Code of Practice for Protection Against Ionizing Radiation Emitted from X-ray Analysis Equipment (1984)

Reprinted from the Report of the 97th Session of the Council, June 1984

NATIONAL HEALTH AND MEDICAL RESEARCH COUNCIL

Commonwealth of Australia 1985
Australian Government Publishing Service, Canberra 1985
R83 990(4) Cat. No. 85 0169 3
Printed by Brindabella Press and Publications Pty Limited

APPENDIX XXIV

CODE OF PRACTICE FOR PROTECTION AGAINST IONIZING RADIATION EMITTED FROM X-RAY ANALYSIS EQUIPMENT (1984)

CONTENTS

1. Introduction

1.1 A wide range of X-ray equipment is used in universities, scientific establishments and industry for the analysis of materials. This equipment makes use of the phenomena of X-ray diffraction, absorption and fluorescence. In this Code, such equipment will be referred to in general as X-ray analysis units or equipment. The dose rate in the X-ray beams from such equipment may be very high and even a brief exposure of any part of a person's body to such a beam could be harmful. Equipment of modern design incorporates safety features which make it unlikely that a person using it in the proper manner will be exposed to the intense X-ray beams. Older units still in use may have few safety features and may not comply with the requirements of this Code. All X-ray analysis units, when improperly used, are potential sources of exposure to limited areas of the body (i.e. eye, skin of the face, fingers and hands) particularly while sample or detector adjustments are made, or when equipment is altered or component parts are replaced.

1.2 Reports are occasionally received of actual or suspected over-exposure to areas of skin onto the eye by older types of units or due to the practice of inactivating safety features on more recent units. Some workers have had repeated episodes of actual over-exposure. In several cases, the victim was not the person who inactivated the safety feature, but an unsuspecting co-worker.

1.3 The National Health and Medical Research Council in its publication 'Recommended radiation protection standards for individuals exposed to ionising radiation' (AGPS, 1981), has laid down recommendations for the annual dose-equivalent limit for radiation workers. The annual dose-equivalent limit for skin and eye may be readily exceeded by an exposure to the primary beam of an X-ray analysis unit for only a fraction of a second (See 3.2). For information on biological effects of radiation and relevant NH&MRC limits, see Annexe I.

1.4 Exposure to a primary beam from an X-ray analysis unit is considered to be avoidable by using a combination of instrumental safety features, working rules and radiation monitoring. This Code lays down appropriate working rules, safety features and monitoring requirements and is intended as a guide to users of X-ray analysis units and to those who teach others about their use.

1.5 It is recommended that establishments draw up their own detailed working procedures based on the appropriate legislation and on this Code of Practice and issue written instructions for safe practices to all Operators.

2. Glossary of Terms

2.1 Aperture: A gap in the protective material of a tube housing through which the radiation from an X-ray tube within the tube housing may pass with little or no attenuation.

2.2 Barrier: A physical guard used to prevent access to an area of potential hazard.

2.3 Collimator: A device to limit a primary beam to the required cross-sectional area at the point if interest.

2.4 Enclosed unit: An X-ray analysis unit which is wholly enclosed by interlocked barriers and/or shields and so designed that it can only be used, adjusted and aligned in ways which involve no possibility of exposure of any person to the primary X-ray beam.

2.5 Enclosure: A combination of shields and/or barriers, that surround a particular space, which prevents access to and attenuates X-radiation emerging from that space.

2.6 Gray: symbol Gy, is the SI unit of absorbing dose and kerma, corresponding to the absorption of one joule per kilogram of matter.

2.7 Inherent filtration: The filtration of the primary X-ray beam effected by the irremovable materials of the X-ray tube assembly.

2.8 Interlock: Two components or pieces of equipment interconnected by electrical or mechanical means so that separation of the components or pieces of equipment automatically shields the primary beam or de-energizes the X-ray tube.

2.9 Leakage radiation: X-radiation emerging from the protective shielding of the X-ray tube housing or enclosure and all other parts of an X-ray analysis unit.

2.10 Operator: A radiation worker given the responsibility, by the user to operate an X-ray analysis unit.

2.11 Partly enclosed unit: An X-ray analysis unit, which is partly enclosed by interlocked barriers and/or shields or partly or wholly enclosed by fixed barriers and/or shields which require the use of tools for removal and is so designed that, in its normal use, adjustment and alignment, there is no possibility of an inadvertent exposure of any person to the primary X-ray beam.

2.12 Personal monitor: A radiation sensitive device that is worn by an individual and is used for the measurement of radiation dose.

2.13 Primary beam: That part of the X-radiation from an X-ray analysis unit which passes through an aperture of the tube housing and is intended for use as the primary source of X-radiation incident on a target.

2.14 Radiation Safety Officer: A person having appropriate qualification and experience in radiation safety, who is appointed to carry out the responsibilities of Radiation Safety Officer as specified in this Code.

2.15 Shield: A wall or cover made of material having sufficient density and thickness to attenuate X-radiation to a safe level.

2.16 Sievert: Symbol Sv, is the SI unit of dose equivalent, corresponding to the absorption of one joule in one kilogram of biological matter. taking into account the quality factor and other modifying factors.

2.17 Scattered radiation: Radiation that has been deviated in direction, during the passage of the primary beam through matter.

2.18 Shall: Indicates that the particular requirement is necessary to ensure protection from radiation.

2.19 Should: Indicates a procedure or precaution which is to be applied whenever practicable, in the interests of minimizing hazards.

