RADIATION PROTECTION

ICRP PUBLICATION 15

Protection against Ionizing Radiation from External Sources

A Report by Committee 3 of the
International Commission on
Radiological Protection

ADOPTED BY THE COMMISSION IN NOVEMBER 1969

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DEDICATION

BRIAN ERNEST JONES
1927–1969

THE SUDDEN death of Brian Jones on 28 November 1969 was a severe loss to all his colleagues in the field of radiological protection. His hard work and enthusiasm as secretary of the Task Group responsible for the preparation of this report are particularly appreciated. It is accordingly the wish of the Commission and of those who worked with him on this task that the report should be dedicated to his memory.

PREFACE

In April 1967 the International Commission on Radiological Protection appointed a Task Group consisting of

P. Grande (*Chairman*)
K. Becker (*Vice-Chairman*)
B. E. Jones (*Secretary*)
J. P. Kelley
K. Koren
C. B. Meinhold
P. Pellerin
R. H. Thomas

to consolidate, modify and expand the material previously published in ICRP Publications 3 and 4 into a new report on protection against external radiation, covering medical, industrial and research uses of all types of ionizing radiation, essentially up to energies of 100 MeV and with the main emphasis on the medical uses. The recommendations in the present report have been made by Committee 3 on the basis of the suggestions and the material compiled by the Task Group. The recommendations relating to protection of the patient have also been based upon advice received from members of the ICRP Task Group on the Protection of the Patient in X-ray Diagnosis.

A supplement to this report is being published separately; it contains data that have been prepared by the Task Group for the purpose of providing reference material which will allow quantitative assessments to be made of primary and secondary radiation fields and of the effectiveness of protective walls and barriers.

Membership of Committee 3 (1965–9)

B. Lindell (*Chairman*)
E. E. Smith (*Vice-Chairman*)
L.-E. Larsson (*Secretary*)
F. P. Cowan
J. Dutreix
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E. D. Trout
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† Joined in 1967.

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INTRODUCTION

(1) It is the Commission's wish to maintain fully its traditional contact with medical radiology and to fulfil its responsibilities to the medical profession; it is therefore appropriate that the Commission should give guidance and recommendations on the safe use of ionizing radiation and radioactive substances having regard to the external exposures that will occur from this use.

(2) The radiation sources that are used for non-medical purposes are often similar to those that are used in medical diagnosis or therapy, and the basic precautions to protect the staff are essentially the same irrespective of the use. It has therefore been felt that an extension of the recommendations to cover also veterinary and industrial uses and research applications of radiation would be justified. The corresponding sections are, however, less extensive than those dealing with the medical uses.

(3) By utilizing the practices outlined in this report, it should in general be possible to maintain radiation doses below the maximum permissible levels recommended by the Commission (ref. 9) and to provide adequate protection to the patient. The national regulatory authorities are, however, expected to establish the necessary standards and control procedures and to expand detailed technical requirements. For guidance, it has been considered desirable to publish a supplement to this report, containing graphs, tables and examples from which the necessary numerical values for radiation protection can be obtained.

(4) The current maximum permissible doses that are recommended for exposure to internal and external radiation are summarized in the Appendix to this report.

(5) It should be stressed that recommendations for the installation and operation of x-ray and other equipment producing ionizing radiation or for dealing with radioactive materials are not in themselves sufficient to guarantee adequate protection. Such protection depends also on the knowledge of the staff and on their co-operation in carrying out the instructions prepared by their supervisors in the interest of radiation protection.

(6) In the recommendations given in this report, the words *shall* and *should* have the following meaning:

shall—necessary or essential for adequate protection against radiation;
should—to apply, whenever practicable, in the interests of improving radiation protection.

The Commission is aware that compliance with some of the *new* recommendations may entail structural changes in existing installations and/or changes in operative procedures. It is desirable that such changes be made as soon as practicable, but not in such a way as to deprive patients of necessary medical attention (see also paragraph 38).

QUANTITIES AND UNITS

(7) This section gives a brief review of the basic concepts and units used in the evaluation of Absorbed Dose and Dose Equivalent. Reference is given to material in the supplement to this report and elsewhere which will be of help in the solution of the practical problems of radiation protection.

ABSORBED DOSE, EXPOSURE AND DOSE EQUIVALENT

(8) *Absorbed dose* (D) due to any directly or indirectly ionizing radiation is the energy imparted to matter by ionizing particles per unit mass of irradiated material. The special unit of absorbed dose is the *rad* and is equal to an energy absorption of 0.01 joule kg^{-1} or 100 ergs g^{-1} (ref. 16).

