Office of the Prime Minister
and
First Lord of the Treasury (Atomic Energy)
Ministry of Health
Department of Health for Scotland
Ministry of Health and Local Government
for Northern Ireland

Code of Practice for the Protection of Persons exposed to Ionizing Radiations

LONDON
HER MAJESTY'S STATIONERY OFFICE

EIGHT SHILLINGS NET

THE PATENT 'LOXON' LOOSE-LEAF BINDER

Patent No. 700547
Prov. Patent No. 22808/55

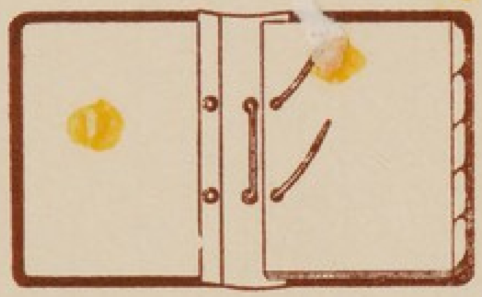
OXFORD SERIES

LIST OF STANDARD SIZES

Ref. No.	Size of leaf
51	8 x 6½
52	9 x 7
53	10 x 8
55	13 x 8

Reference and Quality

W.T. 16582/57

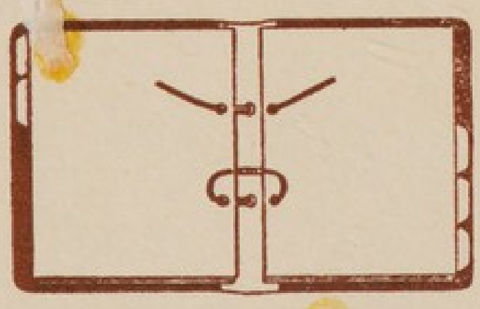


HOW TO USE

To add leaves to the front, merely disconnect the tags and withdraw laces from the flange.

To insert or withdraw leaves at any point without the leaves being freed from the control of the laces at any time:—

Unhitch the laces from the spiral springs, unthread the laces from the flange and join together the two ends of each lace thus forming two separate loops.



Draw the tags through to the required place, disconnect, insert or remove sheets.

Always have the laces free from the springs when the book is in use.

...TD., OXFORD

Office of the Prime Minister and First Lord of the Treasury (Atomic Energy)
Ministry of Health
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Code of Practice for the Protection of Persons exposed to Ionizing Radiations

PART A:
Use of X-rays for diagnosis;
use of X-rays and γ-ray beam units for therapy.

PART B:
Use of radioactive isotopes.

SUPPLEMENT:
Protection against ionizing radiations—
fundamental data.

LONDON
HER MAJESTY'S STATIONERY OFFICE
1957

Preface

This Code of Practice, which has been prepared by the Standing Advisory Committee set up to advise Ministers under the Radioactive Substances Act, is intended primarily for the protection of persons exposed to ionizing radiations in hospitals in the National Health Service. Detailed specifications about installations and techniques have been avoided, since it is felt that these would involve serious limitations on radiological work. It is considered better that certain rules of protection should be laid down, together with the relevant medical, scientific and technical information for the guidance of the staff concerned. This Code will be reviewed from time to time in the light of new knowledge.

Members of Radioactive Substances Standing Advisory Committee responsible for the preparation of the Code of Practice

Sir Charles Darwin (Chairman)
Dr. E. A. Birse
Dr. C. P. Black
Professor G. R. Cameron
Sir Ernest Rock Carling
Sir John Cockcroft
Professor K. G. Emeleus
Professor N. Feather
Dr. L. H. Gray
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Professor B. W. Windeyer
Mr. W. Binks } Secretaries
Mr. L. H. Brandes }

CODE OF PRACTICE

PART A

Use of X-rays for diagnosis; use of X-rays and γ-ray beam units for therapy

PART A

Use of X-rays in diagnosis; use of X-rays and γ-ray beam units for therapy

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Contents

1. Introduction

Part A of this Code of Practice gives the protection rules, applicable to the use of X-rays for diagnostic purposes and to the use of X-rays or γ-ray beam units for therapeutic purposes. (Part B of the Code deals with therapeutic uses of radioactive isotopes, either sealed or unsealed. The sealed sources include radium, radon or cobalt in needles, tubes or applicators used for purposes other than γ-ray beam therapy.)

The fundamental scientific information, together with technical details concerning the design of departments in accordance with the rules of the Code, is given in the Supplement headed "Protection against Ionizing Radiations—Fundamental Data." Definitions of the terms used in this Code appear in Appendix I of the Supplement.

The word "must" is used in clauses involving essential requirements; the word "should" indicates a desirable requirement.

2. General Rules

2.1. The officer in charge of a department in which ionizing radiations are used is responsible for the working conditions of personnel and for the instruction of new personnel in safe working practices for dealing with ionizing radiations and in the nature of the effects due to over-exposure. The officer is responsible for the radiation levels in rooms adjacent to, and above, and below, those in which ionizing radiations are used; also for non-radiological staff who enter the rooms containing radiological equipment, for such purposes as cleaning. A member of the radiological staff should be designated as Safety Officer who would be responsible for radiological protection measures in the department.

2.2. Every employee is required to read the sections of this Code of Practice which affect his work and well-being. He must also read any additional rules which the officer in charge may promulgate, and must then sign a statement that he has understood these sections and rules. The officer in charge of the department is responsible for the safe keeping of such statements.

3. Radiation Surveys of Departments[1]

3.1. A radiation survey of any new or modified department must be made by a qualified expert[2]. (A "modification" in this sense means that the radiation output of the X-ray or γ-ray equipment has increased beyond the level for which the original protection was designed, or that the position of the radiation source or the direction of the beam has been changed.)

3.2. A radiation survey of an establishment does not necessarily involve the personal attendance of the expert to carry out radiation measurements on the site. The survey could be effected by placing, at the sites concerned, ionization chambers or film badges provided by the expert, such radiation detectors being returned, after exposure, to the expert so that the doses received can be assessed. In the case of departments where radium is used and, accordingly, where radon gas might be present in the atmosphere, air samples could be taken and forwarded to the expert for assay.

3.3. If a radiation survey indicates that personnel will receive doses in excess of the permissible amounts, the expert should determine the cause (e.g. defective equipment or inadequate protection afforded by screens or walls) and should indicate the measures to be adopted to rectify the situation.

4. Personnel Tests

4.1. Persons under the age of 16 must not be employed in work involving occupational exposure to ionizing radiations.

4.2. All new personnel employed in such work should be subjected to a pre-employment general medical examination, which should include a blood examination. The results of such an examination should determine the acceptance or refusal of the potential employee. Enquiries should be made into previous radiological exposure.

[1] In setting up a new department, the attention of the architect should be drawn to the necessity for the protection of rooms. Detailed information on protection measures is given in the Appendix to this part of the Code and in the Supplement.

[2] See Definition of Terms (Section 8 of the Supplement). The Radiological Protection Service, Clifton Avenue, Belmont, Sutton, Surrey, is available to advise on radiation protection measures.

4.3. The amount of ionizing radiation received by personnel employed in these departments should be systematically checked[1] to ensure that the maximum permissible doses and the permissible cumulative doses[2] for the various types of external radiation involved are not exceeded. For the purpose, ionization chambers or film badges should be carried on the person. No single test should extend beyond a period of four weeks.

The monitcring should be continuous and a personal cumulative record should be kept of the doses of radiation received, not only occupationally but also from all other sources such as personal examination by means of diagnostic radiology.

4.4. Provided that radiation monitoring (both site monitoring and personnel monitoring) is carried out in all circumstances involving occupational exposure to penetrating ionizing radiations, then:

(*a*) routine blood counts are unnecessary in the case of workers who receive average doses not exceeding one-half of the maximum permissible weekly level averaged over a period of three months; and

(*b*) routine blood counts are desirable in the case of workers who receive average doses exceeding one-half of the maximum permissible weekly level averaged over a period of three months. The blood counts should be carried out periodically, at intervals of not longer than three months.

These rules are a simplification of those recommended by the International Commission on Radiological Protection.

4.5. If personnel tests indicate that doses in excess of the permissible levels are being received, an inspection of the department should be made by a qualified expert to determine the cause (e.g. defective equipment, inadequate protection afforded by screens or walls, wrong technique, or insufficient staff). The expert should indicate the measures to be adopted to rectify the situation.

4.6. In the case of staff in rooms adjacent to, and above, and below, X-ray and γ-ray rooms, personnel monitoring and medical examination are not necessary, if the weekly dose can never exceed one-tenth of the maximum permissible weekly dose for those occupationally exposed.

[1] Personnel monitoring tests will be undertaken by hospital physicists associated with major hospitals or by the Radiological Protection Service.

[2] See Section 6 of the Supplement.

5. Protection in X-Ray Diagnostic Departments

5.1. The operator must never stand in the useful beam.

5.2. In the case of diagnostic X-ray tubes, the radiation proceeding through the tube housing in any direction outside the useful beam must not exceed 100 mr/hour at a distance of 1 metre from the X-ray source, when the tube is operating continuously at its maximum rated current for the maximum rated voltage.

The lead equivalent of the protection which the tube housing should afford can be calculated from the data supplied in the Supplement.

5.3. All fluoroscopic examinations should be conducted as rapidly as possible with minimum dose-rates and apertures. As an additional precaution, it is recommended that the circuit on the primary side of the equipment used for fluoroscopy should incorporate a limiting device to guard against excessive tube currents during screening examinations. Alternatively, if a "high-low" milliamperage switch is provided, the low current should be used to locate the site of interest and the high current to explore the area quickly.

Before fluoroscopic examinations are undertaken, the eyes should be completely dark adapted. Unless preliminary adaptation has been effected by wearing suitable goggles, the adaptation period should be not less than 10 minutes.

Palpation with the hand should be reduced to a minimum.

Protective clothing, e.g. gloves and body aprons (A.5.8.), should be worn during all types of fluoroscopic examinations in which the nature of the work is such that excessive doses may be received.

Mobile equipment should only be used for fluoroscopic examinations if it incorporates adequate protection for the operator against both useful and scattered radiation. For mobile X-ray equipment operating at voltages up to 100 kV, the minimum target-skin distance should be 12 inches. The operator should stand as far away as possible from the tube and patient during exposure.

5.4. The protective enclosure of the X-ray tube used for fluoroscopic examinations should be provided with an adjustable diaphragm system of the rectangular type and of such a design as will permit it to be completely closed. To prevent the lateral escape of direct radiation the diaphragm system should be fitted within a protective enclosure.

The material of the diaphragm must have a lead equivalent adequate to reduce the transmitted direct radiation to the permissible level for the minimum distance between diaphragm and radiologist. (See the Supplement.)

5.5. The tube diaphragm and fluorescent screen must be mounted on a common support, to ensure that they will always move together. If it is essential for the tube and screen to move separately (as, for example, for orthodiagraphic purposes), an additional protective shield should be provided to protect personnel against any part of the useful beam passing the fluorescent screen.

The diaphragm aperture must be limited, preferably by automatic means, in order that the useful beam cannot overlap the full screen area for any tube-screen distance.

A permanent total filter, including the thickness of the glass, equivalent to at least 2 mm aluminium, should be provided for radiographic and fluoroscopic work.

5.6. The lead glass of fluorescent screens must be of sufficient thickness to reduce to the permissible level the radiation which penetrates it. The lead equivalent must be at least 2 mm at 100 kV peak, an additional lead equivalent of 0·01 mm per kV being required above 100 kV peak.

5.7. All couches and stands for fluoroscopy must be provided with an adequate arrangement for protecting the operator against scattered radiation from the patient. This may take the form of an "apron" which should be not less than 18 inches wide and 18 inches long and should be made of protective material having a lead equivalent of not less than 0·5 mm. It should be attached to the lower edge of the screen holder when the latter is vertical and to the side when the screen is horizontal. Alternatively, a separate protective apron or fixed shield may be attached to the side rail of a couch for use when the screen is horizontal.

A radiographer who stands near the radiologist during vertical screening operations should ensure that he takes up a position behind the radiologist, so that he, too, is protected by the lead glass of the screen and by the apron suspended from it, and is not exposed to scattered radiation from the patient.

Often, when assisting in barium enema examinations of patients undergoing horizontal screening, a radiographer may take up a position on the opposite side of the couch to the radiologist. Under these circumstances it is essential for the radiographer to wear a protective body apron (see next paragraph).

5.8. Protective gloves, which are suitably lined with fabric or other material, must have a protective value, throughout both front and back (including fingers and wrist), of not less than 0·25 mm lead, for X-rays excited at voltages up to 100 kV.

Protective body aprons must have a minimum lead equivalent of 0·25 mm for X-rays excited at voltages up to 100 kV.

Protective gloves designed for work in operating theatres or for work with patients who are bleeding or vomiting or who have infectious diseases must be washable both inside and out.

Protective gloves and aprons should be examined periodically to ensure that the protection afforded has not been impaired due to the development of cracks in the material. Gloves should not be covered with leather as this hides any cracks which might have developed. It may at times be advisable to radiograph the gloves and aprons in order to reveal the presence of defects. Such tests should be carried out by the staff of the department. (See British Standard 2606: 1955.)

5.9. Appropriate protection against the useful beam or secondary radiation must be provided for personnel in rooms adjacent to a radiographic room. The necessary protection can be assessed from data given in the Supplement.

When a room is used solely for fluoroscopic work, protection against the useful beam will already have been provided by the lead glass of the fluorescent screen. Accordingly, only secondary radiation is involved. Where necessary, the floor, ceiling or walls of the fluoroscopic room must protect personnel in adjacent rooms against this radiation. For a tube operating up to 100 kV peak and 5 mA and for a person in an adjacent room not nearer than 2 metres to the tube, the protection required should have a lead equivalent of at least 0·5 mm. The protection required for other operating conditions can be assessed from the data given in the Supplement.

5.10. During radiography and fluoroscopy, the control panel should be situated as far from the patient as is conveniently possible. If the maximum distance possible between patient and operator is not sufficient to ensure that the maximum and average weekly doses of radiation received by the operator are less than the permissible values, a screen having a minimum lead equivalent of 1 mm should be provided.

5.11. Members of the staff of a radiological department should not support children or weak patients during fluoroscopy and radiography.

Children who are patients should be held by their parents or other adults who accompany them. Such persons should be provided with protective clothing and be so positioned as to avoid the useful beam.

6. Protection in X-Ray Therapeutic Departments

6.1. The operator must never stand in the useful beam.

6.2. In the case of therapeutic X-ray tubes, the permissible radiation proceeding through the tube housing in any direction outside the useful beam is dependent upon the conditions of operation.

(*a*) The operator must always be outside the X-ray room during actual treatment at voltages above 100 kV. When setting up procedures involve the presence of an operator in the treatment room whilst the X-ray tube is energized but the shutter closed, the tube housing must be either of the "fully-protective" or of the "highly-protective" type (see Appendix I of the Supplement). The type of tube housing should be indicated on the surface of the housing itself.

(*b*) For treatment at voltages below 100 kV it may be permissible for the operator to remain in the room, provided adequate protection is afforded by means of a screen or screens.

In assessing the required protection in cases (*a*) and (*b*) reference should be made to the Supplement.

6.3. During actual treatment of patients, at voltages above 100 kV, personnel must be stationed outside the X-ray room behind a protective wall, the lead equivalent of which will depend on the circumstances (see Supplement). If the useful beam is directed away from areas occupied by personnel, as is recommended in 8.3, intervening barriers need afford protection against scattered radiation only. Full protection must, however, be provided in all those directions in which the useful beam can operate dangerously.

Observation windows should have the same protective values as those of the surrounding wall.

There should be some means of communication between patient and control room.

6.4. The therapeutic room should be provided with a door or other effective barrier having an interlocking switch so that, when the door is opened, the X-ray equipment is switched off or the tube shutter is closed. When the door is closed again, it should not be possible to re-excite the X-ray equipment except at the control panel.

6.5. Apertures and cones serving to limit the useful beam must be so protected that the dose-rate of the emergent beam, outside the useful beam, should not exceed 1 r per minute wherever measured.

6.6 All filters should have their thicknesses marked upon them as well as the self-filtration of the tube itself, so that there can be no confusion between added filtration and total filtration.

For safety there must be an adequate filter-indicating system installed to permit easy recognition of the thickness and material of the filter inserted in the useful beam, and to avoid omission of a filter during treatment. There should also be an indicator to show whether the shutter is closed.

The filters must be held firmly in place to prevent them from dropping out during treatment.

6.7. During treatment, the dose-rate of the useful beam should be ascertained,

(*a*) by means of a calibrated ionization chamber used at each treatment, or

(*b*) by reference to calibration charts which give the dose-rates at specified kilovoltages, tube currents, filters, sizes of applicator and focus-skin distances; the charts should be frequently checked against an ionization chamber.

It is recommended that an ionization chamber should be built into the aperture of the X-ray tube to indicate any error due to incorrect kilovoltage, tube current or filtration.

Direct-reading kilovoltmeters are an advantage.

7. Protection for γ-Ray Beam Units in Therapeutic Departments

7.1. Persons who deal with sealed sources of β- and γ-rays from radioisotopes require protection against the effects of the easily absorbed β-rays on exposed parts of the body (for example, hands, face, eyes), and of penetrating γ-rays on external and internal tissues. Since faulty radium containers may permit the leakage of radon, care should be taken to avoid inhalation of the gas which would expose the lungs to α-, β- and γ-rays.

7.2. The risks to the operator attendant on the use of quantities of radium or cobalt in beam therapy may be largely obviated if some system of remote control is adopted by which the radioactive sources are introduced into, or rotated within, the beam unit after the latter has been adjusted in position on the patient. If such arrangements are not available, the importance of expeditious handling cannot be over-emphasized.

Rooms used for γ-ray beam therapy should provide adequate protection for adjacent wards and rooms which are occupied.