2.20 Tube housing: The housing surrounding the X-ray tube, or the X-ray tube and parts of the X-ray analysis unit, that is constructed to provide adequate protection from radiation hazards and incorporates apertures to permit the emergence of primary beams in desired directions.

2.21 Tube shutter: An aperture cover designed to reduce, when closed, the intensity of the primary beam emerging from the aperture to such a level that the beam presents no hazard to persons at any point beyond the cover.

2.22 User: The person having administrative responsibility for use of a particular X-ray analysis unit. This person shall be the owner or hirer of the unit or his agent or, if the unit is owned or hired by an institution or organization, the agent of that body.

2.23 X-ray analysis unit: That portion of the equipment used to carry out X-ray analysis, consisting of a high tension generator, X-ray tube and tube housing and the analysis components including attachments such as cameras, goniometer and radiation detectors, but not including sealers or pulse height analysers and associated electronic equipment.

3. Hazards

3.1 Injury may occur to the operator or other persons near X-ray analysis equipment due to exposure to a primary beam or leakage or scattered radiation.

3.2 In particular, exposure to a primary beam, where the dose rate may be as high as 300 $Gy\ s^{-1}$ is extremely hazardous. Exposure to such intense radiation can cause severe injury to the skin, the underlying bone, or the eye in a short time (e.g. seconds).

3.3 Injury resulting from exposure to a primary beam may not be immediately apparent. It may take a few hours or several days before the extent of the injury may be assessed accurately.

4. Responsibilities

4.1 The responsibilities of personnel involved with the use of X-ray analysis equipment are set out in this Section.

4.2 User responsibilities

The user shall be responsible for the safe use of the X-ray analysis equipment at all times and shall ensure that:

4.2.1 all legislative requirements of the Statutory Authority (e.g. licensing) are satisfied (see Annexe II);

4.2.2 all safety features required in Section 5 of this Code are implemented and are regularly serviced and maintained in good working order,

4.2.3 all rules and procedures required in Section 6 of this Code are established and maintained;

4.2.4 no X-ray analysis unit is operated while a safety feature is removed, modified or inactivated except under the provision of 6.2.9;

4.2.5 adequate instruction is given to personnel regarding the safety features available and the procedures to be used in accordance with the provisions of this Code;

4.2.6 the necessary supervision is provided to all employees in the performance of their work in accordance with the provision of this Code;

4.2.7 radiation monitoring is carried out in accordance with Section 7 of this Code, and if applicable with 6.4.7;

4.2.8 in the case of an actual or suspected exposure to the intense primary beam, the persons involved are referred for medical examination (see 8.3), medical reports are retained (see 8.4), and full details of the incident are reported to the appropriate statutory authority as soon as possible;

4.2.9 the signs required by this Code are prominently located and are maintained in a clean, intact and legible state;

4.2.10 a Radiation Safety Officer is appointed if the statutory authority so requires. The person so appointed shall have suitable qualifications and experience in radiation safety, which enables him to readily comprehend and carry out the duties laid down in 4.4 for the Radiation Safety Officer. If the appointment of a Radiation Safety Officer is not required by the statutory authority, the user or a qualified person nominated by the user shall undertake these duties and responsibilities;

4.2.11 the Radiation Safety Officer undertakes the measurements, investigations and assessments, makes the reports and keeps the records required of him by this Code; and

4.2.12 equipment, procedures and the co-operation of employees are provided so the Radiation Safety Officer can discharge the duties set out in 4.4. However, this requirement shaft not preclude use by the Radiation Safety Officer of outside experts and the use of equipment not in the possession of the user in accomplishing his responsibilities and duties.

4.3 Operator responsibilities

Each operator of an X-ray analysis unit shall:

(a) at all times carry out established procedures of operation and maintenance, and

(b) report to the user any actual or suspected case of excessive exposure, endeavour to determine its cause, and take steps to prevent its recurrence.

4.4 Radiation Safety Officer responsibilities

The Radiation Safety Officer shall:

4.4.1 obtain and maintain knowledge of the principles and practice of protection against radiation and of the potential hazards associated with X-ray analysis equipment so as to efficiently undertake the routine measurements, investigations and assessments, and prepare the reports laid down in this Code as his duties, and investigate known and suspected cases of over-exposure to determine the cause and take appropriate remedial action to prevent any further over-exposure;

4.4.2 familiarize himself thoroughly with the requirements of the legislation relevant to X-ray analysis equipment, the provisions of this Code, the detailed working rules and procedures necessary in the case of actual or suspected over-exposure, as adopted in accordance with the provisions of this Code, and the radiation monitoring and protective equipment in use to meet the requirements of this Code;

4.4.3 make available to each employee who may be exposed to radiation, appropriate personal monitoring devices for that person's exclusive use, during the installation, removal, dismantling, maintenance, repair, relocation and operation of the X-ray analysis equipment;

4.4.4 ensure that an adequate number of personal monitoring devices and radiation monitors are readily available and are in good working order;

4.4.5 issue and collect any personal monitoring devices which may be used. He shall seek the advice of the Statutory Authority regarding detailed use of such devices;

4.4.6 ensure that personal monitoring devices are promptly submitted for assessment after use;

4.4.7 ensure that individual radiation monitoring devices known or suspected to have received a dose equivalent in excess of 1000 μSv whilst being worn are assessed promptly. If the devices are returned to a personal monitoring service for assessment, the service shall be advised of the circumstances of the exposure; and

4.4.8 select, with the approval of the statutory authority, radiation monitors to meet the requirements of this Code.