(9) *Exposure* (X) is the term reserved for the quantitative assessment of ionizing electromagnetic radiation fields. The exposure at a given place is a measure of the radiation based upon its potential ability to produce ionization in air. The special unit of exposure is the *roentgen* (R). One roentgen is the exposure of x- or γ-radiation such that the associated corpuscular emission per kilogram of air produces, in air, ions carrying 2.58×10^{-4} coulombs of electric charge of either sign (ref. 16).† For a wide range of energies one roentgen will result in an absorbed dose in soft tissue of approximately one rad under conditions of charged particle equilibrium.

(10) The *kerma* is a dosimetric measure of the radiation field for uncharged particles such as neutrons or x rays. It is equal to the kinetic energy of charged particles generated per unit mass of the material with which the uncharged particles interact. A unit of kerma is the rad.

(11) Equal absorbed doses of radiation may not always give rise to equal risks of a given biological effect, since the biological effectiveness may be affected by differences in type of radiation or irradiation conditions. To apply risk estimates obtained under a given set of conditions to situations in which other types of radiations are used or the conditions of irradiation differ, e.g. with regard to the spatial distribution of absorbed dose it is necessary to multiply the absorbed dose for each type of radiation by one or more weighting factors. In radiological protection the quantity obtained by thus weighting the absorbed dose in rads is called the *dose equivalent* (DE) and its unit is the *rem*. The dose equivalent for a given type of radiation and at a given location in the body is numerically equal to the product of the absorbed dose in rads for that radiation at that position and the modifying factors specified by the Commission. The dose equivalent for a given radiation may thus be expressed by the equation:

$$(DE) = D \times (MF)_1 \times (MF)_2 \times \ldots (MF)_i,$$

where (DE) is the dose equivalent in rems, D is the absorbed dose in rads, and $(MF)_1 \ldots (MF)_i$ are appropriate modifying factors.

When more than one type or energy of radiation is present at the point of interest, the dose equivalent at that point may be obtained by summing the dose equivalents for each of the types and energies of radiation.

MODIFYING FACTORS

(12) The modifying factor most frequently used is the *quality factor* (QF), which accounts for the difference in the linear energy transfer of different directly ionizing radiations at the location of interest.‡ The *linear energy transfer* (L_Δ), defined by the ICRU (ref. 16), includes a limit Δ for energy transfers from the charged particles. For protection purposes all energy transfers are included, and L_∞ becomes numerically equal to the collision stopping power. Table 1 gives the relationship between L_∞ and QF. Intermediate QFs may be obtained by an interpolation from the curve given in Appendix 2 of the supplement. When the incident radiation is x or γ rays, the quality factor of the electrons generated in any position within the body is assumed to be 1, and no other modifying factors apply.

† This is numerically equal to the former definition of 1 e.s.u. of electricity per 0.001293 g of air.

‡ Previously this modifying factor was termed the "RBE", but the use of this term for both radiobiology and protection purposes presents certain problems which are discussed in detail in the Report of the RBE Committee to the ICRP and the ICRU (ref. 14).

TABLE 1. L_∞-QF RELATIONSHIP

L_∞ in water (keV/μm)	QF
3.5 (and less)	1
7	2
23	5
53	10
175 (and above)	20

(13) In some situations the charged particles producing the absorbed dose at the point of interest may have a continuous energy or L distribution (strictly this should be L_∞, but for convenience this has been simplified to L). In that case the dose equivalent is obtained from

$$DE = \int_0^{L_{max}} D(L)QF(L)\,dL,$$

where $D(L)$ is the absorbed dose at the point of interest per unit interval of L at L, $QF(L)$ is the quality factor for this L, and L_{max} is the maximum value of L at the point of interest. Then the effective quality factor, $\overline{QF}$, is given by

$$\overline{QF} = \frac{\int_0^{L_{max}} D(L)QF(L)\,dL}{\int_0^{L_{max}} D(L)\,dL}.$$

(14) *Additional modifying factors:* Further modifying factors might become necessary in certain cases. In the future it may be possible to recommend modifying factors to allow for, among other things, non-uniform spatial distribution of absorbed dose, differences in absorbed dose rate or for fractionation of absorbed dose.