7.3. Radium containers in γ-ray beam units should be tested periodically for leakage of radon.

A record should be kept in the establishment of the results of such leakage tests. If it is found that a container is leaking it must be sealed immediately in an airtight container, and arrangements made for its repair.

If a safe houses radium containers, it should be ventilated mechanically to the outside air. The fan should be operated for not less than two minutes before the safe is opened.

8. Appendix

Protection Measures in Designing New or Modified Departments

8.1. In the case of X-ray or γ-ray installations, protection at various sites can be achieved either by distance from the source or by shields or walls which absorb the radiation. Where the cost of protective shields or walls becomes an important consideration, as with high-voltage X-ray equipment, the siting of the installation relative to other occupied areas may permit economies to be made.

8.2. Calculations of the protection required against useful beams of ionizing radiations, used for diagnostic or treatment purposes, should be based on the assumption that there is no patient in the beam. Calculations of the protection required against secondary radiation should take into account radiation scattered from the patient. The thicknesses of protective materials required under various circumstances can be calculated from the data supplied in the Supplement.

8.3. Wherever possible, the useful beam of ionizing radiation should be directed away from an observation window or from walls, floors or ceilings of rooms which are occupied by personnel and are adjacent to, and above, and below, the equipment room. (Mechanical restrictions on the angulation of the equipment afford a safeguard.) If the protection in the directions mentioned has been reduced below that required to afford adequate protection against the useful beam, on the understanding that the latter will not point in these directions, a notice to this effect should be prominently displayed in the department.

8.4. In assessing the amount of protection required at various sites in a department, the possibility of multiple exposure from several sources of ionizing radiation (for example, from a number of X-ray tubes or γ-ray sources) should not be overlooked.

8.5. Care must be taken to ensure that the protection afforded by screens or walls is not reduced at joints, at fixing nails or bolts, or at holes which are necessary for pipes, louvres, etc. In such regions, an overlapping of the protective material should be provided.

8.6. All occupied rooms (including photographic dark rooms) in departments should be provided with adequate ventilation.

8.7. All rooms should be large enough to permit a convenient lay-out of the equipment. This is particularly important in X-ray diagnostic departments, where several units may be installed and where, therefore, it is necessary to ensure adequate separation of the control panel from all the possible sources of scattered radiation.

8.8. All X-ray equipment must be shock-proof.

8.9. In the case of irradiated space, some form of warning may be provided to indicate the existence of a radiation hazard. The warning may take the form of a lamp which automatically lights up when an X-ray tube is excited or it may be a notice of a type indicating radiation hazard.

8.10. When beams of X-rays or γ-rays are to be used, the thicknesses and specifications of all protective shields, walls, doors or observation windows and the positions of all pipes, ordinary windows and ventilation louvres should be indicated on the plans.

CODE OF PRACTICE

PART B

Use of radioactive isotopes

PART B

Use of radioactive isotopes

Contents

1. Introduction

Part B of this Code of Practice gives the protection rules applicable to the therapeutic, diagnostic, or "tracer", uses of radioactive isotopes, either sealed or unsealed. The sealed sources include radium, radon or cobalt in needles, tubes or applicators, used for purposes other than γ-ray beam therapy. (Part A of the Code deals with the use of X-rays for diagnostic purposes, and with the use of X-rays or γ-ray beam units for therapeutic purposes.)

The fundamental scientific information, together with technical details concerning the design of departments in accordance with the rules of the Code, is given in the Supplement headed "Protection against Ionizing Radiations—Fundamental Data". Definitions of the terms used in this Code appear in Appendix I of the Supplement.

The word "must" is used in the Code in clauses involving essential requirements; the word "should" indicates a desirable requirement.

2. General Rules

2.1. The officer in charge of a department in which ionizing radiations are used is responsible for the working conditions of personnel and for the instruction of new personnel in safe working practices for dealing with ionizing radiations and in the nature of the effects due to over-exposure. The officer is responsible for the radiation levels in rooms adjacent to, and above, and below, those in which ionizing radiations are used; also for non-radiological staff who enter the rooms containing radiological equipment, for such purposes as cleaning.

A member of the radiological staff should be designated as Safety Officer who would be responsible for radiological protection measures in the department and for the safe disposal of wastes.

2.2. Every employee must read the sections of this Code which affect his work and well-being. He must also read any additional rules which the officer in charge may promulgate, and must then sign a statement that he has understood these sections and rules. The officer in charge of the department should be responsible for the safe keeping of such statements.

3. Radiation Surveys of Departments[1]

3.1. A radiation survey of any new or modified department must be made by a qualified expert.[2] It should be appreciated, however, that for the types of work covered by this section of the Code protection is as much a matter of procedure as of design and it is one of the responsibilities of the Safety Officer to ensure that all such procedures are safe. (A "modification" in this sense means that the amounts and/or types of radioactive materials have been increased from those for which the original protection was designed or that the positions of the radiation sources have been changed.)

3.2. As regards external β- and γ-radiation, the survey may be effected by placing, at the sites concerned, ionization chambers, Geiger counters or film badges, so that the doses received can be assessed. Where unsealed radioisotopes are used, environmental surveys with specially-designed equipment may be necessary, if the quantities of radioactive material used can be hazardous, and if there are indications of a hazard.

Some of these surveys do not necessarily involve the personal attendance of the expert to carry out radiation measurements on the site. Thus ionization chambers or film badges could be provided by the expert, such radiation detectors being returned, after exposure, to the expert for the assessment of the doses received.

3.3. If a radiation survey indicates that personnel will receive doses in excess of the permissible amounts, the expert should determine the cause and should indicate the measures to be adopted to rectify the situation.

4. Personnel Tests

4.1. Persons under the age of 16 must not be employed in work involving occupational exposure to radioactive materials.

4.2. All new personnel employed in such work should be subjected to a pre-employment general medical examination, which should include a blood exami-

[1] In setting up a new department, the attention of the architect should be drawn to the necessity for the protection of rooms. Detailed information on protection measures is given in the Appendix to this part of the Code and in the Supplement.

[2] See Definition of Terms (Section 8 of the Supplement). The Radiological Protection Service, Clifton Avenue, Belmont, Sutton, Surrey, is available to advise on radiation protection measures.

nation. The results of such an examination should determine the acceptance or refusal of the potential employee. Enquiries should be made into previous radiological exposure.

4.3. The amount of ionizing radiation received by personnel employed in these departments should be systematically checked[1] to ensure that the maximum permissible doses and the permissible cumulative doses[2] for the various types of external radiation involved are not exceeded. For the purpose, suitable ionization chambers or film badges should be carried on the person. No single test should extend beyond a period of four weeks.

The monitoring should be continuous and a personal cumulative record kept of the doses of radiation received, not only occupationally but also from all other sources such as personal examination by means of diagnostic radiology.

For β-sources of activity greater than 1 mc, β-irradiation of the hands may be the significant factor. The degree of exposure should be controlled by careful planning of the experimental procedures and, if necessary, by making personnel wear wrist or finger films which are sensitive to β-rays.

For workers who deal with unsealed radioactive isotopes, tests may have to be carried out from time to time to determine the total body burden. In many cases, monitoring of the excreta (more particularly, of the urine, or in the case of radium, of the radon in the breath) will permit an assessment of the body burden. In certain circumstances a more elaborate test can be adopted to confirm the body burden, through measurements of the γ-rays or bremsstrahlung emitted by the body.

Workers who deal with unsealed isotopes which may give rise to levels of ingestion or inhalation in excess of the maximum permissible levels for an appreciable fraction of the working week should be subjected periodically to urine monitoring or other suitable tests.

In the case of workers for whom urine monitoring or other tests indicate that there is a measurable quantity of radioactive material in the body, the dose of radiation delivered to the appropriate body organ by this material should be calculated and noted on the personal record. In addition, the permitted doses of external radiation should be adjusted to allow for the "internal" dose.

4.4. Provided that radiation monitoring (both site monitoring and personnel monitoring) is carried out in all circumstances involving occupational exposure to penetrating ionizing radiation, then :

[1] Personnel monitoring tests for external radiation will be undertaken by hospital physicists associated with major hospitals or by the Radiological Protection Service.

[2] See Section 6 of the Supplement.

(*a*) routine blood counts are unnecessary in the case of workers who receive average doses not exceeding one-half of the maximum permissible weekly level averaged over a period of three months, and

(*b*) routine blood counts are desirable in the case of workers who receive average doses exceeding one-half of the maximum permissible weekly level averaged over a period of three months. The blood counts should be carried out periodically at intervals not longer than three months.

These rules are a simplification of those recommended by the International Commission on Radiological Protection.

It should, however, be noted that blood counts may be desirable where a person has assimilated a significant amount of an internally-deposited isotope.

4.5. If personnel tests indicate that doses in excess of the permissible levels are being received, an inspection of the department should be made by a qualified expert to determine the cause (e.g. defective equipment, inadequate protection afforded by screens or walls, wrong technique, or insufficient staff). The expert should indicate the measures to be adopted to rectify the situation.

4.6. In the case of staff in rooms adjacent to, and above, and below, those in which radioactive isotopes are used, personnel monitoring and medical examination are not necessary, if the exposure levels can never exceed one-tenth of the maximum permissible external and internal radiation levels for those occupationally exposed.

5. Protection in Radioisotope Departments

5.1. *Hazards from sealed sources*

(For example, radium, radon and cobalt needles and tubes; radium and Sr–90 β-ray plaques.)

5.1.1. Persons who deal with sealed sources of β- and γ-rays from radioisotopes require protection against the effects of the easily absorbed β-rays on exposed parts of the body (for example, hands, face and eyes), of the penetrating γ-rays on external and internal tissues, and, if radium containers permit the leakage of radon, of α-, β- and γ-rays on the lungs, due to inhalation of the gas.

5.1.2. In order to protect the hands from β-rays, reliance should be placed, primarily, on distance. All manipulations should be effected with long-handled forceps and should be carried out as quickly as possible.

In order to prevent the head from being placed too near the radioactive source, and to protect the eyes and face from β-rays, a transparent plate of adequate thickness should be mounted between the source and the face of the operator.

5.1.3. In order to protect the body from the γ-rays when handling intense γ-emitters such as radium and cobalt, lead (or equivalent) screens should be provided which are adequate, whatever the size of source (see Figures 6 and 7 and Table XI of the Supplement). For details of transporting radioactive materials within an establishment, see Section 6 of this part of the Code.

5.1.4. A separate room should be provided for the "make-up" of tubes and applicators and this room should only be occupied during such work. The room should be adequately ventilated.

5.1.5. Since, in certain types of work and especially in "making-up" applicators, high doses are possible, often resulting in experienced workers receiving doses up to the maximum permissible level, it has been found of value, in controlling exposures, to operate a rota system of duties.

5.1.6. Radium containers should be tested periodically for leakage of radon, as hazardous quantities of radon may otherwise accumulate in radium safes. A record should be kept in the establishment of the results of such leakage tests. If it is found that a container is leaking, it must be sealed immediately in an airtight container and arrangements made for its repair. (For details of storage, see Section 6 of this part of the Code.)

5.1.7. Dressings from patients receiving treatment with sealed sources of radioactive materials should not be destroyed until all the containers used have been removed from the patient and checked, if necessary, by some ionization measuring equipment.

5.2. *Hazards from unsealed sources*

5.2.1. In manipulating unsealed radioactive isotopes, great care should be exercised to reduce deposition of the isotopes in the body as a result of ingestion, of inhalation or of absorption through intact or damaged surfaces of the body. The hazard will arise, in general, from small amounts of activity on contaminated hands, cigarettes, cosmetics and other items brought to the mouth, or from inhalation of radioactive dust, gas or vapour, from contaminated clothing, rooms, floors, equipment and atmosphere.

When the hazards due to ingestion and inhalation are small, the risks in handling isotopes will depend essentially upon the effects of external

β- and γ-radiation and the appropriate recommendations given under Section 5.1 should be applied.

5.2.2. The values which are given in Appendix II of the Supplement for the maximum permissible body burdens and maximum permissible concentrations, in air and water, of various isotopes at present in use, are only a rough guide to the relative harmfulness of the isotopes when deposited in the body. In practice, the degree of hazard associated with the manipulation of unsealed isotopes will also depend upon the other factors such as the types of compounds in which the isotopes appear, the specific activity (depending on degree of dilution or, in the case of naturally occurring radioactive isotopes, on the half-life), the volatility, the radiochemical laboratory facilities provided, the complexity of the procedures involved, and the relative radiation doses to critical organs and tissues (including the gastro-intestinal tract) when accidental inhalation or ingestion occurs. Where it has been possible, the above factors have been taken into consideration in evolving the broad classification of isotopes, given in Tables I and II according to their degree of hazard.

The three grades of laboratory recommended should meet the following requirements. (For full details of a Grade B laboratory, see Section 9 of this part of the Code.)

Grade C laboratory

For manipulation of small amounts of radioactivity (see Table I) few modifications are needed in any modern conventional chemical laboratory having floors covered with linoleum. Work-benches should be provided with non-absorbent tops or with disposable covers. There should be at least one good fume hood with induced draught. The exhaust air should be carried outside the building but need not be filtered.

All working surfaces, including fume hoods, should be strong enough to carry any necessary shielding against γ-rays.

Grade B laboratory

A high-grade chemical laboratory should be provided for work involving the use of isotopes in quantities of the order shown in Table I below. Greater care in design is necessary to facilitate the control of contamination.

In addition to fume hoods, it may be necessary to use glove boxes, which considerably reduce the hazards from inhalation or ingestion of radioactive materials. It should, however, be appreciated that, in some circumstances, the valuable gain from using glove boxes is offset partly by increased exposure to external radiation resulting from longer handling times, and partly by the tendency for workers to exercise less care in maintaining cleanliness.

Grade A laboratory

For the higher levels of activity, a specially-designed laboratory will be required.

It is unlikely that, at present, there will be the need for a Grade A laboratory for clinical work in hospitals. For diagnostic or therapeutic applications of isotopes, a Grade B or Grade C laboratory will suffice, according to the types and quantities of isotopes to be used.

TABLE I

Grade of laboratory required for various quantities of isotopes of various radio-toxicities

Relative radio-toxicity of isotope	Classification	Grade of laboratory required for unsealed isotopes at rough levels of activity specified below		
		C	B	A
Very high . .	1	$< 10\ \mu c$	$100\ \mu c$ – 1 mc	> 10 mc
High . .	2	$< 100\ \mu c$	1 mc – 10 mc	> 100 mc
Moderate . .	3	< 1 mc	10 mc –100 mc	> 1 c
Slight . .	4	< 10 mc	100 mc – 1 c	> 10 c

Modifying factors to be applied to the above quantities, according to the complexity of the procedures to be followed.

Procedure	*Modifying factor*
Storage (stock solutions)	$\times$ 100
Very simple wet operations . . .	$\times$ 10
Normal chemical operations . . .	$\times$ 1
Complex wet operations with risk of spills .	$\times$ 0·1
Simple dry operations	$\times$ 0·1
Dry and dusty operations	$\times$ 0·01

TABLE II

Classification of isotopes according to relative radio-toxicity per unit amount

(The isotopes in each class are listed in order of increasing atomic number.)

Class 1 (very high toxicity)	Sr–90 + Y–90, *Pb–210 + Bi–210 (Ra D + E), Po–210, At–211, Ra–226 + 55 per cent *daughter products, Ac–227, *U–233, Pu–239, *Am–241, Cm–242.
Class 2 (high toxicity)	Ca–45, *Fe–59, Sr–89, Y–91, Ru–106 + *Rh–106, *I–131, *Ba–140 + La–140, Ce–144 + *Pr–144, Sm–151, *Eu–154, *Tm–170, *Th–234 +*Pa–234, *natural thorium, *natural uranium.
Class 3 (moderate toxicity)	*Na–22, *Na–24, P–32, S–35, Cl–36, *K–42, *Sc–46, Sc–47, *Sc-48, *V–48, *Mn–52, *Mn–54, *Mn–56, Fe–55, *Co–58, *Co–60, Ni–59, *Cu–64, *Zn–65, *Ga–72, *As–74, *As–76, *Br–82, *Rb–86, *Zr–95 + *Nb–95, *Nb–95, *Mo–99, Tc–96, *Rh–105, Pd–103 + Rh–103, *Ag–105, Ag–111, Cd–109 + *Ag–109, *Sn–113, *Te–127, *Te–129, *I–132, Cs–137 + *Ba–137, *La–140, Pr–143, Pm–147, *Ho–166, *Lu–177, *Ta–182, *W–181, *Re–183, *Ir–190, *Ir–192, *Pt–191, *Pt–193, *Au–196, *Au–198, *Au–199, *Tl–200, Tl–202, Tl–204, *Pb–203.
Class 4 (slight toxicity)	H–3, *Be–7, C–14, F–18, *Cr–51, Ge–71, *Tl–201.

* γ-emitters.

5.2.3. *Laboratory facilities*

As far as possible, laboratories should be set aside for radioactive work and should not be used for other purposes. If, in a large laboratory, a section is used for radioactive work, this section should not be used for ordinary chemical work.

Great care should be exercised in segregating laboratories from inactive areas and from counting rooms. For a Grade A laboratory access should, therefore, be made through a special changing room.

Those planning laboratories for therapeutic institutions are advised to consider the general radiation level to which the staffs of the laboratories are likely to be exposed.

5.2.4. *Laboratory techniques*

The techniques adopted should aim, not only at avoiding intake of radioactive materials into the body but also at minimizing the spread of radioactive contamination from the site of operations. Control of contamination, either of personnel or of buildings and equipment, is achieved by scrupulous cleanliness and tidiness, coupled with the planning of procedures which will cause the minimum of dust or spray. New procedures should be approved by the officer in charge and should, when necessary, be tried out by dummy runs, with no, or minimal, radioactivity.

Persons handling active materials should wear protective clothing, should be provided with suitable handling equipment and should adopt special techniques. Details of these are given in Section 9 of this part of the Code.