5. Requirements for Equipment Used for X-ray Analysis

5.1 Scope of this Section

The requirements for X-ray analysis equipment given in this Section are considered necessary, in combination with the appropriate working rules given in Section 6, and radiation monitoring requirements given in Section 7, to ensure safety in the use of such equipment. The principal objective of this Section is to ensure that no person is exposed to a primary X-ray beam and the secondary objective is to ensure that the dose rates in fields of leakage and scattered radiation to which persons may be routinely exposed for long periods are as low as reasonably achievable.

5.2 Categories of X-ray analysis equipment

Equipment used for X-ray analysis shall conform to the requirements given below for an enclosed unit or a partly enclosed unit. Units which do not conform to the requirements for an enclosed unit or a partly enclosed unit (see 6.4) shall be modified or replaced by equipment that does satisfy the requirements of Section 5 of this Code.

5.3 All X-ray analysis units

X-ray analysis units shall satisfy the requirements as appropriate for enclosed and partly enclosed units, as set out below:

5.3.1 *Interlocks*

All interlocks fitted in accordance with the requirements of this Code should:

5.3.1.1 be designed so that it is difficult to render them ineffective;

5.3.1.2 be based on mechanical linkages, or any other mechanism that can be shown to be of equal or greater reliability, efficiency and difficulty to render ineffective;

5.3.1.3 if electrical contacts such as microswitches are used, be positioned so that it is very difficult to operate them except by means of the appropriate interlocked component; and

5.3.1.4 incorporate dual microswitches for each interlock in which microswitches are used.

5.3.2 *X-ray tube housing*

Each X-ray tube incorporated in an X-ray analysis unit shall be enclosed in a tube housing which satisfies the following requirements:

5.3.2.1 It shall be constructed of material of sufficient strength and thickness to ensure that it cannot be fractured or deformed by normal use, accidental impact or misuse.

5.3.2.2 Each aperture in the tube housing shall be covered by:

(a) a shutter (see 5.3.3), or

(b) a completely shielded enclosure, all entrances to which are interlocked so that opening one entrance immediately de-energizes the X-ray tube.

5.3.2.3 The dose of radiation in one hour at any accessible point five centimetres from the surface of the tube housing, including the closed shutter or enclosure over each aperture in the housing, shall not exceed 25 μGy when the X-ray tube is operated at any of the permissible ratings specified by the manufacturer of the X-ray analysis unit.

5.3.2.4 The X-ray tube and tube housing shall be interlocked so that the removal of one from the other or the removal of protective covers from any port or service opening will immediately de-energize the X-ray tube.

5.3.3 *Tube shutters*

Each tube shutter shall satisfy the requirements of 5.3.6.2 and shall be:

5.3.3.1 so constructed that the scattered and leakage radiation dose (including scatter from the shutter surfaces) in one hour at any accessible point five centimetres from the shutter does not exceed 25 μGy when the X-ray tube is operated at any of the permissible ratings specified by the manufacturer of the X-ray analysis unit;

5.3.3.2 fitted with a positive closing device which, in the absence of an external applied force, keeps the shutter closed;

5.3.3.3 so constructed that it is impossible to remove the shutter and its operating mechanism without the use of tools; and

5.3.3.4 so constructed that the shutter and its operating mechanism is interlocked with the tube housing so that their removal de-energizes the X-ray tube.

5.3.4 *Enclosures*

Each enclosure specified in 5.3.2.2 shall comply with at least one of the following:

(a) be attached to the tube housing so that it can only be detached by using tools;

(b) be interlocked with the tube housing so that detachment of the enclosure from the housing de-energizes the X-ray tube, or

(c) be attached to the tube housing so that detachment of the enclosure immediately closes the relevant aperture shutters.

5.3.5 *Beam stops*

One or more beam stops shall be placed as close as practicable to each aperture of the X-ray tube housing so as to attenuate the dose in one hour in the line of the primary beam from that aperture during all normal operations to less than 25 μGy at any accessible point five centimetres from the beam stop when the X-ray tube is operated at any of the permissible ratings specified by the manufacturer of the X-ray unit. For an enclosed unit, each beam stop shall, and for a partly enclosed unit, should:

(a) form a fixed part of the unit, removable only by the use of tools, and

(b) be interlocked so that removal of the beam stop

    (i) de-energizes the X-ray tube, or

    (ii) immediately closes the shutter related to that beam stop.

5.3.6 *Warning signs, lights and labels*

Warning signs, lights and labels shall be provided in accordance with the following requirements of this Code and any additional requirements of the appropriate statutory authority.

5.3.6.1 Every X-ray analysis unit shall be fitted with an illuminated sign or a combination of a sign and a light which is activated only if the X-ray tube is energized and which then indicates that the X-ray tube is operating. This sign shall be legible and readily discernible for at least two metres on all accessible sides of the X-ray analysis unit.

5.3.6.2 Each shutter shall be linked with an illuminated sign or light which is illuminated only when that shutter is open and indicates without ambiguity which shutter is open.

5.3.6.3 Each room, cubicle or area in which an X-ray analysis unit is operated shall have a sign at each entrance stating that an X-ray analysis unit is in that room, cubicle or area.