DETERMINATION OF DOSE EQUIVALENT

(15) For radiation protection purposes one must determine the dose equivalent in the critical organs and compare these numerical values with the maximum permissible dose for that organ. However, neither the absorbed dose nor the dose equivalent can be measured directly in any of the critical organs. Thus to obtain the dose equivalent in any position within the body one must make measurements of the radiation fields outside of the body. These measurements, together with determinations of the relative depth dose in the body, permit determination of the dose equivalent at various locations.

(16) For incident monoenergetic radiation of a given type the dose equivalent tends first to increase with depth, then to reach a maximum and finally to decrease. The increase may be due to a buildup of charged particles from an incident uncharged particle beam, to scattering of the incident radiation near the entrance portion of the body or to production of secondary radiations of other types. The decrease of the dose equivalent results from attenuation of the primary beam. The position of the maximum dose equivalent in the body depends upon the energy and type of radiation. When a radiation passes through a shield before reaching the person whose irradiation is to be determined, the increase in the dose equivalent with depth of the body is reduced because much of this increase might take place in the shield itself. Moreover, if the person's orientation is not fixed with respect to the radiation, the peaks tend to be "smeared out". Similar "smearing out" will occur if the radiation is more or less isotropically incident upon the body.

(17) Depending upon the information available with respect to type and energy of radiation, various approximations may be used to assess the value of the dose equivalent in the critical organs (but see paragraph 18). When the incident radiation is x or γ rays, the exposure in roentgens measured outside the body may be assumed to be numerically equal to the absorbed dose in rads at any position in the body and, since the QF is 1, also equal to the dose equivalent at any point in the body. When the incident radiation is neutrons only and the tissue kerma free in air (in rads) is known, this kerma may be assumed to be numerically equal to the absorbed dose in rads at any point in the body. If the energy of these incident neutrons is not known, a QF of 10 should be assumed. Alternatively a measurement with a "rem-meter" may give an adequate determination of the dose equivalent. For singly charged heavy particles of unknown energy, a QF of 15 is recommended, while for multiply-charged particles (or particles of unknown

charge) of unknown energy, a *QF* of 20 should be used. If the energy of such charged particles is not known, it may be assumed that the absorbed dose in tissue obtained free in air will be the absorbed dose at any place in the body.

(18) The above approximate determinations of the absorbed dose and the dose equivalent in the critical organs are adequate when the numerical values so obtained are well below the maximum permissible doses or dose limits (as the case may be) for the organs that are critical in the case of whole-body exposure (i.e. the red bone marrow and the gonads). More accurate assessments are required when the approximate determinations give values close to or exceeding the MPDs or dose limits.

DERIVATION OF DOSE EQUIVALENT FROM PARTICLE FLUENCE

(19) An alternative approach to the estimation of the dose equivalent by the use of quality factors and an assessment of absorbed dose is to convert the particle fluence incident upon the body directly by the use of conversion factors. Appendices 6 and 7 give values of factors for conversion of particle fluence to dose equivalent for neutrons and protons respectively. In calculating the values for the conversion factors those irradiation conditions have been selected which lead to the highest values of the dose equivalent.

RECOMMENDATIONS ON DESIGN AND OPERATION

GENERAL RECOMMENDATIONS

(20) The following recommendations on general principles for operational radiation protection are quoted from ICRP Publication 9 (ref. 9), and are relevant to this section of this report.

"(108) In any establishment or operation the authority in charge should identify a technically competent person or persons to provide advice on all relevant aspects of radiation protection, and to provide such technical services as are needed in the application of appropriate recommendations for radiation protection. The authority itself would, however, be responsible for the protection of persons working in the establishment or on an operation and for limiting the exposure of members of the public, so as to comply with the relevant national or local requirements.

"(109) The design of all projected installations and the plans for all operations should be evaluated in advance for the adequacy of radiation protection, both of workers and of members of the public. The evaluation of radiation protection should also include a review of foreseeable types of accidents. This review should consider the nature and magnitude of foreseeable accidents, their probability of occurrence, their consequences, and the appropriate preventive measures and counter-measures.

"(113) The authority in charge should establish such controlled areas as may be necessary. A controlled area is any area to which access is controlled for the purpose of protecting persons from exposure to radiation or radioactive materials. Access can be controlled in a variety of ways, the minimum being by the use of warning signs. The extent of a controlled area is a matter of professional judgement, but in all cases the extent should be such that it is extremely unlikely that workers outside the controlled area will receive doses in excess of 3/10 of the appropriate Maximum Permissible Doses. Other considerations may require an enlargement of the controlled area.