Smoking is prohibited in Grade A and Grade B laboratories and is undesirable in any active area.

5.2.5. Guidance on decontaminating procedures as applied to personnel, installations, equipment, glassware and clothing is given in Section 9 of this part of the Code.

5.2.6. The primary concern in the event of a spill of radioactive material must be the protection of laboratory personnel from damage. The secondary need is to confine the contamination to the area directly affected. For further details of procedure, see Section 9 of this part of the Code.

5.2.7. As regards patients who are being treated with radioactive isotopes, attention should be paid to the excreta (urine, fæces and, in certain instances, perspiration). Special bedpans should be set aside and should be monitored. Sluices and waste pipes of the wards involved should be checked once per month, to ensure that the background level is below 1 mrad/h (delivered to soft tissue) and that undue activity is not accumulating anywhere in the system due to adsorption.

6. Storage and Movement of Radioactive Materials

6.1. When not in use, radioactive preparations should be stored in an area assigned for this purpose. This should be adequately shielded and secure against tampering. The removal of the preparations from the safe and the period for which they are removed should be controlled by a person made responsible for this.

In the case of γ-emitting isotopes, the safe should be kept as distant from personnel as possible. It should be provided with a number of separate drawers which are individually protected. Data are given in the Supplement which will permit the evaluation of the thickness of lead or concrete required to reduce the γ-rays from radioactive materials to the permissible level at various distances from the sources.

β-ray emitting isotopes should be stored, if possible individually, in containers having walls which will absorb the rays completely. Usually (that is, for β-ray energies up to 2 MeV) 4 to 5 mm of glass, 7 to 8 mm of plastic, 15 to 20 mm of wood, 1·3 mm of iron or 1 mm of lead will suffice. (For further information, see Section 7.3 of the Supplement.)

Protective layers should carry a label specifying the material and thickness. (Because of the toxicity of lead, protective layers of lead should be coated with paint or otherwise covered.)

Where radioactive substances are likely to evolve a radioactive gas or vapour, the safe should be ventilated mechanically to the outside air. The fan should be operated for not less than two minutes before the safe is opened.

Where the storage of unsealed radioactive preparations is concerned, the following procedures should be adopted.

(*a*) Active residues at tracer level should never be stored in Winchesters with glass or screw-on stoppers ; polythene, rubber or cork stoppers should be used.

(*b*) Chemically stable solutions containing radioactive material in excess of 5 millicuries of α-activity, and 50 millicuries of β-activity should always be stored in properly vented containers. This amount of radioactivity may be expected to produce about 1 millilitre per month of gas at N.T.P. from radiation decomposition of water.

(*c*) Thermally unstable solutions containing radioactive material, e.g. nitric acid, or other oxidising solutions containing traces of organic material, peroxides, chlorates, etc., should always be stored in vented containers.

(*d*) Special care should be taken in opening old bottles of radioactive liquors to minimise the danger of bursting or frothing.

(*e*) Highly α-active solutions should not be left in thin glass vessels where the glass is liable to weaken under irradiation. It is not possible to set an activity level at which this becomes serious because the main danger is from dry deposits above the liquid surface. It should be borne in mind at levels of the order of 1 millicurie per millilitre.

(*f*) It is important to keep adequate records of, and to ensure regular inspection of, stored radioactive material.

6.2. In transporting radioactive sources from place to place within an establishment, long-handled boxes, or boxes fitted on trolleys, should be used. If it is desired to stop β-radiation only from penetrating the walls of the boxes, the total protective thicknesses of different materials required are similar to those given in the preceding Section 6.1. For γ-emitting isotopes, the box should have a closed protective lining of lead or other suitable material which will adequately absorb the radiation. The thicknesses required can be estimated from the information given in the Supplement.

7. Protection of Hospital Personnel in Proximity to Patients Undergoing Treatment

7.1. Sisters, nurses and other persons should not remain unnecessarily in a treatment room in which there are patients with more than 50 mg radium or 30 mc Co–60, or equivalent quantities of other gamma-emitting isotopes (see Table X of the Supplement). Where smaller quantities of γ-emitting radioactive materials are being used, the staff should, whenever possible, keep at a distance of at least 3 metres from the sources.

7.2. Beds in which there are patients undergoing treatment with γ-ray emitting sources should carry a notice or symbol indicating the existence of a radiation hazard.

8. Disposal of Radioactive Waste

8.1. Protection rules on the disposal of radioactive waste are under consideration and will be issued as soon as possible.

9. Appendix

Details of design and procedure applicable mainly to Grade B laboratories

9.1. *Laboratory facilities*

9.1.1. *Layout*

As far as possible, active laboratories should be designed and used so as to segregate widely different levels of activity (see Table I). In particular, procedures involving the use of more than about one millicurie of any isotope should be kept away from counting rooms.

In the average hospital laboratory for the therapeutic and diagnostic applications of isotopes, space should be provided for:

(*a*) the manipulation of large quantities of isotopes;
(*b*) the storage of stock radioactive solutions;
(*c*) the assay of isotopes prior to administration to patients, and the measurement of excreta and specimens for radioactivity;
(*d*) the measurement of the up-take of isotopes by patients.

If the types and quantities of isotopes dealt with are large, it may be necessary to have separate rooms in which to carry out the above procedures. Otherwise, (*a*) and (*b*) might be combined, and also (*c*) and (*d*), with (*d*) screened off, if possible.

Washing facilities should be provided in the laboratory. In general, the usual laboratory sinks will suffice, though the taps should be operable by arm, foot or knee, so as not to contaminate them by the hands or gloves. If large quantities of isotopes are being dealt with, it is advisable to provide a shower in case of general body contamination of workers.

The discharge of liquid radioactive waste should be limited to one or two drains.

9.1.2. *Materials*

For most purposes, conventional materials are suitable for active laboratories.

Attention is drawn to the fact that floors may have to support large weights of shielding materials. Floors should have smooth, continuous and non-absorbent surfaces, and should be made of materials that can easily be cleaned and that, preferably, possess a surface which is easily removable. Polished linoleum is a satisfactory floor covering, except where floors have to be hosed, for example, in animal rooms. Floors should be cleaned by wet mopping or by the use of moist compound. Dry sweeping should be avoided.

Walls and ceilings should be finished with a non-porous washable surface, such as a good hard gloss paint. For laboratories to be used for high levels of activity, it may be advantageous to use a strippable paint.

Suitable materials for bench tops are waxed wood, stainless steel, plastic sheets, glass or enamel. The working surface should always be protected by disposable covers of paper, bituminized paper, plastic-coated paper, cellophane or plastic sheets. To minimize the risks from spills, drip trays should always be used.

In some instances, when the shielding of the worker from radiations is effected by a vertical lead screen mounted on top of the bench between the worker and the source, the possibility of radiation penetrating the top of the bench and reaching the lower part of the worker's body should not be overlooked. In such circumstances, the bench top might be made of concrete. Since, however, concrete has a particularly bad surface where the manipulation of isotopes is concerned, it should be painted with a hard gloss paint or otherwise covered with a non-porous surface. (Attention is drawn to the possible need of providing shielding behind and above the bench, in order to protect other personnel who may be involved.)

9.1.3. *Fume hoods*

Adequate fume hood space should be provided. Several small hoods are usually more convenient than one large one. They can be constructed of wood and glass, provided that the former is protected by hard gloss paint. For hoods required for high-activity work a strippable paint, particularly inside the hood, is advocated. The base can be of slate, or linoleum, the choice probably depending upon the type of work to be undertaken.

The exhaust system should be sufficient to produce an air flow of about 100–200 linear feet per minute across the opening of the fume hood, when the window is open to the working position. As fume hoods with air flows as low as this will be sensitive to the movement of air in the laboratory, smoke tests should be carried out to ensure that the draught is adequate under all circumstances (e.g., when there are "down-draughts" or open windows and doors in the laboratory) to prevent radioactive dust and vapours being blown from the fume hood into the air of the laboratory.

At activity levels up to hundreds of millicuries, it is sufficient to discharge the exhaust air through ducting to the outside of the building at a point not immediately adjacent to windows or air intakes. It is not necessary to filter the air at these levels. When considering the design and erection of the exhaust ducting, ease of decontaminating it, as well as minimizing the spread of contamination within buildings during the decontamination of the ducting, should be borne in mind. For example, in the case of a single-storey building, as much as possible of the ducting might be mounted outside the building at a reasonably accessible height. The exhaust fan should be mounted on the outside of the ducting to reduce contamination of the motor and to make it more accessible for maintenance purposes.

At higher levels (Grade A laboratory) the extraction of air from the active area must be specially designed to prevent the movement of activity into inactive areas and measurement rooms.

9.1.4. *Glove boxes*

Glove boxes are sometimes used for dealing with radioactive liquids but are generally employed to prevent inhalation of radioactive dust. They are particularly useful for dry materials of specific activity of the order of 1 mc/g and upwards.

The glove box, which is a closed form of fume and dust hood, is designed to avoid actual contact with radioactive materials and to reduce contamination of the laboratory. The box is fitted with an exhaust fan and operated under slightly reduced pressure. Air-flow out of the box is only necessary to maintain the reduced pressure whilst using a transfer port or when changing gloves. Materials and equipment are introduced into the box through an airlock, and are handled inside the box by inserting the hands and forearms into long rubber gloves fixed permanently into the front of the box.

9.2. *Laboratory techniques and equipment*

9.2.1. *Choice of processes*

The quantity of radioactive material chosen for a specific purpose should always be as small as is practicable. If possible, solutions should be used rather than dry materials.

It is an advantage to work with materials, particularly solutions, of low specific activity. The manipulation processes selected should be those which produce the minimum of dust or spray, and which avoid excessive transfers from one vessel to another.

As radioisotopes are more dangerous if they enter the bloodstream directly, extreme precautions must be taken to avoid cuts or puncture wounds, especially when dealing with the more hazardous isotopes. Equally, no work should be permitted with the more hazardous materials and quantities if there are open wounds below the wrist, whether these are bandaged or not. To reduce the chances of injury, cracked or chipped vessels should not be employed in radiochemical laboratories.

9.2.2. *Equipment*

Special equipment should be provided for dealing with radioisotopes. This should include tongs, forceps, trays and, for the higher levels of γ-activity, apparatus for remote handling. All equipment used for handling radioactive isotopes should be confined to the radioisotope department.

It is necessary to ensure the periodic maintenance of handling equipment and the examination, at frequent intervals, of protective clothing (including gloves and respirators) so that items can be rejected as soon as possible after defects occur.

Containers for active materials should, where possible, incorporate the necessary shielding close to the source. Liquid samples should be kept in double-walled containers, the outer one being unbreakable.

All manipulation should be carried out over a suitable drip tray or with some form of double container which will minimize the importance of breakages and spills.

Pipetting of solutions and operation of wash bottles should never be performed by mouth, but by means of compression bulbs. Alternatively, pipetting can be done by hypodermic syringes. Glass-blowing on contaminated apparatus should be done only using techniques which avoid blowing by mouth.

9.2.3. *Protective clothing*

Laboratory coats or protective gowns used in active areas should not be worn elsewhere. This should apply even at very low levels in order to avoid contamination of other work. Rubber gloves for manipulating radioactive materials should not be used for handling other items, even in the active laboratory. Contaminated gloves should be washed before they are taken off. The method of putting on, and removing, gloves should be based on the surgical technique, so as to avoid transferring activity to the inside surface of the gloves or to the hands.

It should be noted that, whilst gloves may provide adequate protection against soft β-emitters, such as C–14 and S–35, they do not stop hard β-rays. Accordingly, high doses may be received by the skin if strong sources are picked up even with gloved hands. (An average figure for the β-ray dose at 3 mm from 1 μc of free isotope is 3 rad/h delivered to soft tissue.)

9.3. *Decontamination procedures*

9.3.1. *Decontamination of personnel*

Those working with radioisotopes should wash their hands thoroughly with soap and water, before leaving the work area and especially before eating or smoking. Particular attention should be paid to the fingernails. After washing, the hands should be checked with a radiation monitoring instrument. The permissible levels of contamination of the hands and of other parts of the body are given in Table III.

If washing with soap and water fails to reduce the contamination to the required level, a detergent should be tried. If necessary, treatment with a saturated solution of potassium permanganate, followed by decolourization with 5 per cent. sodium bisulphite, may be used. Chemical treatment should not, however, be resorted to vigorously, as the skin becomes porous. Similarly, when using mild abrasives, or even when scrubbing, care should be taken not to injure the skin.

In the case of contamination of other skin areas (or of the hair), soap and water or, if necessary, a detergent, should first be used. Potassium permanganate should not be applied to contaminated hair as there is a risk of causing a semi-permanent change of hair colour.

When high-level contamination of parts of the body other than the hands is suspected, the safety officer or officer in charge of the department should be notified at once. It is a mistake for the subject to have a shower prior to such notification, as contamination from the "hot spot" may spread all over the body. Great care should also be taken, during decontamination of the face, that contaminated liquid does not fall on to the lips or enter the eyes. Equally, if the eye is being irrigated for contamination, it should be ascertained that the adjacent skin is not highly contaminated, as measures must first be taken to prevent such contamination from being irrigated into the eye.

If the skin is accidentally broken when working with radioactive materials, the wound should be irrigated immediately with tap water, the edges of the gash being spread to assist the flushing action of the water and bleeding being encouraged. All wounds of this nature should be reported to the officer in charge as soon as the first-aid measures have been taken, so that steps can be taken to get wounds contamination free.

TABLE III

Permissible levels of contamination

Class of radioactive isotope	SITE	
	Parts of body; personal clothing; hospital bedding; "inactive" areas	Protective clothing; active laboratories; glassware; tools
1. (Very high toxicity)	α-emitters: 10^{-5} μc/cm² β-emitters: 10^{-4} μc/cm²	α-emitters: 10^{-4} μc/cm² β-emitters: 10^{-3} μc/cm²
2. (High toxicity) . . 3. (Moderate toxicity) . 4. (Slight toxicity) . .	10^{-4} μc/cm²	10^{-3} μc/cm²

In close contact with a contaminated surface: 10^{-4} μc/cm² of β-activity gives about 1 mrad/h (delivered to soft tissue).

Equivalent counting rates for contamination

1. The Radiation Monitor A.E.R.E. type 1021B is a typical contamination monitor. The standard probes are a scintillation α-counter and a G.M. β-counter, type B.12, in a protective housing.

10^{-4} μc/cm² (α-rays) = 3 to 10 counts/sec. (with α-probe);
10^{-4} μc/cm² (1 MeV β-rays) = 5 counts/sec. (β-probe).

2. The mica-windowed counter type EHM 2 can be used for both α- and β-monitoring. Discrimination against β-rays can be obtained by operating the counter between 5 and 20 volts below the threshold of the β-plateau. The α-sensitivity then depends sharply upon operating voltage.

10^{-4} μc/cm² (α-rays) = 0·3 to 1 count/sec.
10^{-4} μc/cm² (β-rays) = 1·5 counts/sec.

Equivalent dose-rates

The β-probe of the monitor type 1021B can also be used to estimate dose-rates.

1. For γ-rays between 0·3 and 3 MeV :—1 mr/h = 80 counts/sec.

2. For 1 MeV β-rays in an unidirectional beam, e.g., from a point source at a distance: 1 mrad/h (delivered to soft tissue) = 50 counts/sec.

Note.—This probe cannot be used to measure β-ray dose rates at a surface directly because it views only part of the surface and because the counter is about 2 cm away from the surface.

9.3.2. *Decontamination of equipment*

Scrupulous care in the cleaning of glassware is necessary. After use, all vessels should be marked and segregated for special attention when cleaning. Glassware can be cleaned by any of the normal chemical agents, of which chromic-sulphuric solution is probably the most useful. Other cleaning agents are concentrated nitric acid, ammonium citrate, pentasodium triphosphate and ammonium bifluoride. The solutions used for cleaning should not be returned to the stock bottle.

All metal tools should be surveyed to detect possible contamination. They may be cleaned by washing with a detergent, followed, if necessary, by dilute nitric acid, or a 10 per cent solution of sodium citrate, or ammonium bifluoride. When all other procedures fail with stainless steel, hydrochloric acid should be used, though this may corrode the tools, causing greater difficulty in future decontamination.

Paint work can be cleaned with soap (or detergent) and water, or, in extreme cases, removed with a paint remover. Polished linoleum can be cleaned with soap and water, followed, if necessary, by the removal of the wax polish by means of a solvent. If activity still remains the linoleum should be replaced.

The permissible levels of contamination of benches and floors of active laboratories and of glassware and laboratory tools are given in Table III.

If, after decontaminating procedures have been carried out, the levels of activity of equipment and glassware remain greater than those specified, the items should be regarded as radioactive waste.

9.3.3. *Decontamination of clothing*

Protective clothing and personal clothing of staff, or clothing or bedding of hospital patients who are being treated with radioisotopes, should be monitored at regular intervals spaced according to the radioactive hazard involved. Any article that is known to be, or suspected of being, contaminated, should be placed in a container provided for the purpose. The permissible levels of contamination are given in Table III.

9.4. *Laundering*

Contaminated clothing and bedding should not be released to public laundries unless the activity is below the permissible levels given in Table III.

For articles contaminated above these levels with short-lived radioactive isotopes, storage is recommended until the activity has fallen below the safe levels. Care must be taken to prevent air-borne contamination from clothing placed in storage.

When storage is not practical, but special laundering facilities are available in a hospital, a contaminated garment or bedding with an activity above the permissible levels should be given a series of hot rinses, followed by washing in a hot solution of 3 per cent citric acid, which tends to produce soluble citrate complexes of the radioactive isotopes. The article should then be given further rinses with soapy and clear water, followed by washing in a hot solution of 1·5 per cent citric acid, and finishing with a series of cold rinses. The article should then be monitored, and the procedure repeated if necessary. An automatic washing machine is very useful for this purpose.

Clothing that cannot be laundered satisfactorily or held for storage should be regarded as radioactive waste.