5.3.6.4 Each room, cubicle or area in which a unit, other than an enclosed unit, is operated shall have at each entrance an illuminated sign or a sign combined with a light which is activated only when the X-ray tube is energized and which then indicates that the X-ray tube is operating.

5.3.6.5 The lights, signs and illuminated signs specified in this Code should be red. However, orange lights, signs or illuminated signs supplied on or with new equipment are acceptable provided they indicate in a clear and unambiguous manner and fulfil the appropriate requirements of this Code.

5.3.6.6 The tights specified in this Code shall be designed to be 'fail safe' (i.e. to de-energize the X-ray if a light fails); alternatively, adequate warning that a light has failed shall be indicated in a clear and unambiguous manner.

5.3.6.7 Partly enclosed units which incorporate fixed shields and/or barriers shall be designed to give a clear and positive warning if the barriers or shields are incomplete. A clear and unambiguous notice shall also be displayed on or near the unit indicating the hazards of operating the unit while barriers or shields are incomplete.

5.3.6.8 Partly enclosed units which are partly enclosed by interlocked or fixed barriers and/or shields shall have displayed on or near them a prominent notice which warns of the hazard of placing any part of the body, such as the hand, inside the barriers or shields.

5.3.6.9 Each X-ray analysis unit shall be clearly labelled to indicate whether it is an enclosed unit, or a partly enclosed unit.

5.3.7 *Radiation Shields*

Radiation shields shall be made of lead backed by supporting material having greater resistance to distortion than lead, or of dense materials not readily distorted, such as steel, brass or lead glass.

5.3.8 *Barriers*

All barriers shall be constructed of material of sufficient strength and configuration, and be adequately affixed to prevent access to the protected region.

5.4 Enclosed units

Each enclosed unit shall satisfy the relevant requirements of 5.3 and the following additional requirements:

5.4.1 It shall incorporate an enclosure or enclosures which completely enclose the primary X-ray beams, preventing access to them. These enclosures may be composed, partly or wholly, of the analysing components and collimators of the X-ray analysis unit or may enclose the analysing components and collimators. Each enclosure may enclose one or more shutters and may enclose the tube housing.

5.4.2 The sections of the enclosure or enclosures specified in 5.4.1 shall be permanently attached to each other or shall be interlocked either:

(a) so that removal of any part of a complete enclosure can only be done when the shutter admitting the primary beam to that enclosure is closed and a shutter can only be opened when the enclosure is complete, or

(b) so that removal of any part of the complete enclosure de-energizes the X-ray tube.

5.4.3 The enclosure or enclosures specified in 5.4.1 shall provide adequate shielding to ensure that the dose of radiation in one hour at any accessible point five centimetres from the surface of each complete enclosure does not exceed 25 μGy when the X-ray tube is operated at any of the permissible ratings specified by the manufacturer of the X-ray analysis unit.

5.4.4 Enclosed units shall be so constructed that all operations which involve energizing the X-ray tube can be readily done while the enclosure or enclosures specified in 5.4.1 are complete and all interlocks are in operation.

5.4.5 At each aperture in the tube housing of an enclosed unit which is fitted with a shutter, the shutter mechanism shall incorporate a permanent shield in the form of a sleeve over-lapping the collimator. This shield should be recessed to permit the introduction, to a depth of at least five millimetres, of each X-ray beam collimator which is used with the analysis unit when that collimator is attached to any of the cameras or other analysis devices to which it can be fitted. This collimator shield shall be constructed to attenuate all Leakage and scattered radiation from the collimator and shutter to 25 μGy in one hour at any accessible point five centimetres from the shield.

5.5 Partly enclosed units

Each partly enclosed unit shall satisfy the relevant requirements of 5.3 and the following additional requirements:

5.5.1 It shall be so constructed that it incorporates an enclosure or enclosures which partly enclose the primary X-ray beams sufficiently to ensure that no person may inadvertently expose any part of their body to a primary beam. The enclosure shall:

(a) be interlocked in accordance with 5.4.2. or fixed so as to require the use of tools for removal.

(b) incorporate collimator shields in accordance with 5.4.5, and

(c) contain appropriate shielding material or be located at a sufficient distance from the X-ray tube that the dose of radiation at any accessible point five centimetres from the surface of each partial enclosure shall not exceed 25 μGy in one hour.

5.5.2 It should be so sited that if for any reason a shutter is opened while an entrance to an enclosure is uncovered or barriers are incomplete, the resultant, primary beam is directed away from areas that may be occupied. If such siting is not possible, beam stops or fixed shields shall be placed to adequately protect persons in these areas from the beam.

5.5.3 It should be sited in a separate room or cubicle in which there are no other radiation sources.

5.5.4 It should be so constructed that all operations are most easily and quickly carried out with all shields in place and all interlocks in operation.

6. Working Rules

6.1 Scope of this section

The working rules given in this Section are considered necessary to achieve a similar standard of safety for each type of X-ray analysis unit. To this end, additional procedures and precautions are required in the use of analysis unit; lacking certain instrumental safety features. Nevertheless, measures should be taken to ensure that each unit meets the standard of safety for the type of unit requiring the fewest working rules, i.e. an enclosed unit.

6.2 General Working Rules for all X-ray analysis units

6.2.1 Each person who uses an X-ray analysis unit shall avoid exposing any part of the body to a primary X-ray beam. If actual or suspected exposure has occurred the appropriate course of action (see Annexe III) should be taken.

