Dose to Water"* (in press), provides information on current methods used in primary standards laboratories.

The protection quantities, introduced by the ICRP, are conceived to be proportional to the potential radiation risk for almost all types of radiations. They were introduced mainly for the purpose of exposure control and thus risk limitation.

Operational quantities are defined in a 30 cm diameter sphere of ICRU tissue and are conceived to provide an (almost always conservative) estimate for the relevant protection quantities. Personal and environmental monitoring with instruments calibrated using ICRU-defined operational quantities permits the control of exposure as well as the assessment of the overall exposure.

The numerical relationship between physical quantities such as particle fluence and air kerma, and the protection and operational quantities can be determined using the computational methods of numerical dosimetry, anthropomorphic phantoms for protection quantities, and the ICRU sphere for operational quantities.

ICRU Report 57: *Conversion Coefficients for use in Radiological Protection against External Radiation* is the product of collaboration between the ICRU and the ICRP. The report was prepared by a joint task group of the two Commissions, and underwent separate reviews by each of the Commissions and has been published in the report series of both Commissions.

The Report was published as ICRP Publication 74 in the beginning of 1997 and as ICRU Report 57 early in 1998. It provides an extensive and authoritative set of data-linking field quantities, operational quantities, and protection quantities in a way that will be of help to those working in radiation protection for external exposure. Conversion coefficients are provided for idealized irradiation geometries, monoenergetic radiations in anthropomorphic phantoms (mathematical models) and measurement phantoms. Publication of ICRU Report 57 is timely in view of the European Commission (EC) Directive revising the Basic Safety Standards adopted by the European Council in May 1996 and the publication of the International Basic Safety Standards published by the IAEA.

RECOMMENDATIONS FOR RADIATION PROTECTION MEASUREMENTS

Besides involvement in the development of concepts and quantities, the ICRU has always played an important role in providing guidance for radiation protection measurements.

An early example is ICRU Report 20, *"Radiation Protection Instrumentation and its Application"* (1970). ICRU Report 36, "*Microdosimetry"* was published in 1983. Later on, the ICRU provided guidance for the determination of operational quantities in three reports: Report 39 *"Determination of Dose Equivalents Resulting from External Radiation Sources"* (1985), Report 43 "*Determination of Dose Equivalents from External Radiation Sources* (Part 2)"(1988) and Report 47 "*Measurement of Dose Equivalents from External Photon and Electron Radiations"* (1992). A report on " *Determination of Operational Quantities for Neutrons" is in preparation.*

In addition to issues concerning dosimetry for monitoring external irradiations, the ICRU is addressing topics in the overall area of radiation and radioactivity measurements for protection purposes. Examples are, the ICRU Report 52, "*Particle Counting in Radioactivity Measurements"*, was published in 1994 and Report 53, "*Gamma Ray Spectrometry in the Environment"* (1995). The latter was prepared in recognition of the fact that methods for quickly assessing radionuclides in the environment have become increasingly important, particularly in the context of accidental releases from nuclear facilities.

Gamma-ray spectrometry, based on the measurement of the energy distribution of the photon fluence, is used for the determination of activity levels in the ground or in air and of radionuclide-specific dose quantities. It is also applied to the control of planned releases, in dose reconstruction and environmental remediation projects and in the search for radioactive sources in the environment.

Report 56, *Dosimetry of External Beta Rays for Radiation Protection*, published in 1997, recognizes that the general aim of beta-ray dosimetry in radiation protection is to provide dosimetric information that will help in keeping any harmful effect of beta rays within acceptable limits and that, in the event of serious over-exposure, will assist medical treatment and hence prognosis.

Other reports on specific measurement techniques are in preparation, including "*In vivo Determination of Body Content of Radionuclides"* and in the area of radiation protection of patients, on "*Dosimetric Procedures in Diagnostic Radiology".*

CONCLUSION

The ICRU played a decisive role in the development of concepts and quantities for radiation dosimetry in radiation protection for 70 years.

The current system of quantities for radiation protection dosimetry meets the requirements of scientific rigour and practical applicability for monitoring in almost the entire range of exposure conditions of workers and the public.

In the field of quantities and units, one of the main contributions of the ICRU is the introduction of the concept of absorbed dose to quantify "the amount of radiation". The quantity absorbed dose (with its special unit gray) is found to be most useful for the majority of radiation applications above all in radiation medicine, and is universally accepted.

However, some limitations in the concept of absorbed dose have been identified in particular when the conditions for the "averaging procedure" implied in the concept are no longer met Examples of such cases include: administration of low activities of radionuclides emitting weakly penetrating radiation or short-ranged particles in nuclear medicine diagnostic studies, situations of a few particle tracks (protons, ions,..) in radiation protection, therapy with unsealed sources, BNCT, etc.

The ICRU is considering this issue very carefully and is preparing a report. This report ("Dose specification in nuclear medicine") will be limited, for the moment, to administration of low activities of radionuclides for diagnostic and therapeutic purposes in nuclear medicine. The report specifically deals with inhomogeneous distributions of radionuclides as well as tissues inhomogeneous in density and composition. Low doses and low dose rates are inherent to such situations. Moreover, energy deposition, i.e. imparted energy, is considered at a sub-millimeter level. This report provides a link between macroscopic- and microscopic dosimetry. The potential implications for radiation protection are apparent.

Finally, the increased focus on guidance for specific measurement procedures and techniques will further harmonize the approaches and improve the reliability of results.

ICRU recognizes the role of ICRP in developing concepts and practical guidance for practical radiation protection. The role of both Commissions complements each other and, if beneficial for users of the recommendations, both Commissions collaborate as documented by the reports ICRU 57 and ICRP 74.

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