9.5. *Spills*

9.5.1. *Minor spill—involving no radiation hazard to personnel*

Absorbent paper should be laid immediately over a wet spill. Sites where there has been a dry spill should be damped down and absorbent paper laid over the affected areas. The papers should then be removed to a suitable waste receptacle and the affected areas of the laboratory monitored. Decontamination should then be carried out until the contamination levels have been reduced below those given in Table III.

9.5.2. *Major spill*

A spill may be regarded as a major one when the quantity of isotope which has been spilt is in the range of quantities given for Grade B laboratories in Table I.

In such a case, the following procedure should be carried out.

All other persons in the affected laboratory should be notified at once. Persons who have been contaminated should not proceed far into the inactive area until they have been monitored, unless there is urgent need for them to do so, for example, if they have been injured. A danger notice should be attached to the barrier to warn others not to enter the contamination area inadvertently.

Until a plan for dealing with the decontamination of the area has been worked out, only the minimum emergency action should be taken, for example:

(*a*) evacuate all staff; re-enter to carry out emergency measures only with adequate protective equipment e.g. respirator or breathing apparatus;

(*b*) if the spill is on the skin, flush thoroughly with tap water;

(*c*) if the spill is on clothing, remove protective or outer clothing immediately and leave in the affected room;

(*d*) switch off all fans;

(*e*) if radioactive dusts, gases, vapours, etc., are involved and if time permits, switch of all circulating equipment and close all stop-cocks, etc., which would otherwise lead to further dispersal of the contaminant;

(*f*) close windows and doors;

(*g*) notify the safety officer or officer in charge of the department.

In the meantime, steps should be taken to reduce the surface contamination of persons involved in the spill. Cleaning should proceed until either radiation monitoring indicates that the contamination has been reduced below the permissible level, or until any further normal efforts would result in damage to the skin and risk of entry of the radioactive materials into the bloodstream through the skin. No further action should be taken except on instructions from a physician qualified to deal with radiation injuries.

In some instances, it may be necessary to carry out tests on personnel involved in the accident to determine the amount of radioactive material which has entered the body. (See Section 4.3 of this part of the code.)

Before re-entering the area to effect decontamination measures, personnel involved should wear suitable protective clothing, gloves, footwear and masks, according to the seriousness of the accident. These persons should, in due course, be submitted to the necessary decontamination and monitoring procedures.

No-one must be allowed to resume work in the area until radiation surveys have indicated that it is safe to do so and the approval of the officer in charge has been given.

CODE OF PRACTICE

SUPPLEMENT

Protection against ionizing radiations: fundamental data

SUPPLEMENT

Protection against ionizing radiations: fundamental data

Contents

1. Introduction

All types of ionizing radiations (X-rays, α-, β- and γ-rays, neutrons and protons) produce changes in living cells. It might therefore be anticipated that, even though some of the changes do not appear, in the light of present knowledge, to be deleterious to health, the aim in devising measures to protect human beings against radiations would be to intercept the rays completely. This is neither practicable nor economically possible. Furthermore, it should be appreciated that it is normal for human beings to live in an environment which includes exposure to ionizing radiations at micro-levels of intensity, since they are always subjected to cosmic rays, to rays from certain naturally radioactive elements, such as potassium in the body, and to rays from radium and other naturally radioactive isotopes in the soil, in building materials, in food, water and air.

Evidence on radiation effects such as skin injuries, changes in the blood-forming organs and in the number and nature of circulating blood cells, cancer formation, cataract formation, impaired fertility and genetic effects, has indicated that exposure up to certain levels for different types of radiation, arising either external to, or within, the body, is permissible throughout the working lifetime of a radiological worker, without involving a risk as great as that from many common and, at times, voluntarily accepted, hazards of life. The values given in this document for maximum permissible dose (see definition in Appendix I of this Supplement) serve as a basis for the protective measures advocated in this Code of Practice. It should nevertheless be emphasized that the evidence from which these values have been assessed is still scanty. It will be noted that, in general, they greatly exceed levels of natural radioactivity referred to above. Moreover, since there is a latent period, sometimes of the order of 20 years, before any radiation effect is apparent, every reasonable effort should be made to reduce exposure to all types of ionizing radiations to the lowest practicable level.

2. Critical Organs and Effects

In the past, occupational exposure has been limited largely to X-rays, and the maximum permissible dose has been expressed in terms of a dose or surface dose in röntgens. Extension to other types of radiation necessitates consideration of the doses actually received by different organs of the body. The following organs are considered critical from the point of view of protection:

Skin

Blood-forming organs.

Gonads with respect to impaired fertility.

Eyes with respect to cataract.

Organs (e.g., gut or thyroid) in which maximum damage occurs from an internally deposited radioactive isotope.

3. Effective Depths of Critical Organs

When the whole body is irradiated, a rough approximation of the dose in the organ may be made on the basis of an average or effective depth of the organ below the surface of the skin. For the purposes of calculation, the following effective depths for the critical organs are accepted:

Skin (basal layer of epidermis)	7 mg/cm^2
Blood-forming organs	5 cm
Ovaries	7 cm
Testes	Variable, depending on conditions of exposure. Maximum is 1 cm
Lens of the eye	3 mm

4. The Standard Man

(Conventional)

In calculations of the maximum permissible body burdens and the maximum permissible concentrations in air and water of various radioactive isotopes, data are required concerning the masses of the body organs and the rates of inhalation and ingestion. The data accepted at the present time for the conventional "Standard Man" are given in Tables I and II.

TABLE I

Masses of organs of human body

Organ	Mass in g
Total body	70,000
Muscle	30,000
Skin and subcutaneous tissue	6,100
Skin only	2,000
Fat	10,000
Skeleton: without bone marrow	7,000
red marrow	1,500
yellow marrow	1,500
Blood	5,400
Gastrointestinal track	2,000
Contents of G.I. tract	
Stomach	250
Small intestine	1,100
Upper large intestine	135
Lower large intestine	150
Liver	1,700
Brain	1,500
Lungs (2)	1,000
Lymphoid tissue	700
Kidneys (2)	300
Heart	300
Spleen	150
Urinary bladder	150
Pancreas	70
Salivary glands (6)	50
Testes (2)	40
Spinal cord	30
Eyes (2)	30
Thyroid gland	20
Teeth	20
Prostate gland	20
Adrenal glands or suprarenal (2)	20
Thymus	10
Miscellaneous (blood vessels, cartilage, nerves, etc.)	390

TABLE II

Daily rates of ingestion and inhalation

(Conventional)

	cm^3
Water intake in food	700
Water intake in fluids	1,500
Water of oxidation	300
Total water consumption	2,500
Air inhaled during 8 h working day	10^7
Air inhaled during 16 h not at work	10^7
Total inhaled	2×10^7

As regards the distribution of inhaled particulates in the respiratory tract, values are available for certain isotopes. Where data are lacking, the convention given in Table III is adopted.

TABLE III

Particulates in respiratory tract

Distribution	Readily soluble compounds	Other compounds
Exhaled	25 per cent	25 per cent
Deposited in upper respiratory passages and ultimately swallowed	50 per cent	50 per cent
Deposited in lungs . .	25 per cent (taken up in body fluids)	25 per cent (12·5 per cent eliminated from lung and swallowed in first 24 hours; remaining 12·5 per cent retained in the lungs with a half-life of 120 days and then taken up into the body fluids)

5. Relative Biological Effectiveness

All ionizing radiations interact with tissue in such a way as to produce effects which are qualitatively, though not necessarily quantitatively, similar. Quantitative differences arise from the fact that the total energy per gramme imparted to tissue which is irradiated is not the only factor to be considered. A heavy particle, such as an α-particle or proton produces very many more ions per cm length of its track than does a β-particle or a secondary electron ejected from an atom by X- or γ-rays. As a result of these different "specific ionizations", radiations have different "relative biological effectiveness". It is found that the biological effectiveness of a tissue dose delivered by electrons does not vary much with specific ionization. Therefore, for protection purposes, it is assumed that all β-rays, X-rays and γ-rays have the same biological effectiveness. Since most of the directly applicable information on protection has been obtained from the occupational exposure of radiologists and technicians to ordinary X-rays up to 250 kV, this X-ray energy range is used as a point of reference, especially since the specific ionization in this range is nearly constant. Hence, radiations in this region are assumed to have a biological effectiveness of 1. For other types of radiation, having greater specific ionizations, it is necessary to consider the relative biological effectiveness (r.b.e.), that is, the biological effectiveness relative to that of the radiation used as the point of reference. The r.b.e. values given in Table IV are accepted, at the present time, for particular types of radiation and particular biological effects.

TABLE IV

R.B.E. factors for different types of radiation

Radiation	r.b.e.	Biological effect
X-rays, γ-rays, and electrons and β-rays of all energies	1·0	Whole-body irradiation (Blood-forming organs critical)
Fast neutrons. Protons up to 10 MeV	10	Whole-body irradiation (Cataract formation critical)
Naturally occurring α-particles	Compare with 0·1 μc Ra; otherwise take value of 10	Cancer formation
Heavy recoil nuclei . .	20	Cataract formation

6. Values of Maximum Permissible Doses

6.1. *Controlled and uncontrolled areas*

Occupied space in the vicinity of a source of ionizing radiation may be divided into controlled and uncontrolled areas. A controlled area is one in which the occupational exposure of personnel to radiation or radioactive material is under the supervision of a Safety Officer. In such an area the values for the maximum permissible doses and for all other working conditions specified in this Code are deemed to apply. Any area which is not under the control of a Safety Officer is regarded as uncontrolled, and in such an area the maximum permissible levels of exposure are 10 per cent of the corresponding levels in a controlled area.

6.2. *External radiation in controlled areas*

6.2.1. *Maximum permissible weekly doses for whole-body exposure*

(*a*) *For radiation measurable in röntgens*[1] (that is, for X- and γ-rays of quantum energy less than 3 MeV)

(i) Skin at 7 mg/cm^2 . . . . . . 600 mr per week
(ii) Blood-forming organs, gonads and eyes . 300 mr per week
whichever is the less.

(*b*) *For radiation measurable in rads*[1]

In the above, the milliröntgen is replaced by the millirad. When necessary, the appropriate allowance must be made for the r.b.e. factor.

(*c*) *For radiation of very low penetrating power* (half-value layer less than 1 mm water) *and for β-rays*

(i) Skin (at 7 mg/cm^2) . . . . 1,500 mrem[1] per week
(ii) Lens of the eye (3 mm deep) . . . 300 mrem per week
(r.b.e. factors : for soft X-rays and β-rays = 1
for α-rays = 10).

(*d*) *For neutrons*

The maximum permissible exposure to neutrons in the energy range 0·025 eV (thermal) to 10 MeV shall be either :

(i) that exposure which would produce an energy absorption of 0·03 rad per week at a depth of 2 cm below the surface of soft tissue, or

(ii) exposure for periods not exceeding 40 hours per week to the neutron fluxes given in Table V.

[1] See Appendix I of this Supplement for definitions of the units.

TABLE V

Maximum permissible neutron fluxes

Neutron energy	Maximum permissible flux (neutrons/cm²/sec.)
0·025 eV 10 eV	2,000
10 keV	1,000
0·1 MeV	200
0·5 MeV	80
1 MeV	60
2 MeV	40
3–10 MeV	30

6.2.2. *Maximum permissible cumulative doses for whole-body exposure*

(*a*) *In any period of* 13 *consecutive weeks :*

Blood-forming organs, gonads and eyes . 3·0 rem

(*b*) *Up to age of* 30 *years :*

Blood-forming organs, gonads and eyes . 50 rem

(*c*) *After age of* 30 *years :*

Blood-forming organs, gonads and eyes . 50 rem per decade

(*d*) *In a lifetime :*

Blood-forming organs, gonads and eyes . 200 rem

It will be noted that the limits applicable for exposure up to 30 years and per decade thereafter are equivalent to an average weekly dose of 100 mrem. This is one-third of the maximum permissible weekly dose. In the case of long-term exposure, the protection must be planned accordingly.

6.2.3. *Exposure of limited regions of the body*

For exposure of the hands and forearms, feet and ankles, head and neck, the maximum permissible dose is 1,500 mrem per week in the skin, with the proviso that in all cases the dose in deeper tissues must be less than 1,500 mrem per week and the whole body exposure is in accordance with 6.2.1 and 6.2.2 above.

6.3. *Internal radiation in controlled areas*

6.3.1. *Maximum permissible body burdens for various radioisotopes*

In assessing the maximum permissible body burdens for various radioisotopes, which enter the body through inhalation or ingestion, one would prefer to have clinical evidence of the effects of each isotope over a period of years. In the case of only one isotope, radium, is such evidence available. Assuming that this typifies the class of isotopes which are bone-seeking, it is possible, from observations of the biological effect of any isotope in this class relative to that of radium, to derive a figure for the permissible body burden. For isotopes whose biological effectiveness relative to radium is unknown, and for isotopes which have no affinity for bone, the procedure adopted in evaluating the maximum permissible body burden is to calculate the amount of the isotope under consideration which would produce a rate of energy absorption biologically equivalent to 0·3 rad per week (7 days of 24 hours) in the organ (so-called critical organ) in which maximum concentration, due to selective action, occurs. Then from a knowledge of the amount of the isotope in the whole body relative to that in the organ considered, the maximum permissible total body burden can be evaluated.

In the case of those isotopes for which the critical organ is the whole body or gonads, the average total body burden should not exceed one-third of the maximum in order to conform to the maximum permissible cumulative doses.

6.3.2. *Maximum permissible concentration of various radioisotopes in air and water*

The portions of inhaled or ingested isotopes which are retained in the body vary according to the isotope and to the type and nature of the compound (for example, soluble or insoluble). From data regarding these portions and regarding the rates of loss of activities of isotopes in the body, due partly to excretion and partly to radioactive decay, the rates of intake into the body which would ultimately result in the maximum permissible body burden being reached, can be calculated. These rates then fix the maximum permissible concentrations of various isotopes in air and water.

The recommended values of maximum permissible body burden and of the maximum permissible concentration in air and water for various radioisotopes are given in Appendix II of this Supplement. These values represent the best available at the moment.

For those isotopes for which the average total body burden must not exceed one-third of the maximum, the average permissible concentrations in air and water must also not exceed one-third of the maxima.

(It will be noted that, in those cases when the G.I. tract appears alone as the critical organ, two values are given for the maximum permissible body burden. This arises because I.C.R.P. has determined body burden indirectly. The procedure adopted is that the body burden has been estimated for long-term depositions, involving tissues and organs such as bone and lungs. From the body burden estimated in this way, I.C.R.P. has evaluated the corresponding m.p.c. in water and air. Other values for the m.p.c. in water and air can be determined directly from consideration of the doses to the G.I. tract. The total body burdens resulting from continuous exposure to the maximum permissible concentrations calculated from the dose corresponding to the G.I. tract as the critical organ are calculated from the relationship :

Body burden (based on G.I. tract)

$$= \frac{\text{m.p.c. in} \begin{Bmatrix} \text{water} \\ \text{or air} \end{Bmatrix} \text{(G.I. tract)}}{\text{m.p.c. in} \begin{Bmatrix} \text{water} \\ \text{or air} \end{Bmatrix} \text{(other critical organ)}} \times \text{body burden (based on other critical organ)}$$

For example, the body burden for Be–7, taking bone as the critical organ, is 725 μc. The corresponding m.p.cs. in water and air are 1 μc/cm^3 and 5×10^{-6} μc/cm^3. The m.p.cs. in water and air, based on G.I. tract, are 2×10^{-2} μc/cm^3 and 3×10^{-6} μc/cm^3. Hence, the body burdens, based on G.I. tract, are 15 μc and 440 μc.)

7. Evaluation of Protective Thicknesses of Materials for External Beams of Radiation

The determination of the protection required in any particular instance against an external source of ionizing radiation, whether this radiation is received direct from the source or by scattering from bodies placed in the path of the useful beam, involves a knowledge of the dose-rate of the radiation which would be received at the point of interest, in the absence of a protective screen, and a knowledge of the transmission values of the radiation in question through various thicknesses of lead or other absorbents.

7.1. *X-rays*

7.1.1. *Protection against useful beam*

Details about the dose-rate can be obtained from the manufacturer of the X-ray tube. However, as an approximate guide, the values given in Table VI can be used.

TABLE VI

X-ray dose-rates

Exciting voltage in kV (constant potential)[1]	X-ray dose-rate in r/mA.min at 1 metre		
	Total filtration = 1 mm glass (or 0·07 mm Cu)	Total filtration = 0·1 mm Cu	Total filtration = 0·5 mm Cu
50	0·32	0·18	—
75	0·7	0·5	0·05
100	1·2	0·85	0·16
150	2·3	1·75	0·6
200	3·6	2·9	1·25
250	—	—	1·9
300	—	—	2·8
400	—	—	5·6
500	—	—	8
1,000	—	—	33

[1] Dose-rates with pulsating potential generators are about one-half to two-thirds of those for constant potential.

Transmission curves in lead for X-rays excited at various voltages between 50 kV and 2 MV are given in Figures 1 to 3. The lead equivalents of concrete (density 2·2 g/cm³) for X-rays of 50 kV to 2 MV are indicated in Table VII, whilst lead equivalents of brick (density 1·6 g/cm³) and of barium concrete (density 3·2 g/cm³) for 50 to 400 kV X-rays are given in Tables VIII and IX. There is no experimental evidence concerning transmission in lead for X-rays above 2 MV.

Available data for concrete for 1 to 30 MV X-rays have been plotted in Figures 4 and 5. As a rough guide, the corresponding thicknesses of lead can be estimated by multiplying the concrete values by a factor of $\frac{2 \cdot 2}{11 \cdot 4}$ which represents the ratio of the densities of concrete and lead.