6.2.2 No person shall allow the X-ray tube of an X-ray analysis unit to remain energized unless all warning lights, as required by this Code, are operating correctly.

6.2.3 No X-ray tube shall be energized:

(a) while outside its protective tube housing, or

(b) with an unshielded aperture in the tube head or protective barrier.

6.2.4 No sample, collimator or analysing crystal shall be changed or adjusted while a primary X-ray beam passes through that collimator or is incident on that sample or crystal unless:

(a) the sample, collimator or crystal, during and after the change or adjustment, is within a shielded enclosure, and

(b) the change or adjustment is done by remote means from outside the enclosure.

6.2.5 Immediate measures shall be taken to remove potentially hazardous situations arising from X-ray beams that may be emitted due to equipment defect, misalignment or any other reason.

6.2.6 A list of additional working rules shall be drawn up for each X-ray analysis unit where necessary to ensure safety. This is of particular importance for units which do not meet the requirements of this Code for enclosed or partly enclosed units. (See 6.4)

6.2.7 The necessary operations of the X-ray analysis equipment shall not be performed by inexperienced persons unless under direct supervision of an experienced operator.

6.2.8 Alignments or adjustments shall not be carried out visually while the X-ray tube is energized, unless a viewing system is used which is shielded or designed to prevent exposure of the eye or other parts of the body to the primary beam.

6.2.9 The X ray analysis unit shall not be operated, by inactivation of an interlock or with part of its enclosure removed without prior approval of the statutory authority or unless the X-ray tube is wholly enclosed by the tube housing with all apertures completely covered by interlocked shutters and/or fixed covers.

6.2.10 If under prior approval of the statutory authority (see 6.2.9) the X-ray analysis unit is operated with an interlock inactivated or part of its enclosure removed exposing the primary beam, the following rules shall be applied:

6.2.10.1 The number of persons who carry out the alignment of a camera or sample in an X-ray beam, or who make any adjustment or alteration to the analysis equipment while the X-ray tube is energized, shall be the minimum necessary to carry out the operation safely.

6.2.10.2 An experienced person not engaged in the operations specified in 6.2.10.1 shall observe the procedures and warn each operator doing them of any operation which might lead to any part of the body being exposed to a primary beam or any excessive level of leakage radiation or scattered radiation.

6.2.10.3 When the X-ray tube is energized, access of non-essential personnel to the room containing the unit shall be prevented by physical barriers. A sign warning of the operations in progress shall be placed at each entrance to the room containing the unit.

6.3 Working Rules for partly enclosed units

The working rules for each partly enclosed unit shall include those given in 6.2. All working rules given in 6.2.10 shall be implemented whether or not an interlock is inactivated or shielding structure is removed.

6.4 X-ray analysis units not complying with Section 5 of this Code

Each X-ray analysis unit which does not comply with the requirements of Section 5 of this Code (i.e. does not meet the requirements for an enclosed or partly enclosed unit) shall not be used until modified to meet those requirements, unless the user has prior approval of the appropriate statutory authority to do so for an interim period. When such approval is given a set of working rules approved by the statutory authority shall be drawn up for use pending the required modifications or replacement by a unit that complies with Section 5. These working rules shall be designed to achieve the same standard of safety as the required modifications of the equipment, shall be prominently displayed on or near the X-ray analysis unit, and shall be rigorously implemented. The interim working rules shall include rules and requirements as follows:

6.4.1 The rules required in 6.3 for partly enclosed units shall be included, and implemented whenever the unit is used.

6.4.2 Supplementary interim rules shall be included to minimize the risk that any person will be exposed to a primary X-ray beam from the unit or otherwise receive a dose of radiation in excess of the recommended dose limit.

6.4.3 A checklist of step-by-step procedures shall be prepared and used during the following operations:

(a) before initiating an exposure

(b) during an exposure

(c) in terminating an exposure, and

(d) during any non-routine operation of the unit, such as alignment of an X-ray beam.

6.4.4 The unit shall not be operated if any person other than those essential to its operation occupies the cubicle, room or area in which the unit is placed.

6.4.5 No alternation should be made to the analysing equipment in use with the unit unless the X-ray tube is de-energized.

6.4.6 Interim working rules shall include the requirements for siting given in 5.5.2 and 5.5.3, with the requirement 'should' being replaced by 'shall',

6.4.7 The requirements of Section 7 (radiation monitoring) shall be incorporated in the working rules with the following amendments:

6.4.7.1 The requirement 'should' in 7.2.1 and 7.2.2 shall be replaced by 'shall'.

6.4.7.2 Periodical monitoring shall be performed not less than once in each month and the unit shall be thoroughly examined for hazards and all safety features checked at least once in each week. This requirement is the same as that for a partly enclosed unit (see 7.3.3).

7. Radiation Monitoring

7.1 Scope of this Section

Radiation monitoring is an essential aid in the control of radiation hazards in the vicinity of X-ray analysis units. However, the accurate measurement of radiation from these units is often difficult and a person seeking to do such a measurement needs specialized equipment, careful technique, and an understanding of the principles involved. The performance of measurements following an accidental exposure of a person to a primary beam is important as a realistic assessment of the dose received is needed to assist in the prediction and treatment of radiation injury. However, radiation monitoring required during use of X-ray analysis units need not be as accurate. In this case simple measurements directed towards prevention of exposure to primary beams and reduction of leakage and scattered radiation to suitably low levels are adequate. The following rules should apply:

7.1.1 Accurate measurements of radiation exposure or dose, or their rates, in primary, scattered or leakage beams should only be attempted by, or under the supervision of, a person competent to perform such measurements.