"(114) Workers should be suitably in-

formed of the radiation hazard entailed by their work and of the precautions to be taken. This will require training in safe procedures and in effective methods of avoiding unnecessary exposure.

"(115) Necessary protective equipment should be provided and its appropriate use should be enforced.

"(116) Working conditions and equipment should be reviewed from time to time to ensure that they remain as intended. They should also be reviewed when an operation is modified.

"(124) The authority in charge of any establishment or operation which might cause environmental contamination should limit the exposure of members of the public so as to comply with relevant national or local requirements, and with the Commission's recommendations, by controlling the release of radioactive material into the environment. Any radiation sources which might cause public exposure by external radiation should be subject either to adequate shielding or restrictions of access."

(21) The final plans for new installations or for modifications of existing installations involving structural shielding should be reviewed by a qualified expert and should be approved by the competent authority before building is commenced. Copies of the plans of the installation, including the shielding specifications, should be retained and be readily available at the site.

(22) Before any equipment or installation is put into use, surveys shall be carried out in order to establish that the approved plans have been followed and that the shielding and operating conditions are such as to provide protection for all persons in accordance with national and local requirements and/or the recommendations of the Commission. For details on surveys and monitoring, see paragraphs 290–307. Subsequent surveys shall be made after every change in the equipment, installation or conditions of use that might affect the protection and at such intervals as may be necessary to check that satisfactory conditions still obtain.

(23) Protection can be achieved by distance, by shielding and by reduction of the exposure time. Proper siting of the installation and limitations of the possible directions of the useful beam are examples of means by which the cost of the shielding can be reduced.

(24) The shielding of the radiation source and the dimensions and siting of the installation in which it is situated shall be such that work can be carried out in compliance with the recommended maximum permissible doses and dose limits for workers and members of the general public. In the case of work that is undertaken outside fixed installations (e.g. site radiography), temporary barriers and warning signs to restrict access to the controlled area shall be used when necessary. In the supplement to this report absorption data and other information are provided for the computation of shielding requirements.

(25) In the planning of a radiation installation, account should be taken of the maximum practicable workload of the equipment.

(26) The shielding requirements depend on the nature of the occupancy of surrounding areas, that is whether (either as controlled areas or not) they are accessible to adults during their work or to members of the public (including patients). For some areas it may be possible to employ "occupancy factors" and "use factors" in order to reduce the shielding requirements. Since these factors may differ considerably between installations, no recommendations regarding their magnitude are given in this report. Where such factors are employed, relaxations of the shielding requirements always need careful consideration and shall be in conformity with the requirements of the relevant national or local authority. Attention should also be paid to shielding of certain areas such as those used for storage of x-ray film or other sensitive radiation detectors.

(27) In calculating the shielding, consideration should be given to the possible irradiation of persons of all categories from other sources of radiation, including irradiation from internal sources (see ICRP Publication 9 (ref. 9), paragraphs 53 and 71, footnote to paragraph 68; ICRP Publication 12 (ref. 12), paragraphs 12–14).

(28) In calculating the shielding required against the primary radiation beam, removable objects (e.g. patient, phantom, casting) by which the beam may be partly absorbed should not normally be taken into account. Exceptions to this recommendation should

only be permitted with the agreement of the competent authority.

(29) In calculating the shielding required against stray radiation,† the anticipated conditions of use which give rise to the maximum leakage radiation from the equipment and the maximum secondary radiation should be assumed.

(30) Windows and doors of radiation rooms shall be subject to the same protection requirements as the adjacent parts of the walls in which they are located. It should be noted that the shielding requirements of a door are reduced if there is a shielded entrance maze between it and the radiation area.

(31) Shielding materials such as lead shall be mounted in such a manner that they will not creep under their own weight. They shall also be protected against mechanical damage. When materials such as concrete, particularly when they are cast on site, are intended to provide radiation shielding, care must be exercised to ensure that they are sufficiently homogeneous and are of the composition and density specified by the competent authority.

(32) In building a radiation installation, care should be taken to ensure that the shielding is not impaired at joints, nails, bolts, etc., where pipes, conduits and louvres, etc., are present and at the edges of doors and windows. At a joint between two different shielding materials the overlap shall be not less than the required thickness of the material of the lower protective capability.

(33) Where appropriate, the nature of and the shielding provided by walls and other barriers which form part of the shielding of an installation should be marked upon them.

(34) Wherever practicable, locks or interlocks should be provided which preclude access to radiation areas while the rate of irradiation exceeds acceptable levels (see paragraph 41).