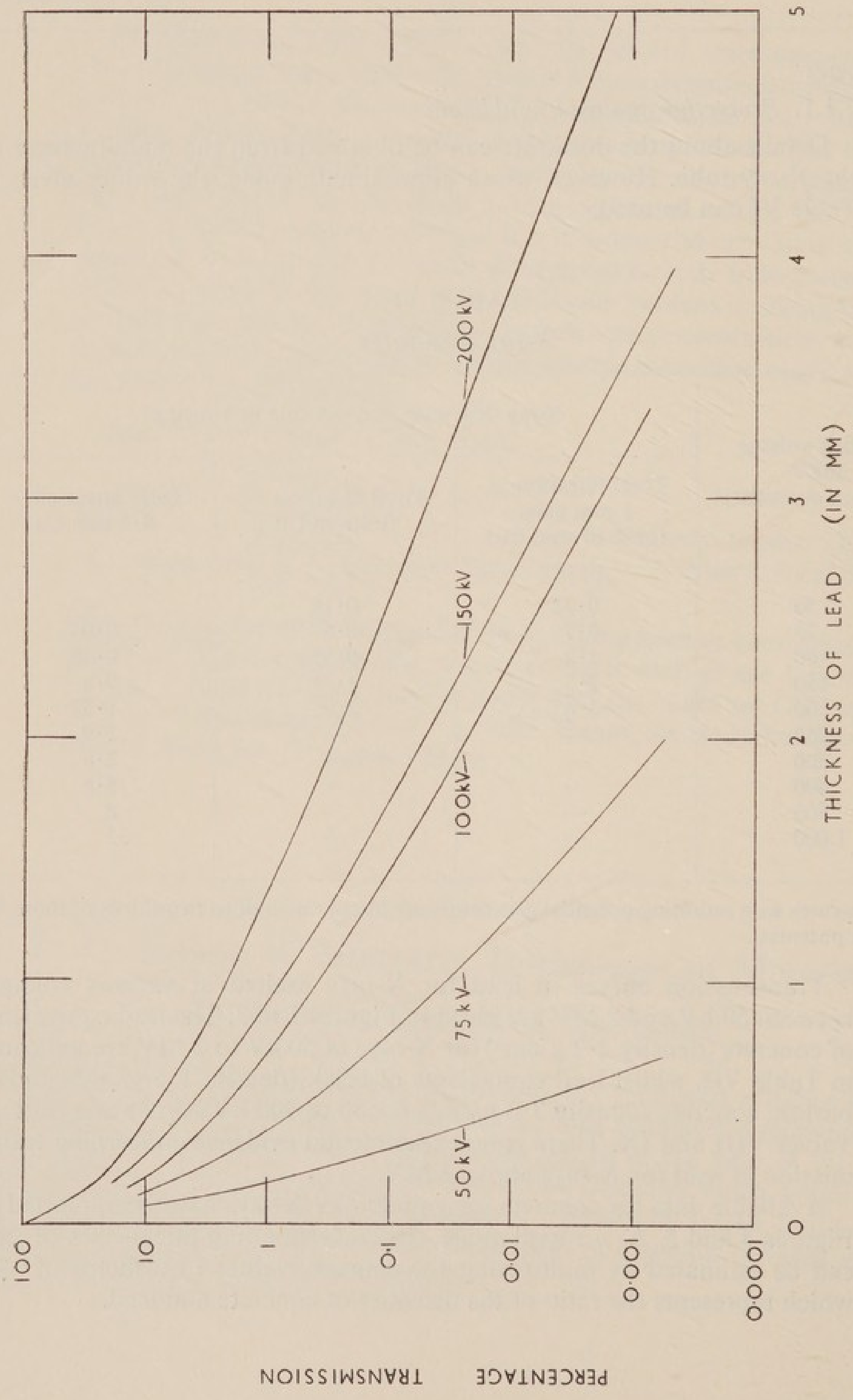

FIG. 1. Transmission curves in lead for X-rays excited at various constant voltages between 50 kV and 200 kV with initial filtration of 1 mm glass (or 0·07 mm copper).

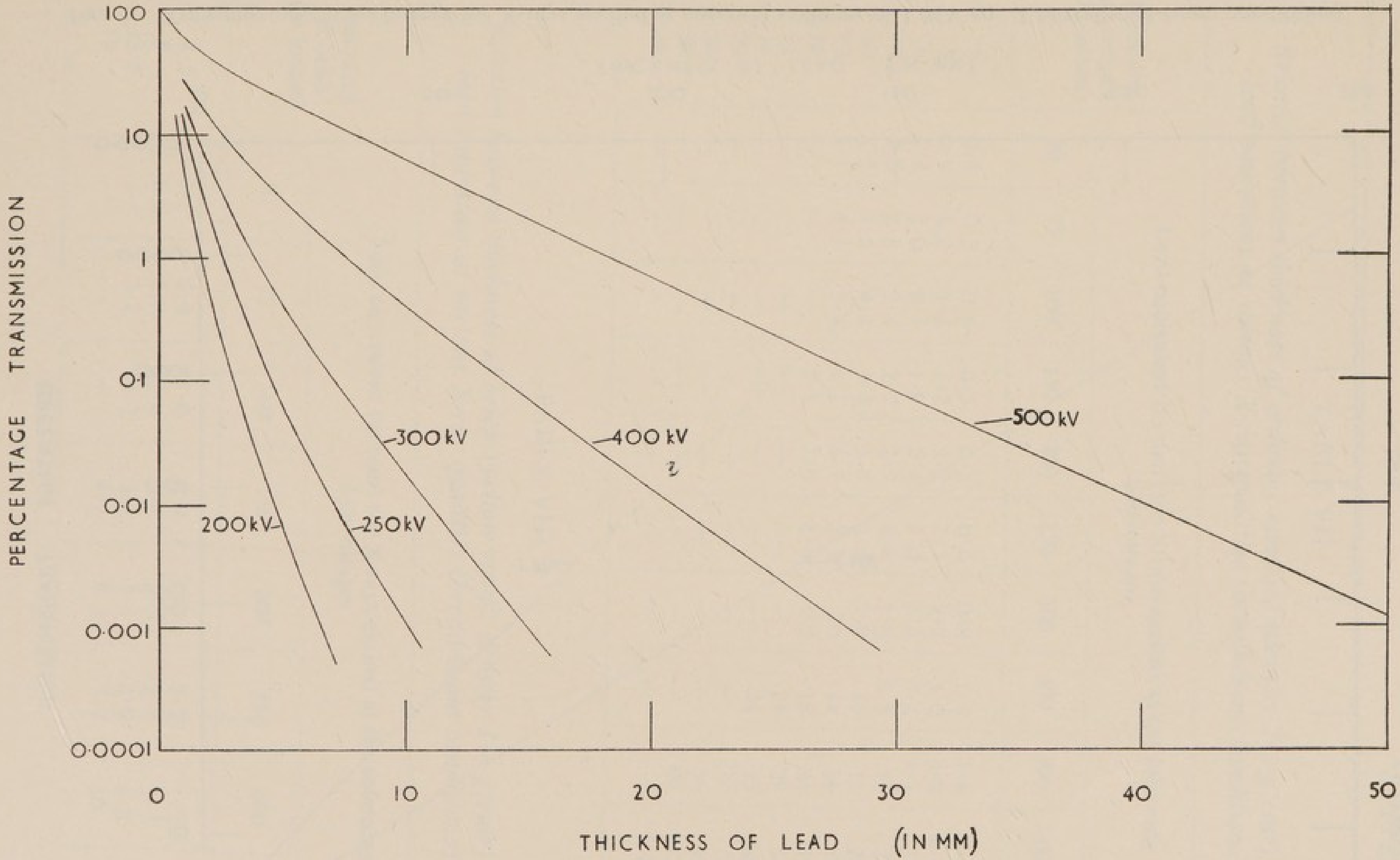

FIG. 2. Transmission curves in lead for X-rays excited at various constant voltages between 200 kV and 500 kV (broad-beam conditions).

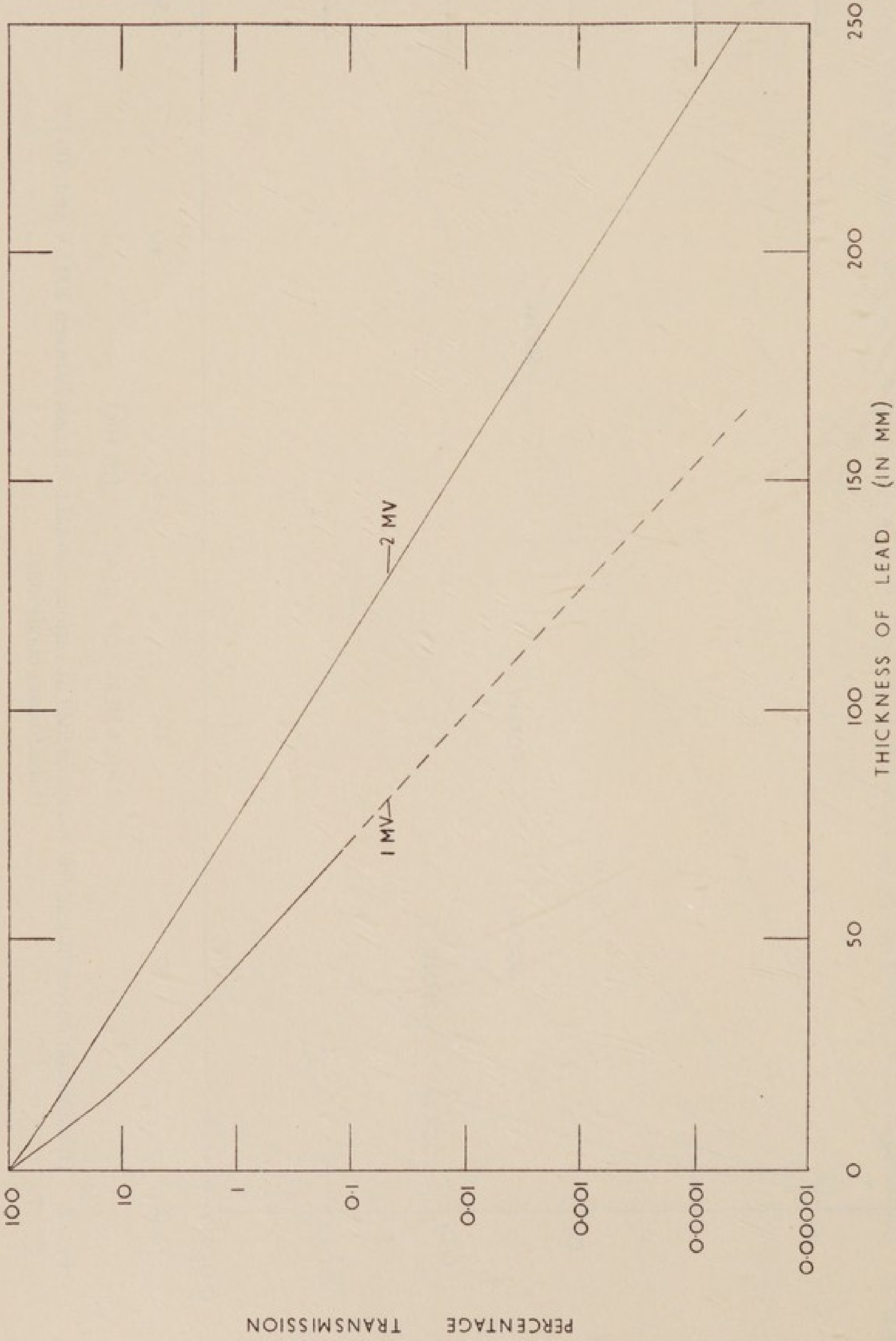

FIG. 3. Transmission curves in lead for X-rays excited at constant voltages of 1 MV and 2 MV (broad-beam conditions).

TABLE VII

Relation between thickness of ordinary concrete (density 2·2 g/cm³) and lead equivalent at various X-ray qualities (broad-beam conditions)

Thickness of concrete (in inches)	Lead equivalent (in mm) for X-rays excited at the following kilovoltages										
	50	75	100	150	200	250	300	400	500	1,000	2,000
2	0·4	0·5	0·6	0·5	0·5	0·6	0·8	1·1	1·6	4·0	6
4	0·9	1·2	1·4	1·2	1·2	1·7	2·2	3·0	3·9	8·6	13
6	1·4	2·0	2·4	1·9	2·1	3·0	3·8	5·4	7·1	13	22
8	2·0	2·8	3·4	2·7	2·9	4·4	5·8	8·5	11	21	31
10	2·5	3·6	4·4	3·4	3·8	5·8	7·9	11	15	29	40
12	3·1	4·3	5·4	4·2	4·7	7·3	10	14	19	37	49
14	—	—	—	5·1	5·6	8·6	12	18	24	45	58
16	—	—	—	—	—	—	—	21	28	54	67
18	—	—	—	—	—	—	—	24	33	62	76
20	—	—	—	—	—	—	—	—	37	71	85
24	—	—	—	—	—	—	—	—	46	88	103
30	—	—	—	—	—	—	—	—	60	112	130
36	—	—	—	—	—	—	—	—	—	138	159

TABLE VIII

Relation between thickness of brick (yellow stock: density 1·6 g/cm³) and lead equivalent at various X-ray qualities (broad-beam conditions)

Thickness of brick (in inches)	Lead equivalent (in mm) for X-rays excited at the following kilovoltages							
	50	75	100	150	200	250	300	400
4·5	0·7	0·9	1·0	0·9	0·9	1·2	1·3	1·5
9	1·6	2·0	2·4	2·0	2·0	2·8	3·7	5·6
13·5	—	3·2	3·7	3·1	3·1	4·9	6·8	10·3
18	—	—	—	4·3	4·3	7·2	10	15·2

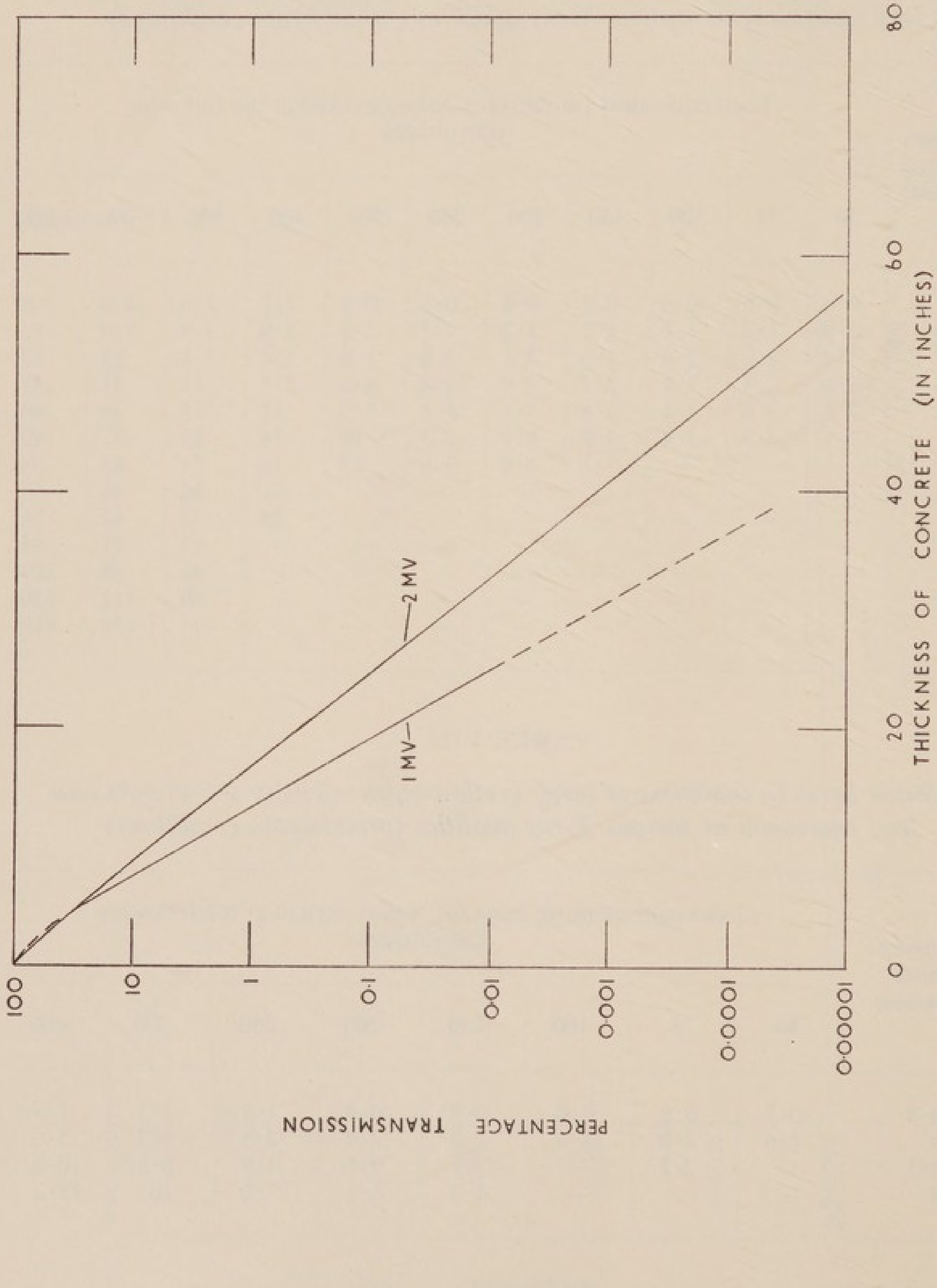

FIG. 4. Transmission curves in concrete for X-rays excited at constant voltages of 1 MV and 2 MV (broad-beam conditions).