7.1.2 Accurate measurements of leakage and scattered radiation should only be attempted if difficulty is encountered in ensuring the radiation levels are well below the requirements of 5.3.2.3, 5.3.3.1, 5.3.5, 5.4.3, 5.4.5 and 5.5.1.

7.2 Personal Monitoring

Localized personal monitors are usually inadequate indicators of exposure to the narrow beams of radiation which may be emitted from X-ray analysis units. However, personal monitors have been found useful in the discovery of some cases of exposure of persons to primary beams from X-ray analysis units and in the assessment of whole body dose due to exposure of leakage and scattered radiation from such units. The following requirements for personal monitoring are therefore recommended:

7.2.1 Each person working in the vicinity of X-ray analysis equipment should wear a suitable personal monitoring device on the chest throughout all exposures made with the unit.

7.2.2 Additional personal monitoring devices should be worn on a wrist or finger of all persons using X-ray analysis equipment, other than enclosed units except when an enclosed unit is operated with an interlock inactivated or part of an enclosure opened under the provision of 6.2.9.

7.3 Monitoring of Equipment

The user of each X-ray analysis unit shall ensure that regular radiation monitoring of the unit is carried out to detect unintended radiation emissions and to assist in preventing such emissions. The following requirements shall apply to such radiation monitoring:

7.3.1 Each instrument used for dose rate monitoring shall comply with the following requirements:

7.3.1.1 its indication shall be accurate to within ± 50% for incident radiation over the particular energy range of the X-ray analysis unit to be monitored. More than one monitor or detector may be used to meet this requirement provided their individual energy responses are known for the particular X-ray spectrum of interest.

7.3.1.2 Its sensitivity shall be adequate to give a positive indication with a time response of not more than 20 seconds for a true dose rate of 10 μGy h^{-1} then measured in a field of radiation uniform over the sensitive volume of the detector and having an effective energy within the range specified in 7.3.1.1.

7.3.1.3 If provided with meter indication, the meter shall be either:

(a) calibrated in arbitrary units only, and the appropriate method of conversion from these units to exposure rate or dose rate for a radiation field uniform over the sensitive volume of the detector indicated on the instrument, or

(b) calibrated in units of exposure rate or dose rate, with a statement clearly displayed on the instrument that its calibration is correct only for a radiation field uniform over the sensitive volume of the detector.

7.3.2 Each of these radiation surveys shall be conducted with the X-ray tube of the analysis unit operated at the maximum rated voltage and the maximum rated current for that voltage, and with no filtration in the primary beams other than the inherent filtration.

7.3.3 Periodical radiation monitoring shall be carried out on each X-ray analysis unit that is operated on a regular basis. The frequency of monitoring should be not less than that given in the following schedule, but some variation of this schedule may be warranted with certain units or periods of use:

Type of Unit	*Frequency of Monitoring*
Enclosed	*Quarterly*
Partly Enclosed	*Monthly*

In addition, partly enclosed units should be examined for hazardous situations and all safety features checked at least once in each week. For units that do not comply with Section 5 of this Code see 6.4.7.2.

7.3.4 Special radiation monitoring shall also be conducted in the following circumstances:

(a) installation of the X-ray analysis units,

(b) replacing an X-ray tube,

(c) any modification or reassembly of any shielding component,

(d) any actual or suspected over-exposure, and

(e) after any extended period of non-use.

This monitoring should include the use of radiographic film or collimated detector to determine accurately the location and extent of any cracks or defects in the shielding.

7.3.5 Adequate records shall be kept of all radiation monitoring and examinations for hazards and each entry should include a description of the equipment arrangement and any action taken as a result of the monitoring or examination.

8. Medical Requirements

8.1 Recommendations concerning the nature and frequency of medical examinations for radiation workers have been made by the National Health and Medical Research Council in its publication 'Recommended radiation protection standards for individuals exposed to ionising radiation' (AGPS, 1981)

8.2 When presenting for medical examination, each operator of an X-ray analysis unit should inform the medical practitioner of the nature of his employment.

8.3 The operator or any other person involved in the use of an X-ray analysis unit shall undergo a medical examination following any known or suspected occasion when the person has been exposed to a primary beam from the unit, (See 4.2.8). The medical officer shall be given an early indication of the suspected dose, with follow-up confirmation.

8.4 The user shall ensure that records of all medical examinations, as required under 8.3, for each employee are retained. The advice of the appropriate statutory authority shall be sought regarding the period of retention.

ANNEXE I

Biological effects of ionizing radiation and limits on exposure to such radiations

Note: *This statement provides background information. Not all of it is relevant to this Code.*

Considerable knowledge has been gained during this century, and particularly during the past three decades, on the possible biological effects of ionizing radiation on man. These effects may manifest themselves in the exposed individual and they are then referred to as somatic effects or they may arise in the descendants of the exposed individual, in which case they are referred to as hereditary effects. It is important to recognize, however, that many of the biological effects that can be caused by ionizing radiation may also result from exposure to other agents and it is not always possible to determine the cause of a particular effect in an individual.

