International Tables for Crystallography (2006). Vol. C, Chapter 10.1, pp. 958–961.

10.1. Introduction

By D. C. Creagh and S. Martinez-Carrera

WARNING. In this section, the main objectives of protection from ionizing radiation will be discussed and such information as may be necessary for the interpretation of legal documents relating to radiation protection will be given. The material contained herein is drawn from a wide variety of sources but principally from Vol. 26 of the International Commission on Radiological Protection (1977) (ICRP, 1977) and Part 4 (AS-2243/4) of the Standards Association of Australia (1979).

It must be stressed that the recommendations made here have no legal force, nor indeed do either ICRP-26 or AS-2243/4. The precise legal requirements will be stipulated in government legislation and by the regulations pertaining to the laboratory in which the researcher is working.

Notwithstanding the legal requirements, a moral requirement exists for the operator of a laboratory involved in research with ionizing radiation to be aware of the dangers involved, and to take such steps as are necessary to ensure that both he* and his workers are fully educated in the protective measures to be taken to preserve their own safety.

In Vol. III of *International Tables for X-ray Crystallography*, Cook & Oosterkamp (1968) restricted their discussions, in the main, to the effects of X-rays and neutrons. However, with the increasing use of Mössbauer and other γ-ray techniques in crystallography and the development of nuclear magnetic resonance techniques involving the orientation of (radioactive) nuclei (NMRON), the scope of this chapter will be necessarily more general than that of *IT* III (1968).

Finally, since this chapter can have only an advisory nature and the final arbiter is the legislation of the state and local authority concerned, a list of countries that are known to have legislation concerning radiation protection is given in Table 10.3.1. Also shown in the table is the law under which control is effected and the authority responsible under the act for the implementation of radiation safety procedures. This list results from the return of questionnaires sent to all countries and is believed to be correct as of 1 October 1997.

10.1.1. Definitions

10.1.1.1. *Ionizing radiation*

Ionizing radiation is defined as radiation that by its nature and energy has the capacity to interact with and remove electrons from (*i.e.* ionize) the atoms of substances through which the radiation passes. Sufficiently energetic radiations may cause permanent changes in the nuclei of the atoms of the substance. Radiation may be propagated in the form of electromagnetic radiation (X-rays and γ-rays) or particles (β and α particles, neutrons, protons, and other nuclear particles).

In the list of definitions that follows SI units will be used. The relation between these SI units and the earlier system of units is given in Table 10.1.1.

10.1.1.2. *Absorbed dose*

The energy per unit mass imparted to matter by ionizing radiation at the place of interest [SI unit = gray (Gy)].

*In what follows, 'he', 'his' and similar pronouns are to be interpreted in a non-gender-specific manner.

Table 10.1.1. *The relationship between SI and the earlier system of units*

Quantity	SI	Earlier
Absorbed dose [gray (Gy = J kg^{-1})]	1 J kg^{-1} 0.01 J kg^{-1}	100 rad 1 rad
Activity [becquerel (Bq = s^{-1})]	1 Bq 3.7×10^{10} Bq	2.7×10^{11} Ci 1 Ci
Dose equivalent [sievert (Sv = J kg^{-1})]	1 Sv 0.01 Sv	100 rem 1 rem
Exposure	1 C kg^{-1} 2.58×10^{-4} C kg^{-1}	3876 R 1 R

10.1.1.3. *Activity*

The number of nuclear transformations per unit time occurring in a radionuclide.

10.1.1.4. *Adequate protection*

Protection against ionizing radiations such that the radiation doses received by an individual from internal or external sources, or both, are as low as reasonably achievable and do not exceed the maximum levels given in Table 10.1.2.

10.1.1.5. *Background (radiation)*

Ionizing radiation other than that to be measured, but which contributes to the quantity being measured.

10.1.1.6. *Becquerel (Bq)*

The SI unit of activity 1 Bq corresponds to one nuclear transformation per second. It replaces the curie (Ci).

10.1.1.7. *Designated radiation area*

An area where the occupational exposure of personnel to radiation or radioactive material is under the supervision of a designated radiation safety officer.