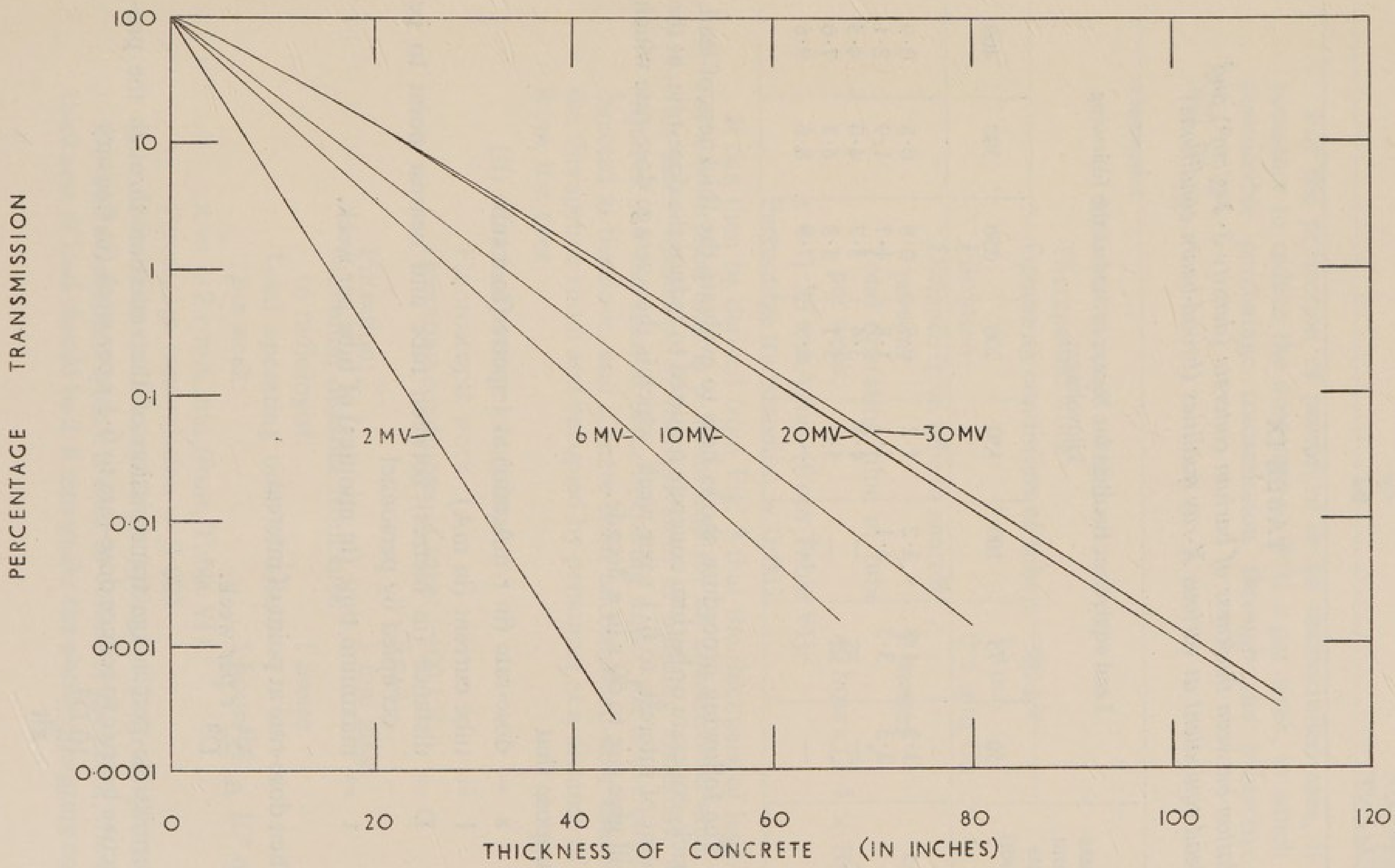

FIG. 5. Transmission curves in concrete for X-rays excited at voltages between 2 MV and 30 MV (broad-beam conditions).

TABLE IX

Relation between thickness of barium concrete (density 3·2 g/cm³) and lead equivalent at various X-ray qualities (broad-beam conditions)

Thickness of barium concrete (in inches)	Lead equivalent (in mm) for X-rays excited at the following kilovoltages							
	50	75	100	150	200	250	300	400
0·5	1·2	1·8	2·2	1·2	0·9	0·8	0·8	0·9
1	2·3	3·3	4·1	2·3	1·8	1·7	1·9	2·1
2	—	—	—	4·3	3·4	3·7	4·0	4·5
3	—	—	—	5·9	5·1	5·8	6·3	7·0
4	—	—	—	—	6·9	7·9	8·6	9·6

The following procedure shows how to evaluate the thickness of lead, brick, concrete or barium concrete required to reduce the dose-rate, at the point of interest, to 0·1 r per week, which is the average dose-rate which will give rise to 50 r in a decade.

Suppose that

x = dose-rate (in r/mA.min) at 1 metre from tube

i = tube current (in mA)

D = distance (in metres) between tube and nearest point to be occupied by personnel

t = maximum time (in minutes) of tube per week.

Then dose-rate at point of interest

$$= \frac{xit}{D^2} \text{ r per week.}$$

Permissible percentage transmission of the radiation through the protective barrier to reduce dose-rate to 0·1 r per week (in free air)

$$= \frac{10\,D^2}{xit}$$

For the protection of personnel in an uncontrolled area, it may be necessary to reduce the dose-rate to 0·01 r per week, in which case the permissible percentage transmission through the protective barrier will be $\frac{D^2}{xit}$.

Examples

(i) Assumed average conditions:

Therapeutic work	
Operating conditions of tube:	200 kV
	10 mA
Filtration:	0·5 mm Cu
Distance from tube to nearest person:	3 metres
Total operating time of tube per week:	40 hours ($2·4 \times 10^3$ min)

x = 1·25 r/mA.min (from Table VI).
Percentage transmission = 0·003.

It can then be derived from Fig. 2 that the thickness of lead required for a controlled area is 5·5 mm and for an uncontrolled area 7·5 mm. This latter thickness, or its equivalent in building materials, would be required if a therapeutic tube, operating under the above conditions, is directed at the floor, and if there is an uncontrolled area situated below the therapeutic room and occupied by personnel at a distance of 3 metres from the tube.

(ii) Assumed average conditions:

Fluoroscopic work	
Operating conditions of tube:	100 kV
	5 mA
Filtration:	1 mm glass
Minimum distance from tube to radiologist:	1 metre
Total operating time of tube per week:	5 hours (3×10^2 min)

x = 1·2 r/mA.min (from Table VI).
Percentage transmission = 0·005
Minimum thickness of lead required = 2·6 mm (from Fig. 1).

If a lead diaphragm system is used to collimate the beam, the minimum thickness of lead should be 2·6 mm under the above operating conditions.

7.1.2. *Protection against scattered radiation*

The available experimental evidence on scattering from materials composed of elements of low atomic number (for example, human tissue, wood, brick or concrete) indicates that, at 1 metre to the side of an irradiated object (90^0 between direction of scatter and direction of initial useful beam) the dose-rate is about 0·02 to 0·05 per cent of that at the surface of the irradiated body for each 100 cm^2 of field. In the case of back-scattered radiation, the dose-rate is about three times greater than for side scatter.

In calculating the protection required against scattered radiation, the dose-rate of the radiation at the point of interest must first be estimated; then the percentage transmission required to reduce this dose-rate to 0·1 r per week can be calculated.

Suppose that

x = dose-rate (in r/mA.min) at 1 metre from tube

i = tube current (in mA)

a = area of field (in cm^2)

d = distance (in metres) from tube to surface of irradiated body

p = percentage scatter at 1 metre from irradiated body per 100 cm^2 field

D = distance (in metres) from scattering body to nearest point at side occupied by personnel

t = maximum time (in minutes) of operation of tube per week

Then dose-rate of scattered radiation at point of interest

$$= \frac{x\,i\,t}{d^2} \times \frac{p}{100\,D^2} \times \frac{a}{100} \text{ r per week.}$$

Permissible percentage transmission of the radiation through the protective barrier to reduce dose-rate to 0·1 r per week (in free air)

$$= \frac{d^2\,D^2}{x\,i\,t\,p\,a} \times 10^5$$

If the person to be protected is at a distance of D metres in the direction of back-scattered radiation, the percentage transmission for the above conditions must be reduced by a factor of 3. If the person is in an uncontrolled area, a reduction by a factor of 10 of the appropriate percentage transmission will be required.

Example

Assumed average conditions:

Therapeutic work

Operating conditions of tube: 200 kV
20 mA

Filtration: 0·5 mm Cu

Maximum field size: 400 cm^2

Focal-skin distance: 0·5 metre

Total operation time of tube per week: 40 hours ($2{\cdot}4 \times 10^3$ min)

Percentage scatter per 100 cm^2 field: 0·05

Distance from patient to nearest person (at side): 2 metres

r = 1·25 r/mA.min (from Table VI)

Percentage transmission

$$= \frac{(0{\cdot}5)^2 \times 2^2 \times 10^5}{1{\cdot}25 \times 20 \times 2{\cdot}4 \times 10^3 \times 0{\cdot}05 \times 400}$$
$$= 0{\cdot}08$$

Minimum thickness of lead required = 3·2 mm (from Fig. 2). If the person to be protected is in the direction of back-scattered radiation instead of side-scattered radiation, the appropriate percentage transmission will be 0·03 and the thickness of lead 3·8 mm.

For an uncontrolled area, the corresponding thicknesses of lead will be 5·0 mm and 5·6 mm.

It will be noted that the transmission curves which have been used to determine the protection against scattered radiation are, in fact, those obtained for the useful beams and not for secondary radiation. This procedure is necessary as there are no available transmission curves for scatter. Since, however, scattered radiation is softer than the primary radiation which produced it, the error made in evaluating the protection is on the safe side.

7.2. γ-*rays*

7.2.1. *Protection against useful beam*

The procedure to be adopted here is the same as that for X-rays. In Table X are given the dose-rates in r per hour at 1 metre from 1 curie of various γ-ray emitting isotopes. Data on the half-life of decay and on the energies of the emitted radiation are also shown.

Absorption data for radium and Co–60 γ-rays in lead and ordinary concrete for broad-beam conditions are presented in Figs. 6 and 7.

The lead equivalents of concrete (density 2·2 g/cm³) for Ra and Co–60 γ-rays are indicated in Table XI.

The γ-ray transmission through brick and barium concrete can be derived by applying to Fig. 7 the appropriate factors for the ratios of the densities of these substances to that of ordinary concrete. That is, for any transmission value, the thickness of concrete must be multiplied by factors of $\frac{2\cdot2}{1\cdot6}$ and $\frac{2\cdot2}{3\cdot2}$ respectively to obtain the thicknesses of brick and barium concrete.

TABLE X

Gamma-ray dose-rate at one metre from a curie source of various isotopes*

Isotope	Half-life	Gamma-ray energy (MeV)	Dose-rate† in röntgens per curie-hour at 1 metre
Na–22	2·6 years	1·3	1·32
Na–24	15·0 hours	1·38, 2·76	1·89
K–42	12·4 hours	1·5	0·15
Cr–51	27 days	0·32	0·02
Mn–52	5·7 days	0·73, 1·46	1·93
Mn–54	300 days	0·84	0·49
Fe–59	47 days	1·1, 1·3	0·67
Co–58	70 days	0·50, 0·81	0·56
Co–60	5·3 years	1·17, 1·33	1·35
Zn–65	250 days	1·11	0·30
As–74	19 days	0·6	0·46
As–76	27 hours	0·5–2·05	0·33
Br–82	36 hours	0·55–1·35	1·50
I–130	12·6 hours	0·42–0·74	1·25
I–131	8·0 days	0·08–0·72 (mainly 0·36)	0·225
I–132	2·3 hours	0·69–2·00	1·21
Cs–137	30 years	0·66	0·33
Tm–170	129 days	0·08	0·005
Ta–182	111 days	0·15–1·22	0·61
Ir–192	74 days	0·13–0·61	0·50
Au–198	2·7 days	0·41–1·09 (mainly 0·41)	0·24
Ra (B + C)	Filtered through 0·5 mm Pt.		0·83

* " Curies " are parent curies, and gamma-branching ratios have been allowed for.

† Dose-rates in milliröntgens per millicurie-hour at 1 foot may be obtained by multiplying the values in column 4 by 10·8.

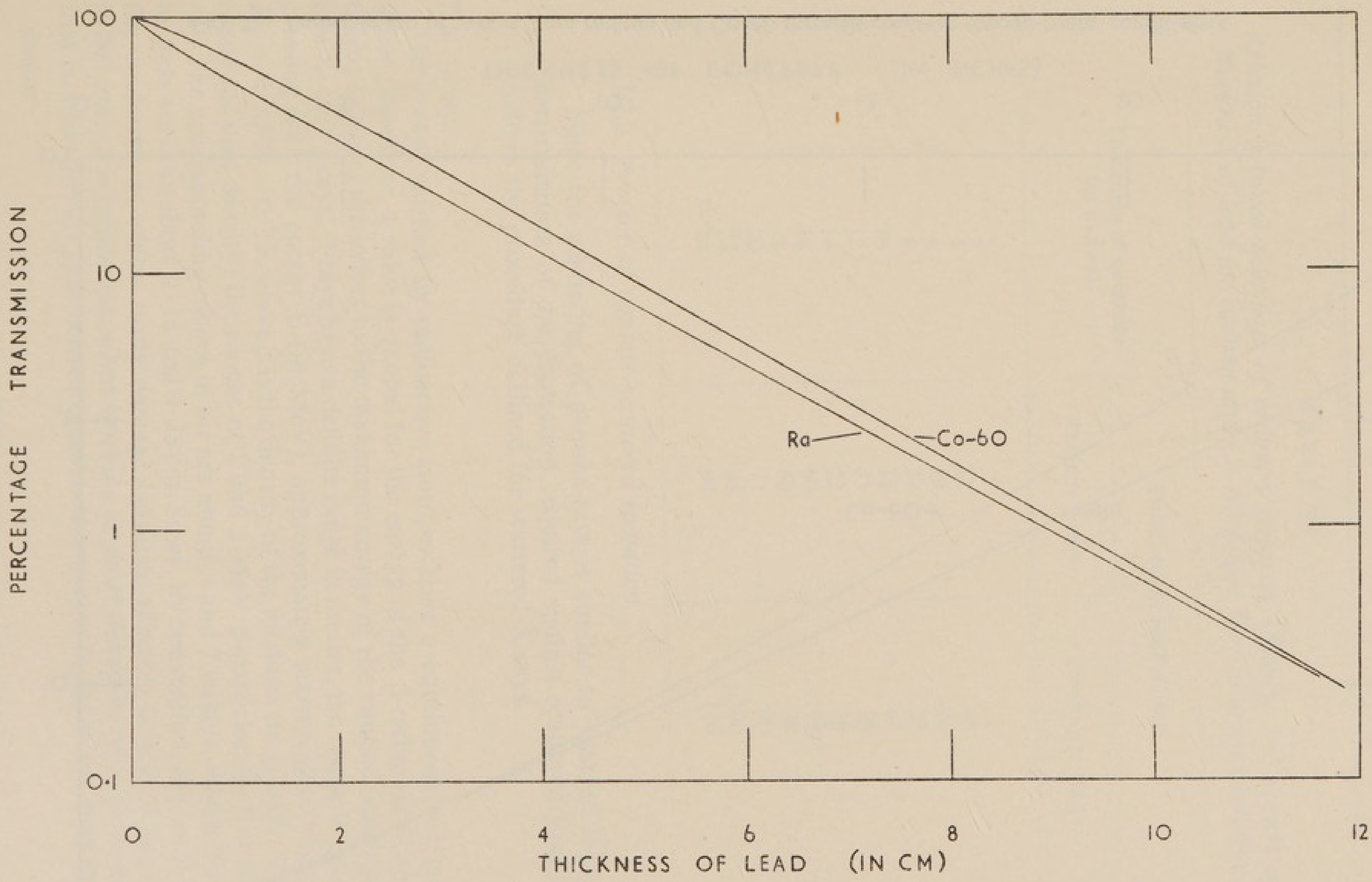

FIG. 6. Transmission of γ-rays from radium and Co–60 through lead (broad-beam conditions).

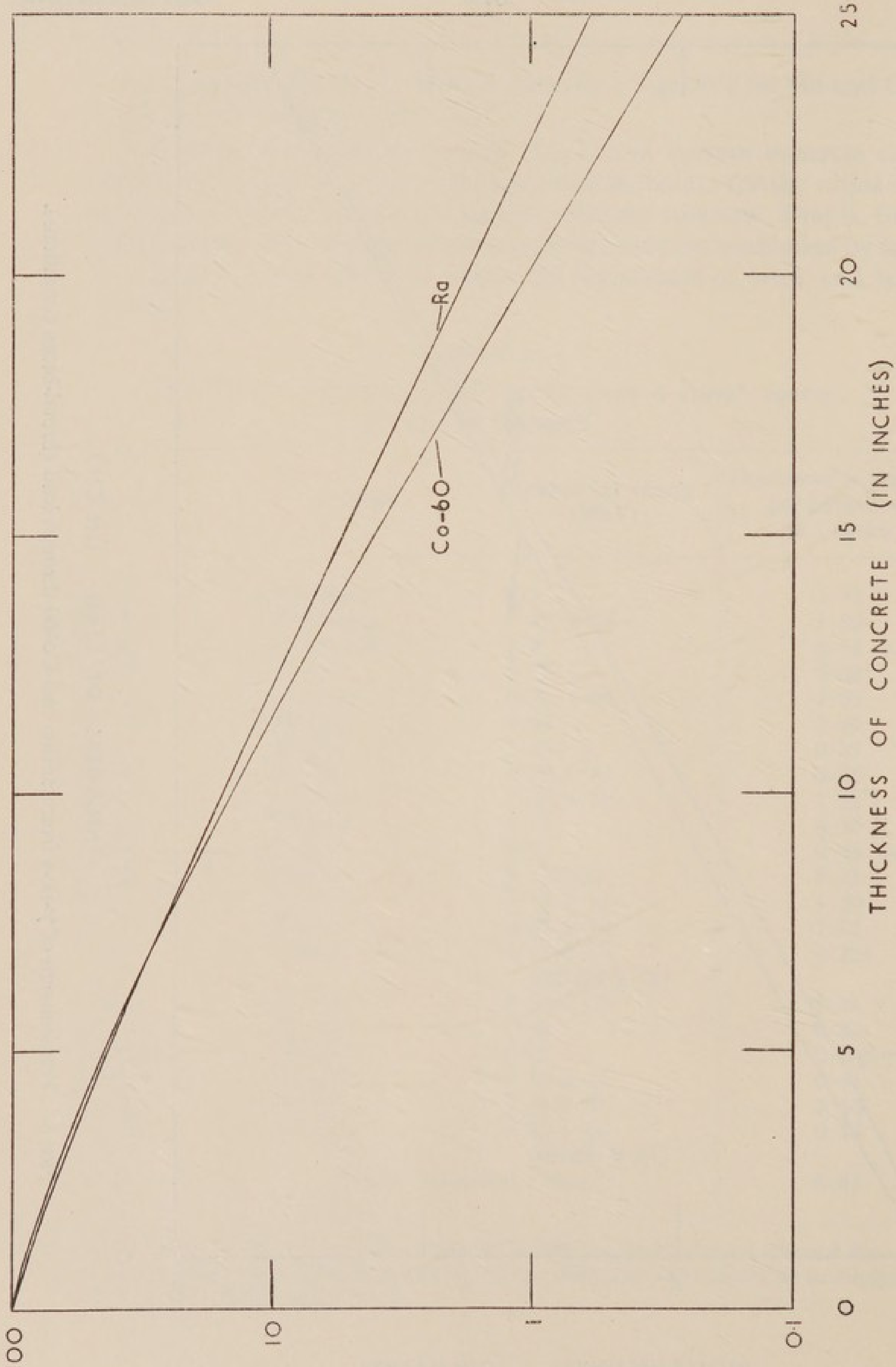

FIG. 7. Transmission of γ-rays from radium and Co–60 through concrete (broad-beam conditions).