Man has always been exposed to radiation, and this arises from terrestrial sources, cosmic radiation and radionuclides deposited in the body. This natural background radiation varies from place to place on the earth, but for most of the world's population, the average effective dose equivalent has been estimated to be about 2000 microsievert* (μSv) per year, although there are a few places where the contribution from terrestrial sources results in values which are considerably higher for individuals. Effects on man from natural background, if they exist, are not discernible. On the other hand, radiation-induced effects have been observed in man when individuals have been exposed to very large radiation doses and it is from such doses that our knowledge of biological effects from radiation exposure is derived.

Injury to tissue became evident in the past from a number of different sources - for example, as a result of using radium luminous compounds for painting dials on watches and instruments, some workers develop bone sarcoma; many miners working in uranium mines developed lung cancer; a number of radiologists developed skin erythema and leukaemia as a result of inadequate radiation protection. In addition, there was a small excess of leukaemia and other malignant diseases above the expected incidence rates observed among survivors of the atomic bombs in Hiroshima and Nagasaki in Japan following their exposure to large doses of radiation from the bombs. In all the above examples, and there are many more demonstrated radiation-induced effects, the doses received by individuals were large - very many times the doses arising from natural background radiation. Radiation doses high enough to cause acute effects have occurred following even very short exposures to the intense primary beams from X-ray analysis equipment. Even in recent years, there has been a number of reports of incidents involving radiation burns to the hands and eyes of operators following accidental exposures to primary X-ray beams.

The effects arising from large radiation doses are well known and many studies have been undertaken in order to correlate radiation-induced effects with small doses. However, it has not been possible to correlate any observed effects directly with the doses received. Because of statistical limitations, data available from such studies have not been, and may never be, sufficient to lead to definitive conclusions. Accordingly, studies have been carried out on animals and plants to observe any effects produced and the correlation, if any, with the total dose delivered

* The sievert is the unit used in radiation protection for dose equivalent alert and is equal to 100 rem.
1 μSv = 10^{-6} Sv; 10 μSv = 1 mrem.

and/or dose rate. In these latter studies, the incidence of many biological effects produced has been related to the total dose delivered, whilst for other effects, there appears to be threshold doses below which those effects are not detectable. Although it is difficult to apply the results of these studies directly to man, they provide a useful guide in indicating possible dose-effect relationships.

The effects arising from exposure to ionizing radiation fall into two categories. Stochastic effects are those for which the probability of an effect occurring but not the severity of the effect is regarded as a function of the dose to which the individual is exposed. It is assumed for radiation production purposes that there is no threshold dose below which the probability of such an effect occurring is zero. On the other hand, non-stochastic effects are those for which the severity of the effect varies with the dose to which the individual is exposed and there may exist a threshold dose, below which such effects do not occur.

From the studies undertaken, it is known that malignancies, including leukaemia, are stochastic effects of radiation, although such malignancies may not become manifest until many years after the radiation exposure. Mutagenic effects are also stochastic effects and these may be propagated through the population for many generations. However, a mutagenic defect causing slight physical or functional impairment, and which may not even be detectable, may tend to continue in the descendants, whereas a severe defect will be eliminated rapidly and not be passed on to future generations.

Non-stochastic effects arising are specific to particular tissues, for example, non-malignant damage to the skin, cataract of the lens of the eye, gonadal cell damage leading to impaired fertility etc. If an individual receives a dose greatly in excess of the threshold dose, the manifestation of the effect will occur in a relatively short period after the irradiation. However, if the dose is not greatly in excess of the threshold dose, many of the resulting effects will be of a temporary nature and reversion to normal conditions usually occurs.

From our knowledge of biological effects arising from exposure to radiation, it is possible to identify the risk of stochastic effects occurring with the doses received by the various organs and tissues of the body. These risks are derived from exposure of persons to very high doses and from studies on animals etc. As there is very little information on the effects of exposure to low doses, it is cautiously assumed that risk is directly proportional to dose, right down to zero dose and that there is no threshold below which these effects do not occur. These assumptions may lead to overestimates of the risks associated with exposure to low doses of radiation. Although the risks derived from such assumptions may be very small, it is important that they are kept small by ensuring that all radiation exposure of individuals is kept as low as reasonably achievable and that there be a demonstrated net benefit for each exposure. This principle is commonly referred to as the ALARA principle.

Radiation protection is concerned with the prevention or limitation of possible harmful effects of radiation exposure of individuals involved in various radiation practices, as well as of members of the public. It recognizes that various practices involving radiation exposure may be necessary and of benefit to the individuals exposed and to mankind. In undertaking such practices, individuals, as radiation workers or as members of the public, may be irradiated and the exposure resulting from those practices must be minimized in accordance with the ALARA principle. Good radiation protection practice requires the setting of standards for occupational exposure and these are such that the risk of fatalities arising from radiation-induced malignancies from the average dose received in such exposure is no greater than the risk of fatalities arising in other occupations that have high standards of safety. Radiation Protection Standards have been prepared for the National Health and Medical Research Council (1) for use in Australian and are based on the recommendations of the International Commission on

Radiological Protection (2). They assume for stochastic effects a linear relationship between risk and dose and that there is no threshold dose below which effects do not occur. For non-stochastic effects relating to specific organs, the Standards set a limit on the dose received, below which such effects would not be manifest. The limit given in the Radiation Protection Standards for an organ is the lower limit of that derived for stochastic effects and that derived for non-stochastic effects when that organ is the only irradiated organ.