10.1.1.8. *Dose equivalent*

Product of absorbed dose and quality factor (Subsection 10.1.1.24). This enables the dose received by individuals to be expressed on a scale common to all ionizing radiations. Where the term 'dose' is used without qualification it is implied that 'dose equivalent' is meant.

10.1.1.9. *Exposure of X-ray or γ-radiation*

A measure of the radiation at a certain place based on its ability to produce ionization in air. [SI unit = coulomb kg^{-1}. It replaces the röntgen (R).]

10.1.1.10. *External radiation*

Ionizing radiation received by the body from sources outside the body.

10.1.1.11. *Glove box*

A closed box having polymer gloves and viewing ports that is used to enclose completely radioactive materials whilst being manipulated.

10.1.1.12. *Gray (Gy)*

The SI unit of absorbed dose. [SI unit = 1 J kg^{-1}. It replaces the rad.]

10.1.1.13. *Half life*

The period of time in which half the nuclei in a given sample of a particular radionuclide undergo decay.

10.1.1.14. *Internal radiation*

Radiation received from the body from sources within the body.

10.1.1.15. *Irradiating apparatus*

Apparatus capable of producing ionizing radiation.

10.1.1.16. *Leakage radiation*

All radiation except the useful beam coming from within a protective housing.

10.1.1.17. *Licensable quantity*

The amount of any radionuclide or mixture thereof that is permitted under statutory regulations.

10.1.1.18. *Maximum permissible concentration*

The concentration of a radionuclide in the air when breathed or water when ingested that would result in an individual receiving the maximum permissible dose (to the whole body or to a specific organ depending on the radionuclide in question).

10.1.1.19. *Natural background*

Ionizing radiation received by the body from natural sources (cosmic radiation or naturally occurring radionuclides).

10.1.1.20. *Non-stochastic effects*

Effects on a biological system in which the severity of the effect varies with the dose and for which a threshold is likely to occur.

10.1.1.21. *Nuclide*

A species of atom characterized by the number of protons and neutrons in its nucleus.

10.1.1.22. *Occupied area*

An area that may be occupied by personnel and where a radiation hazard may exist.

10.1.1.23. *Protective housing*

A housing of an X-ray tube or of a sealed source intended to reduce the leakage radiation to a specified level.

10.1.1.24. *Quality factor (QF)*

A non-dimensional factor used to reduce the biological effects of radiation to a common scale (see Table 10.1.3).

10.1.1.25. *Radiation laboratory*

A laboratory in which irradiating apparatus or sealed radioactive sources are used or stored. It does not contain any unsealed radioactive material.

10.1.1.26. *Radioactive contamination*

The contamination of any material, surface or environment, or of a person by radioactive material.

10.1.1.27. *Radioactive material*

Any substance that consists of, or contains any, radionuclide provided that the activity of such material is greater than 0.1 Bq kg^{-1}.

10.1.1.28. *Radioisotope laboratory*

A laboratory in which unsealed radioactive material is used or stored. It does not contain any irradiating apparatus.

10.1.1.29. *Radiological hazard*

The potential danger to health arising from exposure to ionizing radiation.

10.1.1.30. *Radiological laboratory*

A laboratory in which unsealed radioactive material and/or sealed radioactive material or irradiating apparatus is used or stored.

10.1.1.31. *Radionuclide*

Species of atom that undergoes spontaneous nuclear transformation with consequent emission of corpuscular and/or electromagnetic radiations.

10.1.1.32. *Radiotoxicity*

The toxicity attributable to ionizing radiation emitted by a radionuclide (and its decay products). It is related to both radioactivity and chemical effects.

10.1.1.33. *Sealed source*

Any radioactive material firmly bonded within metals and sealed in a capsule or similar container of adequate mechanical strength so as to prevent dispersion of the active material into its surroundings under foreseeable conditions of use and wear.

10.1.1.34. *Sievert (Sv)*

The SI unit for dose equivalent.

10.1.1.35. *Stochastic effects*

Effects on a biological system in which the probability of an effect occurring rather than its severity is regarded as a function of dose without threshold.