TABLE XI

Relation between thickness of ordinary concrete (density 2·2 g/cm³) and thickness of lead for radium and Co–60 γ-rays (broad beam conditions)

Thickness of concrete (in inches)	Thickness of lead in mm	
	Radium γ-rays	Cobalt–60 γ-rays
2	5	7
4	12	15
6	19	24
8	27	32
10	35	41
12	43	50
14	52	59
16	60	69
18	69	79
20	77	90
22	86	100
24	94	110

7.2.2. *Protection against scattered radiation*

Since the scattering of gamma-rays is similar to that of X-rays, the determination of the protection required against scattered gamma-rays follows the procedure outlined for scattered X-rays.

7.3. *β-rays*

The β-rays emitted by radioactive isotopes have a continuous energy band. When, therefore, a value is quoted for the energy of the β-radiation from a particular isotope, this refers to the maximum energy of the emitted spectrum. Unlike X- and γ-rays, β-rays have a definite range in matter, the range R (in cm) increasing with the energy E (in MeV), approximately according to the relation $R\rho = 0\cdot55\,E - 0\cdot15$, where ρ is the density of the medium (in g/cm³). Thus, for tissue (of unit density) the ranges of 1 and 2 MeV β-particles are 0·4 and 0·95 cm. The corresponding ranges in air are about 3 and 7 metres, whilst the ranges in glass are only about 0·16 and 0·38 cm. Since, by convention, the basal layer of the epidermis at which β-ray damage becomes effective is only 7 mg/cm² (or 0·007 cm), it is important, when working at short distances with β-ray emitters, that is, when the air path between source and worker is much less than the β-ray range in air, to shield the body—particularly the exposed parts (hands, eyes, etc.)—by interposing thin screens of material, such as glass or perspex. As will be seen, only a few millimetres are required to absorb completely all the β-rays of energy up to 2 MeV.

One millicurie of a β-emitting isotope of maximum energy 2 MeV will, if in contact with, say, 1 cm^2 of the skin, produce the maximum permissible weekly dose in a few seconds. On the other hand, 1 millicurie at a distance of 10 cm from the skin could be handled for about 20 minutes per week. The importance of dealing with millicurie amounts of isotopes with long-handled forceps will be clear.

8. Appendix I

Definitions of Terms

Absorbed dose of any ionizing radiation: amount of energy imparted to matter by ionizing particles per unit mass of irradiated material at the place of interest. Expressed ideally in rads but for X- and γ-rays of quantum energy up to 3 MeV, the röntgen (r) may be used.

Aerosol: air borne particles of matter.

Air dose (*free-air dose*)*:* a dose of radiation measured in air at the point of interest, in the absence of patient (or phantom) or other object, thus excluding secondary radiation, apart from that arising from the air or associated with the source.

Applicator: (*a*) an attachment to an X-ray therapy tube head or telecurie therapy unit designed so that it defines the cross-section of the radiation beam. It may also help to define the distance between the X-ray target and the skin of the patient. It is sometimes called an *X-ray therapy applicator*, *telecurie therapy nozzle*, or *treatment cone*.

(*b*) an appliance carrying radium or other radioactive material and designed to be placed in a known relationship to the part of the patient to be treated. The term may be qualified to indicate the nature of the source, e.g., *radium applicator*, *radiophosphorus applicator*, or the site of use, e.g., *intra-cavitary applicator*, *lip applicator*. When such an applicator is moulded to fit the contour of the patient it is usually called a "*mould*".

Atomic number: number of orbital electrons in a neutral atom, or the electric charge on the nucleus of the atom, or the number of protons in the nucleus of an atom. (The nucleus of an atom consists of protons and neutrons. The number of protons governs the positive charge on the nucleus and hence the number of orbital electrons needed to produce a neutral atom.)

Barium plaster (or concrete): plaster or concrete containing a high proportion of barytes (barium sulphate). Used as a protective building material.

Biologically equivalent energy: quantity (expressed in rads) of X-ray energy absorbed in tissue which produces the same biological effect as the quantity (in rads) of absorbed energy of the radiation under consideration. (See *r.b.e.* and *rem.*)

Bremsstrahlung: X-radiation having a continuous spectral distribution and arising from the retardation of moving charged particles.

Collimation: in radiology; the limiting of a beam of radiation to the required dimensions.

Constant potential (or voltage): in radiological practice this term is applied to a uni-directional potential (or voltage) which has small periodic variations. The periodic component is called the *ripple potential (or voltage)*.

Controlled area: area in which the occupational exposure of personnel to radiation or radioactive material is under the supervision of a Safety Officer.

Cosmic rays: ionizing rays entering the earth's atmosphere from unidentified extra-terrestrial space and resulting in the presence of photons, electrons, neutrons, protons, mesons, etc., by collisions with atoms in the atmosphere.

Curie (c)*:* a unit of radioactivity defined as the quantity of any radioactive nuclide in which the number of disintegrations per second is $3 \cdot 700 \times 10^{10}$. (With this definition, the curie is independent of the disintegration rate of radium.)

Millicurie (mc): 1/1,000 curie.

Microcurie (μc): 1/1,000,000 curie.

Disintegration: process of spontaneous breakdown of a nucleus of an atom resulting in the emission of a particle or a photon. The rate of disintegration of a number of radioactive nuclides is a function of the number present and a disintegration constant characteristic of the atom concerned.

Dose-rate: radiation dose received per unit time.

Dosemeter: instrument that measures radiation dose.

Electron volt (*eV*): unit of energy. The change in kinetic energy of an electron when it is accelerated through a potential difference of 1 volt. 1 eV is equivalent to $1 \cdot 6 \times 10^{-12}$ erg.

Energy spectrum: the orderly separation of the components of a beam of radiation according, for example, to their wavelengths, frequencies or quantum energies.

Film badge: a pack of photographic film used for the detection of radiation exposure.

Fluorescence: phenomenon involving the absorption of radiant energy by a substance and its re-emission, during the period of radiation excitation, as visible or near-visible radiation.

Fluoroscope: equipment involving a screen of material which fluoresces when irradiated with X-rays. It is used in X-ray diagnosis by passing the X-ray beam through a patient or object and allowing it to fall on the screen, thus producing a visible image of the internal structure of the object.

Flux: a rate of flow of radiation across unit area normal to the direction of flow. For example, a neutron flux is the number of neutrons that cross 1 cm^2 per second. (See *Intensity*.)

Geiger-Müller counter: a form of ionization chamber equipped with suitable electrodes and operated at a voltage and gas pressure that will permit ionization by collision and in which the total ionization per event to be detected is independent of the amount of ionization produced by particles or quanta of radiation entering the counter.

Half-life: time taken for the amount of a radioactive nuclide to decrease to half its initial value.

Half-value layer (*H.V.L.*): the thickness of a specified absorbing material which, when introduced into the path of an X-ray beam, reduces the dose-rate to one-half its original value.

Integral absorbed dose: the integration of the energy absorbed throughout a given region of interest. The unit is the gramme-rad or gramme-röntgen. 1 gramme-rad = 100 ergs.

Intensity of radiation at a point: energy flowing per unit time through unit area perpendicular to the beam at the point in question. Expressed in ergs per square centimetre per second, or watts per square centimetre.

Ionization chamber: a gas-filled enclosure, having electrodes between which an electric field is applied to separate the positively and negatively charged ions formed by the passage of radiation through the gas. It is used to measure or to detect radiation by means of the ionization current therein.

Ionizing radiation: electromagnetic radiation (X-ray or γ-ray photons or quanta), or corpuscular radiation (α-particles, β-particles, electrons, protons, neutrons, and heavy particles) capable of producing ions.

X-rays: electromagnetic ionizing radiation which originates from the field outside the nucleus of the atom, and resulting from loss of energy of charged particles, e.g., electrons. Of shorter wavelength than ultra-violet radiation.

γ-rays: electromagnetic ionizing radiation which originates within the nucleus of the atom. (Often the terms "X-rays" and "γ-rays" are used indiscriminately in radiology. Scientifically, there is no distinction between X-ray photons and gamma-ray photons of the same energy.)

α-particle (*α-ray*): corpuscle consisting of the nucleus of a helium atom and emitted by radioactive atomic nuclei. Usually travelling at high speed.

electron (*or positron*): high-speed sub-atomic particle or corpuscle which is negatively (or positively) charged and which originates from extra nuclear sites.

β-particle (*β-ray*): a high-speed corpuscle having the same mass and charge as the electron (or positron) and originating from nuclear processes.

proton: a nuclear particle of unit mass number having a charge equal and opposite to that of an electron. The nucleus of the hydrogen atom (not of the isotopes deuterium and tritium) is a proton.

neutron: radioactive corpuscle which has no electric charge and has a mass slightly greater than that of the proton. It decays, when in the free state, with a half-life of 10 to 20 minutes to a proton and an electron.

The type of interaction which occurs between neutrons and atoms depends upon the kinetic energy of the former. If the kinetic energy of the neutrons lies between about 20 keV and 10 MeV (so-called "fast neutrons") or between 10 MeV and 500 MeV (so-called "high energy neutrons"), they can set in motion the nuclei of atoms with which they collide with sufficient velocity to ionize matter. "Slow neutrons", which are usually classed as having energies up to 0·1 eV, and include "thermal neutrons" which have energies (about 0·025 eV) associated with room temperatures, enter into nuclear reactions with atoms they meet, resulting in the emission of ionizing radiations. Between slow and fast neutrons is a group known as "epithermal neutrons" (or "intermediate neutrons").

Isotopes: nuclides having the same atomic number but different mass numbers.

Kilo-electron-volt (*keV*): unit of energy equal to one thousand electron volts. (See *electron-volt*.)

Kilovolt (*kV*): unit of electrical potential equal to one thousand volts.

Lead equivalent: the thickness of lead affording the same protection under specified conditions of irradiation as the material in question. The lead equivalent of a substance, such as lead glass or lead rubber, which attenuates the radiation essentially by its lead content, is largely independent of the quality of the radiation. The lead equivalent of all other protective materials and also building material for protective walls (concrete, brick, etc.) and barium protective glass show a dependence on the quality of the radiation.

Lead rubber: rubber containing a high proportion of lead compounds. It is used as a flexible protective material.

Lead rubber apron (*protective apron*): a protective shield of lead rubber. It may be a flap suspended from the fluorescent screen of an X-ray couch or stand, or a garment to be worn by the operator. In the latter case it may be called a "*body apron*".

Lead rubber gloves (*protective gloves*): gloves incorporating lead rubber as a protective material.

Lead glass (*protective glass*): glass, containing a high proportion of lead compounds, which absorbs radiation passing through it. Used as a transparent protective material.

mA: 1/1,000 ampere.

Maximum permissible dose: dose of ionizing radiation, that, in the light of present knowledge, is not expected to cause appreciable bodily injury to a person at any time during his lifetime. ("Appreciable bodily injury" means any bodily injury or effect that the person involved would regard as objectionable and/or competent medical authorities would regard as being deleterious to the health and well-being of the individual.)

Maximum permissible weekly dose: dose of ionizing radiation accumulated in one week of such magnitude that, in the light of present knowledge, exposure at this weekly rate for an indefinite period of time is not expected to cause appreciable bodily injury to a person at any time during his lifetime. (One week, as used here, means any seven consecutive days, not a calendar week.)

Mass number: total number of protons and neutrons in a given atomic nucleus.

Megavolt (*MV*): unit of electrical potential equal to 1,000 kilovolts.

Million electron volts (*MeV*): unit of energy equal to one million electron volts. (See *electron-volt*).

Nuclide: a particular variety of atom having a nucleus characterized by a specific atomic number and specific mass number.

Photon: corpuscular manifestation of a quantum of radiant energy.

Proportional counter: a form of ionization chamber equipped with suitable electrodes between which an electric field is applied which is high enough to produce ionization by collision and so adjusted that the total ionization per count is substantially proportional to the ionization produced in the gas by particles or quanta of radiation entering the counter.

Protection: provisions designed to reduce exposure of personnel to ionizing radiation.

Protective barrier: material used for absorbing ionizing radiation for protection purposes.

Pulsating potential (*or voltage*)*:* a unidirectional potential (or voltage) which undergoes periodic variations in magnitude at a frequency related to that of the mains supply.

Qualified expert: a person having the knowledge and training needed to measure ionizing radiations and to advise regarding radiation hazard. The qualification should be of the type specified by a National Committee—in the United Kingdom, the Radioactive Substances Advisory Committee.

Quantity of radiation: time integral of intensity. It is the total energy which has passed through unit area perpendicular to the beam and is expressed in ergs per square centimetre or watt-seconds per square centimetre.

Quantum: the smallest quantity of energy in the form of a bundle or packet of waves of electromagnetic radiation which can be associated with a given phenomenon. (Electromagnetic radiation sometimes appears to consist of waves and at other times of particles. Such particles may be regarded as bundles of waves.)

Quantum energy: energy contained in a quantum of radiation and proportional to the frequency of the radiation waves. (The energy E of a quantum of radiation of frequency ν is $h\nu$ where h is Planck's constant.)

Rad: unit of absorbed dose. It is 100 ergs per gramme.

Millirad (*mrad*)*:* 1/1,000 rad.

Radiation:

(1) *Broad-beam:* condition in which there is no collimation of a beam of X- or γ-rays which penetrate material and in which there is an admixture with the emergent beam of scattered electromagnetic radiation, produced during the Compton process of absorption of the radiation in the material penetrated. (See *Narrow-beam.*)

(2) *Direct radiation:* in the case of X-rays, all radiation, except the useful beam, coming from within the X-ray tube and tube housing. (See *Primary radiation.*)

(3) *Narrow-beam:* condition in which the collimation of a beam of X- or γ-rays which penetrates material is designed to prevent the scattered electromagnetic radiation, produced during the Compton process of absorption of the radiation in the material penetrated, from reaching the measuring equipment.

(4) *Primary radiation:*

(*a*) X-*rays:* radiation coming directly from the target of the X-ray tube. Except for the useful beam, the bulk of this radiation is absorbed in the tube housing.

(*b*) β- *and* γ-*rays:* radiation coming directly from the radioactive source.

(5) *Scattered radiation:* radiation which, during passage through a substance, has been deviated in direction. It may also have been modified by an increase in wavelength (Compton effect). It is one form of secondary radiation.

(*a*) *Side scattered radiation:* radiation which is scattered in directions approximately at right angles to the direction of the primary beam.

(*b*) *Back scattered radiation:* radiation which is scattered in directions approximately opposite to the direction of the primary beam.

(6) *Secondary radiation:* radiation, other than the primary radiation emitted by any matter irradiated with X-rays, γ-rays, etc. It may consist either of X-rays, electrons, or ultra-violet radiation.

(7) *Stray radiation:* radiation not serving any useful purpose. It includes direct radiation and secondary radiation from irradiated objects and represents the portion of the radiation against which special protective measures have to be taken.

(8) *Useful beam:* that part of the primary radiation which passes through the aperture, cone or other device for collimating the X-ray beam.

Radiation hazard: the danger to health arising from exposure to ionizing radiation. It may be due to external radiation or to radiation from radio-active materials within the body.

Radiation survey: an investigation of those factors associated with an installation or process which could give rise to a radiation hazard.

Radioactivity: spontaneous disintegration of an unstable nuclide with the emission of a particle or a photon, to form a different nuclide.

Relative biological effectiveness (*r.b.e.*)*:* ratio of the dose (expressed in rads) of 200–250 kV X-rays to the dose (in rads) of any type of ionizing radiation which produces the same biological effect. Most of the clinical evidence on the effects of ionizing radiations has been obtained with 200–250 kV X-rays. Accordingly this is used as the base-line, being given a biological effectiveness of unity.

Rem: quantity of any ionizing radiation such that the energy imparted to a biological system per gramme of living matter by the ionizing particles present in the locus of interest, has the same biological effectiveness as 1 rad of 200 to 250 kV X-rays.

Millirem: 1/1,000 rem.