For purposes of radiation protection, the limits given in the Standards are specified in terms of annual dose-equivalent limits. For whole body exposure, the annual limit for radiation workers is 50 mSv (or 50 000 μSv). In certain circumstances, it is possible that only partial exposure of the body occurs or that single organ exposure occurs. In these circumstances, limits are prescribed such that the risks associated with partial body exposure or with single organ exposure are the same as the risk with uniform whole body exposure. Accordingly, higher limits are prescribed for these circumstances, for example, annual limits for exposure of the hands, fingers and forearms are 500 mSv and for the lens of the eye 150 mSv.

When exposure is from external sources only, the doses received can be determined by the use of personal monitors, which give the doses received at the point of wearing. From the everyday point of view, it is not convenient to determine from the monitor reading the dose to the whole body or to specific organs. In practice, if the annual dose for an individual, as determined from monitors worn on the body, does not exceed 50 mSv then the dose-equivalent limits for the whole body and for the various organs will be exceeded in the case of whole body exposure, provided the monitor has been worn on the body such that it would most likely have received the highest dose to the body.

Although the standards prescribe limits on an annual basis only, it is useful to ensure that doses reported for monitors do not exceed 1000 μSv per week (or 4000 μSv per four-weekly period). By this means it will become obvious during a year if there is any real likelihood of the annual limits either being approached or exceeded.

In determining the total dose equivalent received from occupational exposure, exposures from normal natural background radiation or from radiological procedures to the individual (including radiodiagnosis, dentistry. radiotherapy and nuclear medicine) are not to be included. The Standards make provision for special limits in circumstances involving planned special exposures. They recognize that limits cannot be set for emergency or accidental exposures, but that attempts must be made to assess as carefully and as quickly as possible the dose equivalents received in those situations so that any necessary remedial action can be taken.

The Radiation Protection Standards do not make any special provision for females of reproductive capacity. However, they state that when a pregnancy is confirmed (and this would normally be within a period of two months), arrangements should be made to ensure that the woman works only under such conditions that it is most unlikely that doses received during the remainder of the pregnancy would exceed three-tenths of the pro-rata annual dose-equivalent limits for occupationally exposed person.

The Standards do not prescribe limits for individual members of the public. However, they require that the design and operation of radiation facilities be such that, apart from radiation received by individuals undergoing radiological procedures, members of the public most likely to receive the highest dose from the sources, ie., the critical group, are unlikely to receive more than one-tenth of the corresponding annual exposure for this group. the annual dose-equivalent limit is 5 mSv, provided the exposure does not occur crier many years. If this should occur, action should be taken to reduce radiation exposures so that in a lifetime, an average annual dose-equivalent limit of 1 mSv is not exceeded.

References

(1) NATIONAL HEALTH AND MEDICAL RESEARCH COUNCIL. '*Recommended radiation protection standards for individuals exposed to ionising radiation.*' Australian Government Publishing Service, Canberra, (1981).

(2) ICRP. '*Recommendations of the International Commission on Radiological Protection*' Oxford: Pergamon Press; ICRP Publication 26 (Annals of the ICRP, Vol 1 No 3) (1977).

ANNEXE II

Statutory Authorities

Owners and users of X-ray analysis equipment requiring information regarding their obligations under the radiation control legislation should refer to the statutory authority in their state or territory.

1. **Australian Capital Territory**

Consultant, Radiation Safety — Telephone: (062) 47 2899
Capital Territory Health Commission
C/- Royal Canberra Hospital
ACTON ACT 2601

2. **New South Wales**

Officer-in-Charge — Telephone: (02) 646 0222
Radiation Branch
Department of Health
PO Box 163
LIDCOMBE NSW 2141

3. **Northern Territory**

Director — Telephone: (089) 80 2911
Occupational and Environmental Health
NT Department of Health
GPO Box 1701
DARWIN NT 5794

4. **Queensland**

Director — Telephone: (07) 224 5611
Division of Health and Medical Physics
Department of Health
535 Wickham Terrace
BRISBANE QLD 4000

5. **South Australia**

Senior Health Physicist — Telephone: (08) 218 3211
Occupational Health and Radiation
Control Branch
South Australian Health Commission
GPO Box 1313
ADELAIDE SA 5001

6. Tasmania

Health Physicist — Telephone: (002) 30 6421
Division of Public Health
Department of Health Services
PO Box 191B
HOBART TAS 7001

7. Victoria

Senior Scientific Officer — Telephone: (03) 616 777
Occupational Health Services
Public Health Services Division
Health Commission of Victoria
555 Collins Street
MELBOURNE VIC 3000

8. Western Australia

The Secretary — Telephone: (09) 380 1122
Radiological Council
State X-Ray Laboratory
Department of Public Health
Verdun Street
NEDLANDS WA 6009

ANNEXE III

Emergency Procedures

In the event of an actual or suspected exposure of any person to a primary beam of an X-ray analysis unit the following should be carried out.

I. Switch off the X-ray analysis unit.

2. Do *not* take remedial action to correct the particular fault, if any, that caused the exposure. Post assessment of the absorbed dose may be more difficult if the fault is corrected.

3. Leave a sign on the unit to indicate that the unit should not be used or altered in any way.

4. Notify the following of the exposure:
   (a) The user
   (b) The Radiation Safety Officer
   (c) The statutory authority

5. Refer the exposed person for medical examination.