10.1.1.36. *Unsealed source*

A source that is not a sealed source and that can produce contamination under normal conditions.

Table 10.1.2. *Maximum primary-dose limit per quarter [based on National Health and Medical Research Council (1977), as amended]*

Note: The annual MPD is typically twice the quarterly MPD

Part of body	MPD (i) (workers)	MPD (ii) (public)
Gonads, bone marrow, whole body	**30 mSv** (3 rem)	**2.5 mSv** (2.5 rem)
Skin, bone, thyroid	**150 mSv** (15 rem)	**15 mSv** (1.5 rem)
Hands, forearms, feet, ankles	**400 mSv** (40 rem)	**35 mSv** (3.5 rem)
Organs (including eye lens)	**80 mSv** (8 rem)	**7.5 mSv** (0.75 rem)
Abdomen of female of reproductive age	**13 mSv** (1.3 rem)	**1 mSv** (0.1 rem)
Foetus between diagnosis of and completion of a pregnancy	**10 mSv** (1 rem)	

Note: The maximum primary dose limits as set here are advisory only, and ultimately one should strive to achieve an MPD limit as low as reasonably achievable (often referred to by the acronym ALARA), economic and social factors being taken into account.

10.1.1.37. *Useful beam*

That part of the primary and secondary radiation that passes through the aperture, cone, or other device for collimating a beam of ionizing radiation.

10.1.2. Objectives of radiation protection

Radiation protection is concerned with the protection of individuals, their offspring, and society as a whole, at the same time allowing for the participation in activities for which radiation exposure might take place. There are two aspects of these deleterious effects: the somatic effects which become manifest in the individuals themselves, and the hereditary effects which become manifest in their descendants.

For the dose range involved in radiation protection, hereditary processes are regarded as being stochastic (thresholdless) processes. Some somatic effects are stochastic, and carcinogenesis is considered to be the chief risk at low doses and therefore a significant problem in radiation protection.

Non-stochastic processes are specific to particular tissues, *e.g.* damage to the cataract of the eye lens, non-malignant damage to the skin, damage to the bone marrow causing depletion of the red-cell count, and gonadal cell damage which impairs fertility. For these changes, the severity of the effect depends on the dose received and a clear threshold exists below which no detrimental effect has been found to occur.

A balance has to be achieved between the risk of damage to individuals and the benefits to society in the use of the ionizing radiation in experiments. Bearing this in mind:

Table 10.1.3. *Quality factors (QF)*

Type of radiation	QF
X-rays, γ-rays, and electrons	1
Neutrons, protons, singly charged particles of rest mass not greater than one atomic mass unit of unknown energy	10
α particles and multiply charged particules	20

1 Sv = (dose in grays) × QF.

(i) no practice ought to be adopted unless its introduction produces a positive net benefit;

(ii) all exposures should be kept as low as reasonably achievable under the existing economic and social circumstances;

(iii) the dose equivalent to individuals should not exceed the limits indicated in Table 10.1.2.

10.1.3. Responsibilities

10.1.3.1. *General*

In laboratories using ionizing radiations, a clearly defined chain of responsibility has to be established with the employer accepting the responsibility for the provision of services and equipment for the implementation of radiation-protection procedures under whatever legal or administrative procedures are valid for the country in question.

10.1.3.2. *The radiation safety officer*

The radiation safety officer (RSO) is responsible for the controlled areas within a given establishment. He (or she) is responsible to his employer for the implementation of a radiation-protection programme. His duties will vary according to the legislation and administrative arrangements applicable to his institution but will include, *inter alia*:

(i) giving advice on working practices to management and employees;

(ii) monitoring and surveying all controlled areas;

(iii) maintaining all equipment for monitoring radiation levels, including personal radiation monitoring devices;

(iv) keeping records of radiation levels in controlled areas, dosages to employees, stocks and locations of all radioactive materials and irradiating apparatus;

(v) keeping in safe custody all radioactive materials;

(vi) arranging the safe disposal of all radioactive waste;

(vii) preparing the local rules concerning accident safety and emergencies;

(viii) recording and reporting to the appropriate authorities all breaches of the radiation-protection rules.