(35) Suitable devices such as diaphragms, cones and adjustable collimators shall be used to limit the useful beam.

(36) Where equipment has been found to comply with existing recommendations or requirements it should, when practicable, be labelled to this effect. Auxiliary equipment such as filters and treatment cones should be marked with the relevant properties in a manner that will prevent unintentional substitution and misuse.

(37) Wherever practicable, equipment that may emit significant amounts of radiation should be provided with a label by which it can be identified as a potential source of radiation.

(38) Equipment that does not and cannot be made to meet modern requirements shall not be retained against the advice of competent experts. No equipment shall be used for other purposes than those for which it has been designed unless it has been surveyed and tested, and certified as satisfactory for the new purpose. Obsolete equipment shall not be handed over to other users unless it will be subject to such surveillance and testing for safe functioning. Particular attention shall be given to the possible misuse of equipment in common use (for example, dental units). The use of modern equipment should be encouraged, but it should also be recognized that there are circumstances where unconditional disapproval of existing equipment merely because it is old may result in unjustified deprivation of valuable medical attention.

(39) In carrying out surveys it is essential to use instruments that are of adequate sensitivity, properly calibrated and suitable for the types of radiation that may occur (see paragraph 294).

(40) In assessing compliance with the requirements for tube and source housings it is adequate for measurements to be averaged over an area up to but not larger than 100 cm^2 at a source distance of one metre or 10 cm^2 at a distance of 5 cm from the tube or source housing, as appropriate.

(41) All controlled areas as defined by the Commission (see paragraph 20:113) shall be identified by appropriate and adequate signals and signs which can be readily recognized by all persons to whom they are intended to give warning. In order to avoid uncertainties in the determination of the extent of controlled areas the boundaries should when possible be walls, doors, etc. Inside controlled areas it may sometimes be useful to indicate where certain rates of irradiation occur.

(42) The information and training of

† Radiation other than the useful beam. It includes leakage radiation and secondary radiation.

workers referred to in paragraph 20:114 should particularly emphasize the importance of distance, time and shielding. Training should be aimed at optimizing these factors, with particular attention paid to the importance of avoiding exposure of any parts of the body to primary beams.

(43) Attention is drawn to the possible existence of non-radiological hazards such as electrical, mechanical and toxic hazards (e.g. the production of ozone and oxides of nitrogen). Information on these hazards should be obtained from national regulations or codes of practice.

Recommendations relating to specific types of equipment

(44) In this report the recommendations are mainly presented on the basis of the type of use of radiation rather than on the basis of the nature of the radiation source. However, a few recommendations specifically related to type of source are given in paragraphs 45–66.

X-ray equipment and particle accelerators

(45) The exposure outside any auxiliary equipment, e.g. high tension generators, shall not exceed 20 mR in one hour at 5 cm from the surface (see paragraph 40), nor 2 mR in one hour at any readily accessible place within the controlled area. If the transformer or valve enclosure is located outside the controlled area, it may be necessary to reduce these exposures.

(46) A reliable indication shall be provided at the control panel and, when practicable, also readily visible near the radiation beam aperture in order to show whether or not radiation is being generated. When appropriate, signs should also be displayed outside the irradiation room.

(47) Warning indicators should be so designed that they will not give rise to a false feeling of safety; e.g. lights indicating when the tube is *not* energized may be provided in addition to lights indicating that radiation is being generated. Alternatively, lights of the latter type may be so designed that the equipment cannot be operated if there is a failure of the indicator.

(48) Where the primary beam strikes material, secondary radiation will be generated. Attention should be given to the choice of material and the arrangement of absorbers to minimize the secondary radiation, which will include x rays when electrons or beta particles are absorbed.

(49) High energy accelerators may produce noxious gases, and materials (including air and dust) irradiated by the accelerated particles or by the photon beam may become activated. Expert advice on these problems should be obtained at the planning stage and any necessary safety measures, e.g. choice of material and the installation of forced ventilation, should be incorporated in the design. Material that may become activated (shielding material, machine components, conveyor systems, beam defining system and sample holders) should be monitored, and any appropriate precautions instituted.

Beam equipment with sealed radioactive sources

(50) In the design of source housings consideration should be given to means whereby the integrity of the source housing is preserved in the event of fire. Information on the location of major radioactive sources should be readily available to the appropriate fire authorities.

(51) A reliable indication shall be provided at the control panel and, when practicable, also at the source housing, in order to show when the source is in the ON position. It is often advisable also to have an indication capable of showing when the source is in the OFF position (see paragraph 47). When appropriate, signs should also be displayed outside the irradiation room.