Röntgen (*r*)*:* unit of dose of X- and γ-rays, but not other ionizing radiation. Defined as below:—

"The röntgen shall be the quantity of X- or γ-radiation such that the associated corpuscular emission per 0·001293 gramme of air produces, in air, ions carrying 1 electrostatic unit of quantity of electricity of either sign." (It becomes increasingly difficult to measure the dose in röntgens as the quantum energy of X- or γ-radiation approaches very high values. The unit may, however, be used for most practical purposes for quantum energies up to 3 MeV.)

Milliröntgen (*mr*)*:* 1/1,000 r.

Microröntgen (μr)*:* 1/1,000,000 r.

Safety officer: a person directly responsible for the safety of all persons in a radiological department. This individual should have the authority to stop operations whenever he believes that the health of workers in his department is being endangered.

Specific ionization of an ionizing particle: linear density of the ions along the path of an ionizing particle. Specific ionization varies as the square of the charge of the particle and is a complicated function of its speed. In general, large differences in specific ionization occur between X-rays and β-rays on the one hand and heavy particle radiation (α-rays, protons, neutrons, etc.) on the other.

Tissue dose: absorbed dose when the irradiated medium is tissue.

Tube shutter: a device, generally of lead, fixed to an X-ray tube to intercept the useful beam when desired.

Uncontrolled area: any area, outside a controlled area, in which the exposure of personnel to ionizing radiations is not under the supervision of a Safety Officer.

X-ray target: structure subjected to bombardment by accelerated electrons in an X-ray tube or accelerator and from which the main beam of X-rays is emitted.

X-ray tube housing: an enclosure which covers the tube and sometimes also other portions of the X-ray equipment (transformer) and which limits the major portion of radiation emitted from the tube to the useful beam.

(*a*) *Diagnostic-type protective tube housing:* a tube housing in which the direct radiation is reduced to, at most, 100 mr/h or 28 μr/sec at a distance of one metre from the tube target when the tube is continuously operated with closed window at its maximum rated current for the maximum rated voltage.

(*b*) *Fully-protective tube housing:* tube housing in which the leakage radiation is reduced to, at most, 6·25 mr/h corresponding to 300 mr/week for 48 hours' exposure time, in contact with the tube housing when the tube is continuously operated with closed window at its maximum rated current for the maximum rated voltage.

(*c*) *Highly-protective tube housing:* tube housing in which the leakage radiation is reduced to, at most, 100 mr/h corresponding 300 mr/week for 3 hours' exposure time, in contact with the tube housing when the tube is continuously operated with closed window at its maximum rated current for the maximum rated voltage.

9. Appendix II

Maximum permissible body burdens and maximum permissible concentrations, in air and water, of various isotopes

(The m.p.c.s in air are for compounds which are soluble in lung fluids, except where stated otherwise.)

Isotope	Critical organ	Maximum permissible body burden (in μc)	Maximum permissible concentrations	
			In Air (in $\mu c/cm^3$)	In Water (in $\mu c/cm^3$)
H-3	Total body	10^4	1×10^{-5}	0·2
Be-7	G.I.	440, 15	3×10^{-6}	2×10^{-2}
C-14 (as CO_2 in air)	Fat	260	1×10^{-5}	3×10^{-3}
F-18	Bone	5	3×10^{-5}	0·2
†Na-22	Total body	63	9×10^{-8}	6×10^{-4}
Na-24	G.I.	8, 15	1×10^{-6}	8×10^{-3}
P-32	Bone	10	1×10^{-7}	2×10^{-4}
S-35	Skin	300	1×10^{-6}	5×10^{-3}
Cl-36	Total body	230	6×10^{-7}	4×10^{-3}
A-41	Total body	33	5×10^{-7}	5×10^{-4}
K-42	G.I.	6, 6	6×10^{-7}	3×10^{-3}
Ca-45	Bone	14	8×10^{-9}	1×10^{-4}
Sc-46	Liver	5	5×10^{-8}	—
	G.I.	6×10^{-3}	—	4×10^{-4}
V-48	G.I.	0·8, 0·01	5×10^{-8}	3×10^{-4}
Cr-51	G.I.	240, 17	4×10^{-6}	2×10^{-2}
†Mn-52	G.I.	17, 2·1	6×10^{-8}	3×10^{-4}
†Mn-54	G.I.	34, 4·3	2×10^{-7}	1×10^{-3}
Mn-56	G.I.	3, 0·4	5×10^{-7}	3×10^{-3}
Fe-55	Blood	10^3	7×10^{-7}	7×10^{-3}
Fe-59	Blood	13	2×10^{-8}	1×10^{-4}
†Co-58	G.I.	1.9, 0.7	2×10^{-7}	1×10^{-3}
Co-60	G.I.	0·2, 0·06	8×10^{-8}	4×10^{-4}
Ni-59	G.I.	1, 0·6	7×10^{-7}	4×10^{-3}
Cu-64	G.I.	22, 10	9×10^{-7}	5×10^{-3}
Zn-65	G.I.	80, 13	4×10^{-7}	2×10^{-3}
Ga-72	G.I.	0·3, 5×10^{-4}	1×10^{-7}	5×10^{-4}
Ge-71	G.I.	5, 0·1	3×10^{-6}	2×10^{-2}

† Evaluated by Radiological Protection Service. Remainder are ICRP (1954) values.

Isotope	Critical organ	Maximum permissible body burden (in μc)	Maximum permissible concentrations	
			In Air (in μc/cm³)	In Water (in μc/cm³)
†As–74	G.I.	3.3, 0.2	6×10^{-8}	4×10^{-4}
As–76	G.I.	0·2, 0·01	4×10^{-8}	2×10^{-4}
*Br–82	Thyroid	4	—	1×10^{-3}
	Lungs	0.5	9×10^{-8}	—
Rb–86	Muscle	64	4×10^{-7}	3×10^{-3}
Sr–89	Bone	2	2×10^{-8}	7×10^{-5}
Sr–90 + Y–90	Bone	1	2×10^{-10}	8×10^{-7}
Y–91	Bone	3	9×10^{-9}	—
	G.I.	0·02	—	3×10^{-4}
Zr–95 + Nb–95	G.I.	12, 0·02	1×10^{-7}	6×10^{-4}
Nb–95	Bone	44	2×10^{-7}	2×10^{-3}
Mo–99	G.I.	0·01, 0·01	5×10^{-7}	3×10^{-3}
Tc–96	G.I.	0·3, 0·2	2×10^{-7}	1×10^{-3}
*Ru–103	—	—	4×10^{-8}	2×10^{-3}
Ru–106 + Rh–106	G.I.	$3, 4 \times 10^{-3}$	2×10^{-8}	1×10^{-4}
Rh–105	G.I.	0·9, 0·02	2×10^{-7}	1×10^{-3}
Pd–103 + Rh–103	Kidneys	7	8×10^{-7}	—
	G.I.	4	—	5×10^{-3}
Ag–105	G.I.	$0{\cdot}1, 4 \times 10^{-3}$	7×10^{-8}	4×10^{-4}
Ag–111	G.I.	$0{\cdot}1, 4 \times 10^{-3}$	8×10^{-8}	5×10^{-4}
Cd–109 + Ag–109	Liver	45	7×10^{-8}	7×10^{-2}
Sn–113	G.I.	42, 0·8	3×10^{-7}	2×10^{-3}
*Sb–125	—	—	8×10^{-8}	5×10^{-4}
Te–127	G.I.	4, 0·9	1×10^{-7}	7×10^{-4}
Te–129	G.I.	1·4, 0·03	4×10^{-8}	2×10^{-4}
I–131	Thyroid	0·6	6×10^{-9}	6×10^{-5}
†I–132	Thyroid	0.1	6×10^{-8}	4×10^{-4}
Xe–133	Total body	320	4×10^{-6}	4×10^{-3}
Xe–135	Total body	100	2×10^{-6}	1×10^{-3}
*Cs–134	—	—	4×10^{-7}	1×10^{-3}
*Cs–135	—	—	7×10^{-6}	1×10^{-2}
*Cs–136	—	—	1×10^{-6}	3×10^{-3}
Cs–137 + Ba–137	Muscle	98	2×10^{-7}	2×10^{-3}
Ba–140 + La–140	Bone	1	2×20^{-8}	—
	G.I.	0·7	—	3×10^{-4}
La–140	G.I.	$0{\cdot}9, 7 \times 10^{-3}$	5×10^{-8}	3×10^{-4}

* Recommended by M.R.C. Protection Committee. No ICRP values available.

† Evaluated by Radiological Protection Service. Remainder are ICRP (1954) values.

Isotope	Critical organ	Maximum permissible body burden (in μc)	Maximum permissible concentrations In Air (in μc/cm³)	Maximum permissible concentrations In Water (in μc/cm³)
*Ce–141	—	—	3×10^{-8}	3×10^{-3}
Ce–144 + Pr–144	Bone	1	2×10^{-9}	—
	G.I.	0·01	—	1×10^{-4}
Pr–143	G.I.	3, 0·04	9×10^{-8}	5×10^{-4}
Pm–147	Bone	25	4×10^{-8}	—
	G.I.	0·3	—	2×10^{-3}
Sm–151	Bone	90	3×10^{-9}	—
	G.I.	14	—	8×10^{-3}
Eu–154	Bone	7	2×10^{-9}	—
	G.I.	0·3	—	4×10^{-4}
*Eu–155	—	—	$1{\cdot}5 \times 10^{-8}$	$2{\cdot}5 \times 10^{-2}$
Ho–166	G.I.	$0{\cdot}4, 4 \times 10^{-4}$	8×10^{-8}	5×10^{-4}
Tm–170	Bone	4	1×10^{-8}	—
	G.I.	0·03	—	5×10^{-4}
Lu–177	G.I.	$4, 3 \times 10^{-3}$	2×10^{-7}	1×10^{-3}
Ta–182	Liver	6	2×10^{-8}	—
	G.I.	0·03	—	5×10^{-4}
W–181	G.I.	0·5, 0·2	1×10^{-7}	7×10^{-4}
Re–183	G.I.	2, 0·8	4×10^{-7}	2×10^{-3}
Ir–190	G.I.	13, 0·3	6×10^{-7}	3×10^{-3}
Ir–192	Spleen	3	3×10^{-8}	—
	G.I.	0·3	—	5×10^{-4}
Pt–191	G.I.	1, 0·2	1×10^{-7}	7×10^{-4}
Pt–193	G.I.	3, 0·5	2×10^{-7}	9×10^{-4}
Au–196	Liver	8	2×10^{-7}	—
	G.I.	0·3	—	2×10^{-3}
Au–198	G.I.	1·5, 0·5	1×10^{-7}	6×10^{-4}
Au–199	G.I.	7, 0·2	3×10^{-7}	2×10^{-3}
Tl–200	G.I.	4, 2	2×10^{-7}	1×10^{-3}
Tl–201	G.I.	89, 35	2×10^{-6}	9×10^{-3}
Tl–202	G.I.	100, 58	9×10^{-7}	5×10^{-3}
Tl–204	G.I.	50, 25	2×10^{-7}	1×10^{-3}
Pb–203	G.I.	4, 1	4×10^{-7}	2×10^{-3}
Pb–210 + dr	Bone	0·2	8×10^{-11}	2×10^{-6}
Po–210 (sol)	G.I.	$0{\cdot}04, 4 \times 10^{-3}$	5×10^{-10}	3×10^{-6}
Po–210 (insol)	Lungs	0·02	1×10^{-10}	—
At–211	Thyroid	1×10^{-3}	5×10^{-10}	3×10^{-6}

* Recommended by M.R.C. Protection Committee. No ICRP values available.

Isotope	Critical organ	Maximum permissible body burden (in μc)	Maximum permissible concentrations	
			In Air (in μc/cm³)	In Water (in μc/cm³)
Tn–220	Lungs	—	1×10^{-7}	—
Rn–222 + dr	Lungs	—	1×10^{-7}	—
Ra–226	Bone	0·1	8×10^{-12}	4×10^{-8}
Ac–227 + dr	Bone	0·01	4×10^{-12}	3×10^{-6}
Th–natural	Bone	0·01	3×10^{-11}	5×10^{-7}
Th–232 (insol)	Lungs	2×10^{-3}	3×10^{-11}	—
Th–234	Bone	2	1×10^{-8}	—
	G.I.	8×10^{-3}	—	2×10^{-4}
U–natural (sol)	Kidneys	0·04	3×10^{-11}	—
	G.I.	8×10^{-4}	—	2×10^{-6}
U–natural (insol)	Lungs	0·01	3×10^{-11}	—
U–233 (sol)	Bone	0·04	3×10^{-11}	—
	G.I.	8×10^{-4}	—	3×10^{-6}
U–233 (insol)	Lungs	0·016	3×10^{-11}	—
Pu–239 (sol)	Bone	0·04	2×10^{-12}	—
	G.I.	0·02	—	3×10^{-6}
Pu–239 (insol)	Lungs	0·02	2×10^{-12}	—
Am–241	Bone	0·06	4×10^{-11}	—
	G.I.	9×10^{-4}	—	3×10^{-6}
Cm–242	Bone	0·06	2×10^{-19}	—
	G.I.	1×10^{-4}	—	2×10^{-6}

10. Appendix III

List of General References

"Recommendations of the International Commission on Radiological Protection." (*Brit. J. Radiol., Supplement* 6, 1955.)

"Some Applications of Nuclear Physics to Medicine." W. V. MAYNEORD. (*Brit. J. Radiol., Supplement* 2, 1950.)

"Atomic Medicine," 2nd edit. C. F. BEHRENS. (Bailliere, Tindall and Cox, London, 1953.)

"Radiations and Living Cells." F. G. SPEAR. (Frontiers of Science Series, Chapman and Hall, 1953.)

"Applied Biophysics—Symposium." *Edited by* HOWARD N. JONES. (Chemical Publishing Co. Inc., Brooklyn, New York, 1949.)

"Symposium on Radiobiology—The Basic Aspects of Radiation Effects on Living Systems." *Edited by* J. J. NICKSON. (Chapman and Hall, London, 1952).

"Advances in Biological and Medical Physics," Vol. 1 (1948), Vol. 2 (1951), Vol. 3 (1953). *Edited by* J. H. LAWRENCE and J. G. HAMILTON. (Academic Press Inc., New York.)

"Biological Hazards of Atomic Energy." *Edited by* A. HADDOW. (Clarendon Press, Oxford, 1952.)

"Protection against betatron-synchrotron radiations up to 100 MeV." Handbook 55. (National Bureau of Standards, U.S. Department of Commerce, 1954.)

"Isotopic Tracers and Nuclear Radiations—with Applications to Biology and Medicine." W. E. SIRI. (McGraw-Hill Book Co. Inc., London, 1949.)

"Modern Radiochemical Practice." G. B. COOK and J. F. DUNCAN. (Clarendon Press, Oxford, 1952.)

"Laboratory Design for Handling Radioactive Materials." Research Correlation Conference (1951) conducted by the Building Research Advisory Board, National Research Council and National Academy of Sciences. (Washington, D.C., U.S.A., 1952.)

"Planning Guide for Radiologic Installations." W. G. SCOTT. (Commission on Public Relations of the American College of Radiology.) (The Year Book Publishers, Inc., Chicago, 1953.)

"Nuclear Particle and Radiation Detectors." Part I. Ion Chambers and Ion Chamber Instruments. Part II. Counters and Counting Systems. D. TAYLOR and J. SHARPE. *Proc. I.E.E.*, 98, Part II, 174, 209, 1951; also "Radiation Measuring Instruments for X-rays to Cosmic Rays." D. TAYLOR and W. ABSON. *Proc. I.E.E.*, 98, 760, 1951.

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"Recommendations of the International Commission on Radiological Protection." (*Brit. J. Radiol.*, Supplement 6, 1955.)

"Some Applications of Nuclear Physics to Medicine." W. V. Mayneord. (*Brit. J. Radiol.*, Supplement 2, 1950.)

"Atomic Medicine," 2nd edit. C. F. Behrens. (Baillière, Tindall and Cox, London, 1953.)

"Radiations and Living Cells." F. G. Spear. (Frontiers of Science Series, Chapman and Hall, 1953.)

"Applied Medical [illegible]." [illegible] (Chemical Publishing Co., Inc., Brooklyn, New York, 1950.)

"Symposium on Radiobiology—The Basic Aspects of Radiation Effects on Living Systems." Edited by J. J. Nickson. (Chapman and Hall, London, 1952.)

"Advances in Biological and Medical Physics." Vol. I (1948), Vol. II (1951), Vol. III (1953). Edited by J. H. Lawrence and J. G. Hamilton. (Academic Press Inc., New York.)

"Biological Hazards of Atomic Energy." Edited by A. Haddow. (Clarendon Press, Oxford, 1952.)

"Protection against Betatron-Synchrotron radiations up to 100 MeV." (Handbook 55, National Bureau of Standards, U.S. Department of Commerce, 1954.)

"Isotopic Tracers and Nuclear Radiations—with Applications to Biology and Medicine." W. E. Siri. (McGraw-Hill Book Co. Inc., London, 1949.)

"Modern Radiochemical Practice." G. B. Cook and J. F. Duncan. (Clarendon Press, Oxford, 1952.)

"Laboratory Design for Handling Radioactive Materials." Research Correlation Conference (1951) conducted by the Building Research Advisory Board, National Research Council and National Academy of Sciences. (Washington, D.C., U.S.A., 1952.)

"Planning Guide for Radiologic Installations." [illegible] (Committee on Public Relations of the American College of Radiology.) (The Year Book Publishers, Inc., Chicago, 1953.)

"Nuclear Particle and Radiation Detectors." Part I. Ion Chambers and Ion Chamber Instruments. Part II. Counters and Counting Systems. D. Taylor and J. Sharpey-Schafer. (*Proc. I.E.E.*, 98, Part II, 174, 209, 1951.) Also "Radiation Monitoring Instruments for Medical Research Purposes." D. Taylor and W. Abson. (*Proc. I.E.E.*, 98, Part II, 1951.)

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