10.1.3.3. *The worker*

In English common law, the employer is responsible for the actions of his employees but this does not absolve personnel from a duty of care to their fellows. Ultimately, the responsibility for radiation protection lies with the worker concerned. He (or she) should:

(i) ensure that he has an appropriate radiation dosimetry device and wears it;

(ii) inform the RSO whenever he is to work with radioactive materials or irradiating devices;

(iii) report to the RSO all known or suspected unsafe situations;

(iv) be aware of the directionality of scattered beams, particularly in the case of X-rays scattered from extended single crystals;

(v) be familiar with the relevant codes of practice as laid down in legislation and local instructions.

10.1.3.4. *Primary-dose limits*

Two classes of people are envisaged

(i) persons exposed to ionizing radiation in the course of the pursuance of their duties,

(ii) members of the general public.

In Table 10.1.2, the *maximum primary dose* (MPD) for those in class (i) and class (ii) is tabulated. SI units are shown in bold type, and the earlier units are shown in parentheses in light type.

Planned special exposures are permissible in emergency circumstances provided that in any single exposure twice the annual dose limit is not exceeded, and in a lifetime five times the limit.

Also, to allow for the different biological effectiveness of different types of radiation, the *quality factor* listed in Table 10.1.3 is applied to determine the dose.

References

Brodsky, A. (1982). Editor. *Handbook of radiation measurement and protection*, Vols I and II. Florida: CRC Press.

Cook, J. E. & Oosterkamp, P. W. J. (1968). *Protection against radiation injury. International tables for X-ray crystallography*, Vol. III, Chap 6, pp. 333–338. Birmingham: Kynoch Press.

International Commission on Radiological Protection (1977). *Recommendations of the International Commission on Radiological Protection* (adopted 17 January 1977). ICRP Publication 26. Oxford: Pergamon Press.

International Tables for X-ray Crystallography (1968). Vol. III. Birmingham: Kynoch Press.

National Heath and Medical Research Council (1977). *Revised radiation protection standards for individuals exposed to ionizing radiation* (as amended). ACT: NHMRC (Australia).

Standards Association of Australia (1979). *Safety in Laboratories*. Part 4. *Ionizing radiations*. AS-2243/4. Sydney: Standards Association of Australia.

Stott, A. M. B. (1983). *Radiation protection. Nuclear power and technology,* Vol. 3, edited by W. Marshall, pp. 50–77. Oxford: Clarendon Press.

Other publications containing relevant material

Information relevant to this part may be obtained from the sources listed below.

Recommendations of the International X-ray and Radiation Protection Commission (1931). *Br. J. Radiol*. **4**, 485.

International Commission on Radiological Protection, Clifton Avenue, Sutton, Surrey SM2 5PU, England.

International Commission on Radiation Units and Measurements, 7910 Woodmont Avenue, Suite 1016, Washington, DC 20013, USA.

International Atomic Energy Agency, Wagramerstrasse 5, PO Box 100, A-1400 Vienna, Austria.

World Health Organization, CH-1211 Genève 27, Switzerland.

National Health and Medical Research Council of Australia, PO Box 100, Woden, ACT 2606, Australia.

International Labour Organization, 4 route des Morillons, CH-1211 Genève 22, Switzerland.

OECD Nuclear Energy Agency, 38 Bd Suchet, F-75016 Paris, France.

National Committee on Radiation Protection and Measurement, C/- National Institute of Standards and Technology, Gaithersburg, MD 20899, USA.

Her Majesty's Stationery Office, PO Box 598, London SE1 9NH, England.

National Radiological Protection Board, Chilton, Didcot, Oxford OX11 0RQ, England.

Food and Drug Administration, 5600 Fishers Lane, Rockville, MD 20857, USA.

Hospital Physicists Association, 47 Belgrave Square, London SW1X 8QX, England.

National Competent Authorities Responsible for Approvals and Authorizations in Respect of the Transport of Radioactive Material (1997). List No. 28. International Atomic Energy Agency, Vienna.