(52) The surface of the housing of the source capsule, particularly the beam aperture, together with any other locations likely to be contaminated in the event of a leakage, shall be tested for leakage of radioactive material at least every year. Guidance on methods of testing sealed sources is given in ICRP Publication 5 (ref. 5). Should the probable presence of free activity of more than 0.05 μCi be indicated, the source shall be considered as leaking, the equipment with-

drawn from use and arrangements made immediately for source repair and decontamination of the equipment.

Sealed sources used without beam collimation

(53) A sealed source is considered to be any radioactive substance sealed in an inactive container or capsule, or bonded wholly within inactive material, so as to prevent dispersion of the radioactive substance during routine use. It should be noted that many sealed sources are fragile and may easily be damaged with consequent release of the radioactive material. A sealed source may normally be regarded as exempted from the following recommendations if it consists of not more than 1 μCi of Group 1 radionuclides (ref. 5) or 100 μCi of other radionuclides and would not give rise to a dose equivalent rate of more than 10 mrem/h at or near its surface.

(54) Sealed sources containing activities exceeding those specified in paragraph 53 will need to be recognizable as such, for two reasons. One is that the layman should be warned of the fact that the source is radioactive (this is particularly important with sources used for industrial radiography); the other is that the expert will need an easy way of identifying the nature and the activity of the radioactive material. Hence, wherever practicable, all such sources should be readily recognizable as being radioactive and the source container, capsule or bonding shall be labelled in such a way that the source can be identified (see paragraph 144). If practicable, the nature and the activity of the radioactive material should be marked directly on the label.

(55) A register shall be kept of all sealed sources. The register should include:

- the serial number or other identification of each sealed source;
- the nature of the radioactive substance, the date of receipt and its activity on that date;
- the date and manner of ultimate disposal from the establishment.

(56) Records shall be kept of the movement of all sealed sources within and outside an establishment in order to minimize the possibility of their loss. Actual or suspected loss of, or damage to, a sealed source shall be reported immediately to the person responsible for radiation protection.

(57) The storage, use, issue and receipt of sealed sources shall be the responsibility of authorized persons only, and an audit of all sealed sources shall be carried out at appropriate intervals and at least every year.

(58) Extreme care shall be taken to avoid mislaying sealed sources. This is particularly important in the case of open installations (see paragraph 220) where a mislaid source may get into the possession of an unsuspecting person.

(59) Local rules shall be prepared detailing the manner of use of sealed sources and the procedures to be adopted in the event of loss of, damage to, or accidents involving a sealed source. In preparing such rules, consideration should be given, as appropriate, to factors such as possible causes of loss, spread of contamination, effects of fire, and identification and treatment of casualties.

(60) When not in use, sealed sources shall be stored under conditions which provide adequate protection for those entering and adjacent to the store, security against unauthorized removal and minimum risk due to fire and flood. Where sources are liable to release a radioactive gas or vapour the store shall, if necessary, be mechanically ventilated to the outside air. Such ventilation may need to be continuous, or for an appropriate period before and whilst the store is open, depending upon the activity and radiotoxicity of the radionuclide concerned.

(61) Sealed sources shall be tested for leakage at appropriate intervals and at least every year. Guidance on methods of testing is given in ICRP Publication 5 (ref. 5). If the probable presence of free activity of more than 0.05 μCi is indicated, the source shall be considered as leaking.

(62) Whenever there are reasonable grounds for believing that a sealed source is, or is liable to be, leaking, it shall be hermetically sealed in a suitable container pending repair by the manufacturer or by a competent establishment. In such circumstances the area in which the source has been used and any person having used it shall be checked for contamination.

(63) In order to ensure the minimum irra-

diation of personnel engaged in the preparation or application of sources, appropriate handling tools or implant instruments shall be used at all times. These tools shall be constructed so as to provide the maximum handling distance compatible with effective manipulation. All operators shall have adequate training, e.g. with dummy sources, in these manipulative procedures. Whenever practicable, remote means of manipulation, which ensure adequate protection of the staff, shall be used.

(64) The transport of sources shall be carried out in such a manner that all individuals are adequately protected. Where the total activity is low, sources may be transported by hand in a long-handled container. While being used for the transport of sources such containers shall be distinguished by suitable markings and shall either be under surveillance or be inaccessible to unauthorized persons. The intended use (nuclides, maximum activities) shall be marked on the transport containers.

(65) An encapsulated source intended for the utilization of β radiation requires a thin window. This window and its mounting shall be so constructed as to minimize the risk of leakage of radioactive material, and when not in use shall be covered by a shield of sufficient thickness to absorb all the β radiation. When the window is being cleaned, or the source tested for leakage, care shall be taken to avoid damaging the window.

(66) It should be recognized that all β-ray sources will emit bremsstrahlung and may emit other types of penetrating radiation such as γ rays, annihilation radiation and characteristic x rays. Possible exposures from such radiations shall be evaluated and the necessary precautions taken. Although the production of bremsstrahlung may be minimized by absorbing the beta rays with a material of low atomic number, the bremsstrahlung may still be excessive. In such cases it may be necessary to provide an outer shield of high atomic number to attenuate the bremsstrahlung. It is therefore usually advantageous to make the whole shield of a material of high atomic number since its attenuation properties will outweigh the increased bremsstrahlung production.

MEDICAL USES OF RADIATION

General recommendations

(67) The recommendations in this section on the medical uses of radiation are primarily intended for the protection of persons operating or using radiation sources. However, many of the recommendations on equipment also provide for the protection of the patient; these paragraphs have been marked with an asterisk. The subject of the protection of the patient is dealt with more comprehensively in a special subsection (paragraphs 150–194) which contains further recommendations on operational procedures.

(68)* When more than one tube can be operated from a single control panel, there shall be indication at or near the tube housing and on the control panel showing which tube is connected.

(69)* Field defining cones and applicators shall be clearly marked with the appropriate field size and other relevant data.

(70)* A device shall be provided which will automatically terminate the exposure after a pre-set time or exposure has elapsed (see also paragraphs 93, 104 and 128). The proper functioning of timers is of particular importance and special attention should be given to those components which may wear out or become detached and, in consequence, cause malfunctioning of the timer.

(71)* The patient shall be observable from the control position. Means should be provided for communication with the patient.

(72)* The simultaneous examination or treatment of more than one patient in the same room may introduce unnecessary and not easily controllable hazards for both personnel and patients and should not take place. Wherever such arrangements are necessary, adequate protection shall be ensured for all persons involved.

Diagnostic installations

(73) All the appropriate provisions of the general recommendations (paragraphs 20–72) shall apply.

(74) The following paragraphs are mainly related to x-ray diagnostic procedures. Diagnostic uses of radioactive substances are referred to only in paragraph 119, since the radiation exposure from such uses is mainly internal exposure. With regard to the latter the reader is referred to the relevant ICRP publications (refs. 2, 5 and 10).

X-ray diagnostic installations

(75)* Every x-ray tube used for diagnostic purposes shall be enclosed in a housing such that the exposure from the leakage radiation measured at a distance of one metre from the focus does not exceed 100 mR in one hour at every rating specified by the manufacturer for that tube in that housing. (For the areas over which these measurements shall be made, see paragraph 40.)

(76)* Means (control settings or meters) at the control panel shall be provided to indicate tube potential and current when these can be varied.

(77)* Diaphragms, cones or collimators shall be used to limit the useful beam to the area of clinical interest and shall be so constructed that, in combination with the tube housing, they comply with the exposure requirements for leakage radiation as given in paragraph 75. A light-beam localizer for indicating the cross-section of the useful beam should be used. The use of a "multi-plane" type collimator will usually result in a reduced integral dose to the patient, and less scattered radiation.

(78)* The minimum permanent total filtration† in the useful beam shall be determined by the maximum voltage specified for the tube in its housing. The permanent total filtration for normal diagnostic work—including dental radiography—shall be equivalent to not less than:

1.5 mm Al at voltages up to and including 70 kV;
2.0 mm Al at voltages above 70 kV up to and including 100 kV;
2.5 mm Al at voltages above 100 kV.

Exception: In some special procedures at operating potentials below 50 kV (e.g. mammography), the minimum total permanent filtration shall be equivalent to at least 0.5 mm Al. (See paragraph 180 for filtration with direct fluoroscopy of the chest.)

(79)* The total filtration permanently in the useful beam as specified in paragraph 78 shall be indicated on the tube housing.

(80)* Some special radiographic procedures (e.g. mammography) require very soft radiation. Such procedures should be carried out on special equipment and not on standard x-ray equipment intended for higher potentials. Under no circumstances shall the total permanent filtration be equivalent to less than 0.5 mm Al. Where special equipment is not employed, means shall be provided which ensure that the tube is not used at higher potentials with inadequate filtration (see paragraph 78).

(81)* Various types of timers are required for fluoroscopic and radiographic work (see also paragraphs 93 and 104). The proper functioning of timers is of particular importance and special attention should be given to those components which may wear out or become detached and, in consequence, cause malfunctioning of the timer.

(82) No person shall remain in an x-ray room when radiological procedures are being carried out, unless his presence is essential.

(83) Persons who work within the x-ray department should not hold patients during diagnostic examinations. Motion-restricting devices shall be used as much as possible and cassettes shall never be hand-held during exposure. When children or other individuals must be held during an examination this should either be done by staff members of other departments or by parents or other persons accompanying them. If it is necessary to ask such staff members to hold patients,

† In actual practice, additional filtration is often appropriate; suggestions on suitable combinations of operating potentials and filtrations are given in the special report on the Protection of the Patient in X-ray Diagnosis (ref. 15).

a rotation system should be employed, subject to the applicable maximum permissible doses. No pregnant women or persons under the age of 18 years shall be permitted to hold patients. Those holding the patients shall wear protective aprons and gloves (see paragraphs 98 and 99) and should ensure as far as practicable that no part of their body, even if covered by protective clothing, is in the path of the beam.

(84)* Attention is drawn to the special problems associated with the use of x-ray diagnostic equipment in surgery. In this connection, particular attention is drawn to paragraph 20:108. The x-ray equipment and protective devices used should be such that they are not unnecessarily obstructive to the work of the surgeon or members of his staff; however, adequate protection shall be provided. Image intensifiers should be used for all surgical procedures requiring fluoroscopy.

(85)* Mobile equipment (i.e. equipment not used routinely at one location) should only be employed when it is impractical to move the patient to a fixed installation.

Fluoroscopy

(86)* An adjustable collimator or diaphragm shall be provided to define the useful beam.

(87) The x-ray tube, collimating device and fluoroscopic screen or image intensifier shall be linked together in such a way that, under normal operating conditions, the beam will not fall outside the screen irrespective of the source–screen distance. The so-called "hand fluoroscope" or "head fluoroscope" shall not be used.

(88) The fluorescent screen shall be covered with a protective glass sheet having a lead equivalent of not less than:

1.5 mm for apparatus having a maximum operating potential up to and including 70 kV;

2.0 mm for apparatus having a maximum operating potential above 70 kV up to and including 100 kV;

an additional 0·01 mm per kV above 100 kV.

Image intensifiers and adjacent mounting parts subject to useful beam exposure shall provide the same protection as that required for a conventional fluoroscopic screen assembly.

(89) If the equipment permits spotfilms to be taken in connection with the fluoroscopic examination, the beam should be intercepted by a barrier having a lead equivalent as specified in paragraph 88, with the maximum operating potential being equal to the highest potential at which such radiographic exposures can be made.

(90)* Under the conditions that obtain in direct fluoroscopy, screen definition is not a limiting factor in the perception of the image and therefore high sensitivity screens should be used (ref. 15). Old screens which are found to be much less sensitive than new ones should be replaced. The protective glass should be replaced if its optical density has increased significantly due to discoloration.

(91)* Recommended values for minimum distances between focus and patient are given in paragraph 92. The design of the equipment shall be such as to ensure that these distances cannot be less than those specified. In the case of mobile equipment, cones, diaphragms or spacer frames shall be provided to achieve this result.

(92)* In radiography and fluoroscopy with *mobile* equipment, the focus–skin distance shall not be less than 30 cm. In radiography and fluoroscopy (other than of the chest) with *stationary* equipment, the focus–skin distance shall not be less than 30 cm and should not be less than 45 cm. In fluoroscopy of the chest the focus–skin distance should not be less than 60 cm (see also paragraph 180) and, for equipment specifically and not only occasionally used for chest examinations, shall not be less than 45 cm. Photofluorography and radiography of the chest shall be performed with a focus–skin distance of at least 60 cm.†

(93)* The device referred to in paragraph 70 shall be supplemented with means for providing the fluoroscopist with an audible signal. The maximum setting of the device terminating the exposure shall not exceed 10 minutes; the setting of the audible signal shall be adjustable within the overall time.

(94)* The fluoroscopic exposure switch

† The recommended values are minimum values, and larger distances are often appropriate; e.g. in radiographic examinations of the chest. See also the special report on the Protection of the Patient in X-ray Diagnosis (ref. 15).